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THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF THE CENTRAL HIGHLANDS

FINAL REPORT
VOLUME III
SUPPORTING REPORT
Gia Lai Province

AUGUST 2002

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Volume Ⅱ	:	MAIN REPORT
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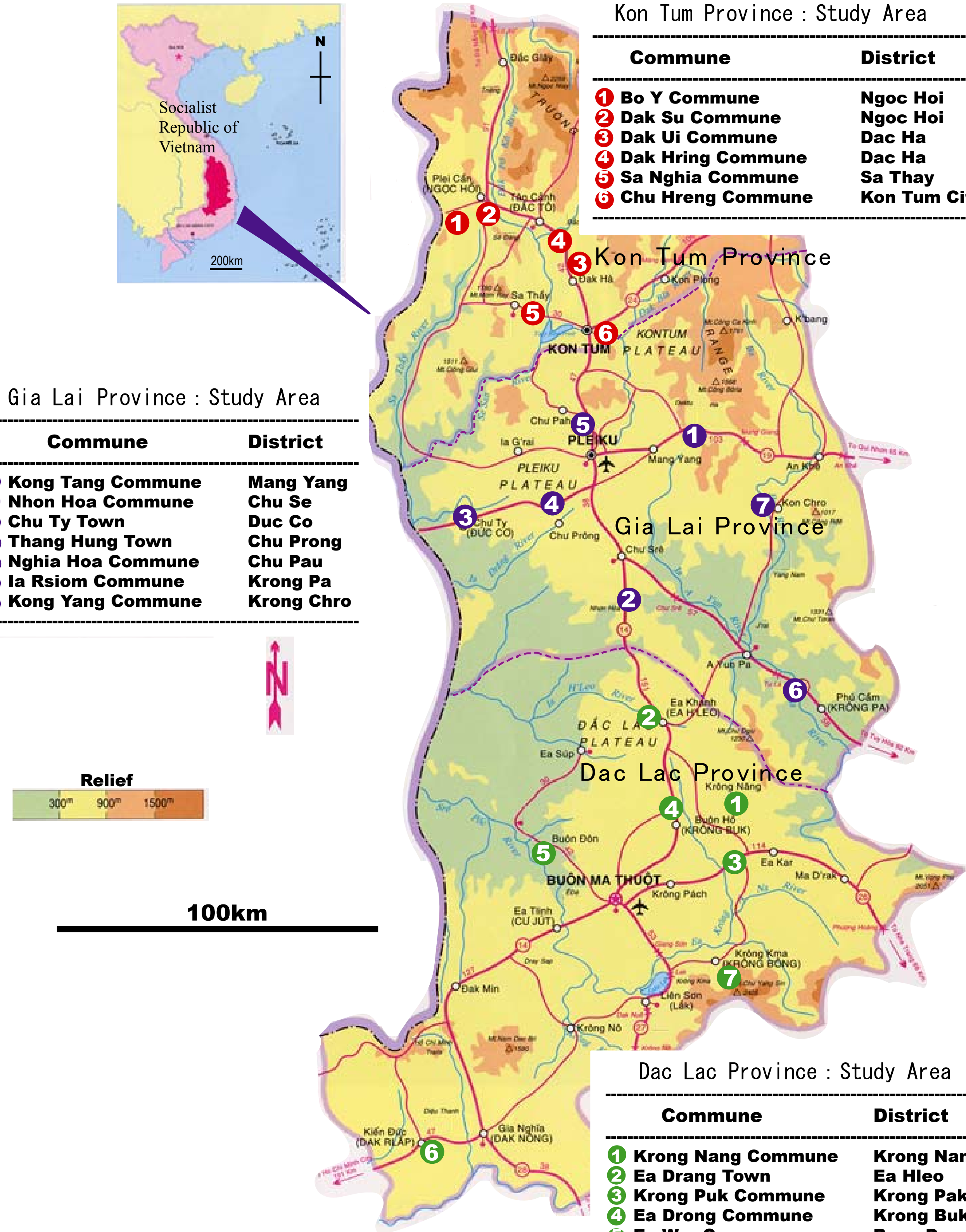

Kon Tum Province : Study Area

	Commune	District
1	Bo Y Commune	Ngoc Hoi
2	Dak Su Commune	Ngoc Hoi
3	Dak Ui Commune	Dac Ha
4	Dak Hring Commune	Dac Ha
5	Sa Nghia Commune	Sa Thay
6	Chu Hreng Commune	Kon Tum City

Gia Lai Province : Study Area

	Commune	District
1	Kong Tang Commune	Mang Yang
2	Nhon Hoa Commune	Chu Se
3	Chu Ty Town	Duc Co
4	Thang Hung Town	Chu Prong
5	Nghia Hoa Commune	Chu Pau
6	Ia Rsiom Commune	Krong Pa
7	Kong Yang Commune	Krong Chro

Dac Lac Province : Study Area

	Commune	District
1	Krong Nang Commune	Krong Nang
2	Ea Drang Town	Ea Hleo
3	Krong Puk Commune	Krong Pak
4	Ea Drong Commune	Krong Buk
5	Ea Wer Commune	Buon Don
6	Kien Duc Commune	Dac Rlap
7	Krong Kmar Town	Krong Bong

Location Map

List of Abbreviations

ADB	Asian Development Bank
As	Arsenic
ATP	Ability to Pay
AusAID	Australian Grant Aid
BARD	bank for Agriculture and Rural Development
B/D	Basic Design
CERWASS	Centre for Rural Water Supply and Sanitation
CHC	Community Health Centre
CIDA	Canadian International Development Assistance
CPC	Commune People's Committee
DANIDA	Danish International Development Assistance
DARD	Department of Agricultural Development
DF/R	Draft Final Report
DFID	UK, Department for International Development
DGMV	Department of Geology and Minerals of Vietnam
DHC or DHS	District Health (Services) Centre
DOF	Department of Finance
DOH	Department of Health
DOSTE	Department of Science, Technology and Environment
DPC	District People's Committee
DPI	Department of Planning and Investment
EIA	Environmental Impact Assessment
EM	Ethnic Minority
F	Fluorine
F/R	Final Report
F/S	Feasibility Study
FU	Farmer's Union
GAD	Gender and Development
GDP	Gross Domestic Product
GSO	General Statistical Office
HDPE	Hard PVC pipes
HRD	Human Resources Development
HC	House Connection
IEC	Information, Education and Communication

IC/R	Inception Report
IT/R	Interim Report
IEE	Initial Environmental Examination
JICA	Japan International Cooperation Agency
KI	Key Informant
kWh	kilo Watt(s) hours
lcd	litre per capita per day
LEP	Law on Environmental Protection
MARD	ministry of Agriculture and Rural Development
MCM	Million Cubic Meter
M/M	Minute of Meeting
MOC	Ministry of Construction
MOET	Ministry of Education and Training
MOF	Ministry of Finance
MOLISA	Ministry of Labour, Invalids and Social Affairs
M/P	Master Plan
NGO	Non-Governmental Organizations
NIPHEP	National Institute of Public health and Environmental Protection
NRWSS	National Rural Water Supply and Sanitation
VIWASE	Vietnam consultant for Water supply Sanitation and Environment
ODA	Official Development Assistance
O&M or O & M	Operation and Maintenance
PC	Portland Cement
PCERWASS	
PCM	Project Cycle Management
PDM	Project design Matrix
PDOSTE	Provincial Department of Science, Technology and Environment
PDPSC	Provincial Disease Prevention and Sanitation Centre
PHSC	Provincial Health Services Centre
PPC	Provincial People's Committee
P/R	Progress Report
PSCWS	Provincial Steering Committee for Water Supply and Sanitation
PE	Poly-Ethylene Pipe
pH or PH	Potential of Hydrogen
PT	Public Taps
PVC	Poly-Vinyl Chlorine Pipe

PWL	Pumping Water Level
QTT2	Quantification Theory Type II
RRA	Rapid Rural Appraisal
RWSS	Rural Water Supply and Sanitation
SPC	State Planning Committee
SRV	Socialist Republic of Vietnam
S/W	Scope of Work
SWL	Static Water Level
TEM	Transient Electromagnetic Method
TDEM	Time Domain Electromagnetic Method
THS	Town Health Services Centre
TPC	Town People's Committee
TV	Television media
UARD	Unit of Agriculture and Rural Development
UFW	
UNDP	United Nation Development Planning
UNICEF	United Children's Fund
USD	US Dollar
VHW	Village Health Worker
VIP	Ventilation type Improved Pit
VND	Vietnam Dong
VNYU or YU	(Vietnam) Youth Union
WB	World Bank
WATSAN	Water Supply and Sanitation
WHO	World Health Organization
WID	Women in Development
WTP	Willingness to Pay
WU or VWU	(Vietnamese) Women's Union

Unit

bar	Pressure
h	Hour
pH	Potential of Hydrogen
q_{max}	Maximum hourly demand
Q_{max}	Maximum daily demand
Q_{av}	Average day demand
mg/l	milligram per litre
l	Litre
m	Medium
vh	Very high
l/c/d	Litre per capita per day
l/s	Litre per second
m^3	Cubic meter
km^2	Square kilometre
μ	1×10^{-6}
ϕ	Diameter
℃	Centi-degree
%	Percent
γ	Gamma (electrical logging)
k	Permeability coefficient
S	Storage capacity

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Chapter 1 Hydrogeological Investigation

In order to clarify the hydrogeological condition in the study area, aerial photo interpretation, site reconnaissance, electro and electro-magnetic survey works were carried out in the first stage of field works.

1.1 Interpretation of Aerial Photos

1.1.1 Purpose

The study area is principally composed of hard basement rocks except with small size overburden of Quaternary deposits along the streams. Prior to the various hydrogeological investigations at site, the aerial photos were interpreted to find and to check the favorable hydrogelogical conditions to select exploratory (test) well sites, in parallel with carrying out the conventional in-site water quality tests. Interpreting the aerial photographs is one of the most convenient methods to assess the site conditions. However, these aerial photographs were not available in the target communes of G-6 and G-7. These were obtained from Vietnam Research Institute of Land Administration. The results of the interpretation were used for the site selection of electro and electro-magnetic surveys and explanatory drilling.

1.1.2 Results

The results of the interpretation are shown in the following table and the location maps are presented in Table 1.1.

Table 1.1 Interpreted Lineament

Commune		Near the Commune Center	In the Commune
Kong Tang Town	(G-1)	No Lineament	No Lineament
Nhon Hoa Commune	(G-2)	No Lineament	No Lineament
Chu Ty Town	(G-3)	No Lineament	No Lineament
Thang Hung Commune	(G-4)	No Lineament	No Lineament
Nghia Hoa Commune	(G-5)	No Lineament	No Lineament

In the communes/towns of Kong Tang town (G-1), Nhon Hoa commune (G-2), Chu Ty town (G-3), Thang Hung commune (G-4) and Nghia Hoa commune (G-5) no lineament can be detected.

1.2 Hydrogeology

The Central Highlands, except for those in the Lam Dong province, can be divided into eight hydrogeological zones as described in the following table and Figure 1.1:

Table 1.2 Hydrogeological Characteristics in the Central Highlands

Hydrogeology		Thickness (m)	Yield (l/sec)	Specific yield (l/sec/m)
Alluvial sediments (Q_4)	Sand, silt and gravel	3 –5		0.05-0.33
Pleistocene sediments (Q_{1-3})	Sand, silt and gravel	10-15	0.2-0.4	
Neogene sediments (N)	Sandstone, conglomerate, siltstone	10-500		0.06-0.54
Middle Pleistocene basalt (βQ_2)	Olivine basalt	10-150	0.16-14.68	0.01-3.06
Upper Neogene – lower Pleistocene basalt (βN_2-Q_1)	Tholeitic basalt	80-150	0.16-10.47	0.01-3.59
Cretaceous sedimentary rocks (K)	Sandstone, conglomerate, siltstone			0.02-0.2
Jurassic sedimentary rocks (J_{1-2})	Limestone, sandstone, conglomerate, siltstone			0.05-0.33
Cambrian – Archeozoic metamorphic rocks and granites (PR-γ)	Gneisses and granites			0.01-0.03

(Source: General Department of Geology and Mines)

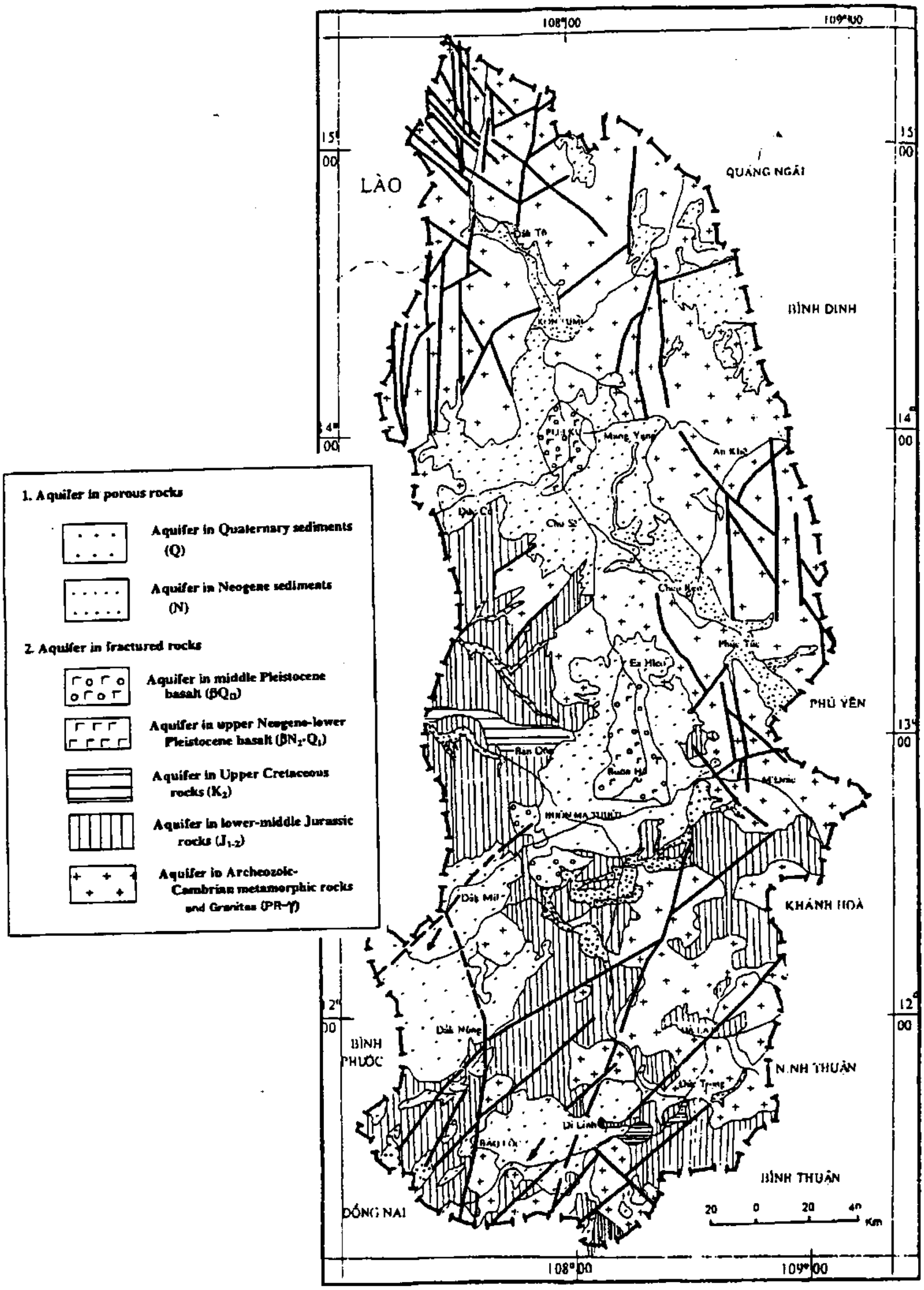

Figure 1.1 Hydrogeological Map of Central Highlands

Figures 1.2 to 1.3 show hydrogeological profiles in the Central Highlands. The profiles are presented for the Plei Ku highlands, in directions of east to west and north to south, respectively.

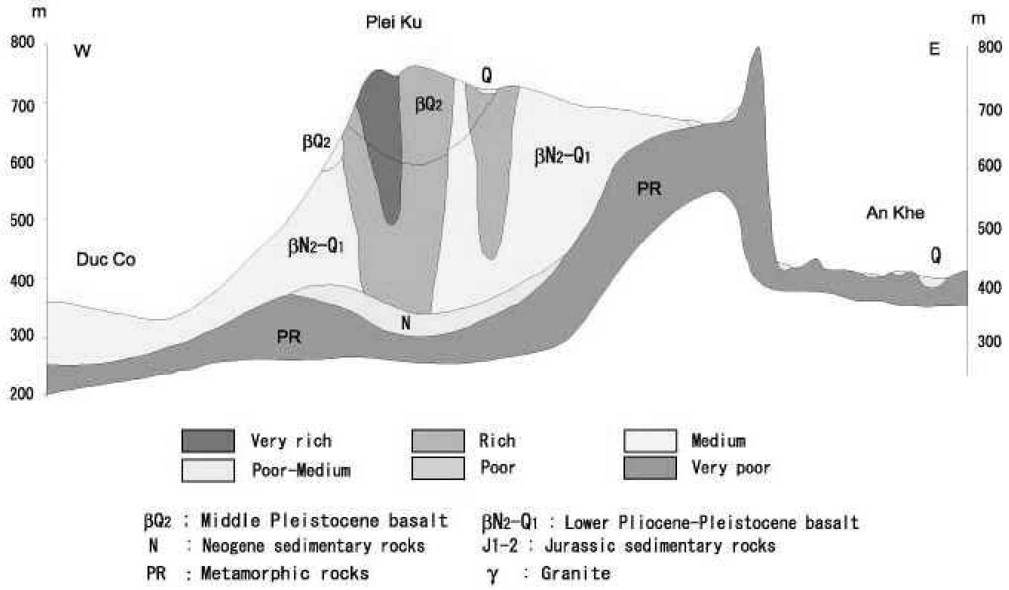

Figure 1.2 Hydrogeological Cross Section of Plei Ku Highland (East-West)

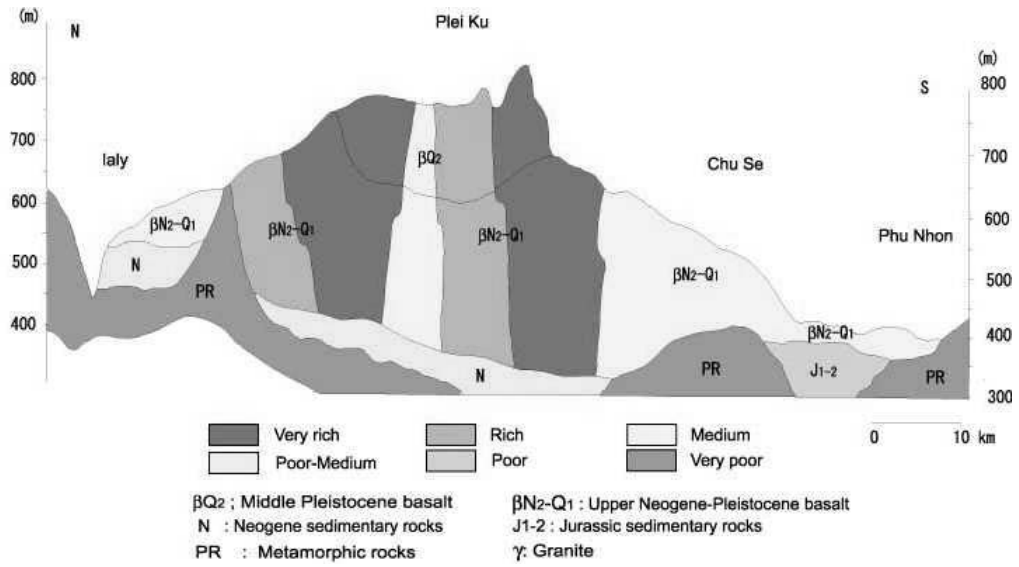

Figure 1.3 Hydrogeological Cross Section of Plei Ku Highland (South-North)

The classification of well production in the Central Highlands area can be estimated as shown below:

Table 1.3 Classification of Well Production in the Central Highlands

Class	Yield (l/s)	Specific Yield (l/s/m)
Rich and very rich	1.0 – 5.0 and higher	0.5 – 1.0 and higher
Medium	0.5 – 1.0	0.2 – 0.5
Poor	0.1 – 0.5	0.05 – 0.2
Very poor (aquitard)	< 0.1	< 0.05

(Source: General Department of Geology and Mines)

The hydrogeological characteristics and features of target communes/towns are summarized as follows:

(1) Kong Tang town (G1)

The basalt ($\beta N_2 - Q_1$) occupies the whole of this area to a thickness of 20 to 200 m. In the layer of 10 to 40 m in depth, the basalt is completely weathered into red clay and silt. The degrees of fracturing of the basalt vary with location and depth. The yield of the basalt is estimated to be 2.0 to 3.0 l/s. The alluvial sediments and granites occur northeast of the town.

(2) Nhon Hoa commune (G2)

The basalt occurs widely over the area. It is composed of compact and porous basalts with a thickness of 70 to 110 m. In the layer of 10 to 15 m in depth, it is fully weathered into clay. The degrees of fracturing of the basalt vary with location and depth. The yield is 1.0 to 2.0 l/s and the maximum yield is not more than 5.0 l/s. The Jurassic sedimentary rock, which is sandstone, claystone and siltstone with fractures in some extents, occurs at a depth of 70 to 110 m.

(3) Chu Ty town (G3)

The basalt ($\beta N_2 - Q_1$) is distributed in the area to a thickness of 120 to 150 m. In the layer from 10 to 35 m in depth, it is fully weathered into red clay and silt. The degrees of fracturing of the basalt vary with location and depth. The yield is medium (LK205b) and rich (LK205a), but poor in the northeast of the town. The borehole LK205 is being used for the town water supply. The weathered granite occurs below a depth of 120 m, but it has no water.

(4) Thang Hung commune (G4)

The basalts ($\beta N_2 - Q_1$) are distributed in the area to a thickness of 30 to 90 m. In the layer of 15 to 20 m in depth, it is fully weathered into red clay and silt. The degrees of fracturing of the basalt vary with location and depth. The yield from existing boreholes is 0.5 to 2.0 l/s. In the north of the commune, there are several springs with a yield of 3 to 5 l/s. Granite underlies the basalt, but it has no water.

(5) Nghia Hoa commune (G5)

The basalt ($\beta N_2 - Q_1$) is distributed in this area to a thickness of 200 to 220 m. In the layer of 15 to 20 m in depth, it is fully weathered into red clay and silt. The degrees of fracturing of the basalt vary with location and depth. The yield is as high as 3- 5 l/s. At a depth of 138 to 184 m of the existing borehole LK120, the scoria and tuff are good water bearing formations with a yield of 11.4 l/s. The granite under the basalt has no water bearing capacity.

(6) Ia Rsiom commune (G6)

The Quaternary sediments (Q_4) are distributed in a narrow band along the Ea Pa river. They are composed mainly of sand and clay and do not exceed 2 to 4 m in thickness. The Pleistocene sediments ($Q_{2\text{-}3}$) are distributed to a thickness of 20 to 50 m. The sediments, which are composed of sand and clay with gravel, are a good water bearing aquifer.

The Neogene sedimentary rock (N_2) of the Ba river is distributed deeply under the Pleistocene sediments. The rock is composed of sandstone, conglomerate and claystone with a thickness of 50 to 500 m. It has good water-bearing potential. The yield of some boreholes in the surroundings reaches 2 to 3 l/s. The layer of the ground surface to 20–30 m in depth is contaminated by human activity. The Triassic Mang Yang System (T_2) is distributed in the west and it has no water.

(7) Kong Yang commune (G7)

The basalt (βN_2-Q_1) is distributed in the center of the commune. It comprises compact and porous basalt with a thickness of 50 to 60 m. In the layer of 5 to 10 m in depth, it is fully weathered into yellow-brown clay and silt. The degrees of fracturing of the basalt vary with location and depth. The granite under the basalt is not a water bearing formation.

Chapter 2　Geophysical Prospecting

For the purpose of selecting of exploratory (test) drilling sites in the proposed 7 communes, geophysical prospectings by both electrical and electro-magnetic soundings were carried out.

Both sounding methods aim to detect an indication of groundwater potential by the variation of electrical resistivity (the mathematical inverse of electrical conductivity) of the subsurface vertically and/or horizontally. Electrical resistivity of earth materials is an indication of the lithology and the characteristics of aquifers. Resistivity measurements can be used to determine the type of rocks or the depth to bedrock, the depth to water, and the conductivity by groundwater flow.

2.1　Electrical Sounding

2.1.1　Introduction

Electric current, discharged into the ground by means of a pair of electrodes, reveals resistivity variations caused by geological or hydrogeological conditions. These variations affect subsurface current patterns on the surface. Moreover, these patterns can be mapped by using a second pair of electrodes to take surface potential measurements at a series of sites that cover the section.

In a Wenner array, which is one of electrode configurations used in electrical resistivity sounding, the electrodes are spaced equally in-line as shown below. The apparent resistivity (ρ_a) is given by the following equation for the Wenner array:

$$\rho_a = 2 \pi a V / I$$

Where,　a : electrode spacing in meter

V : potential difference in volt

I : electric current in ampere

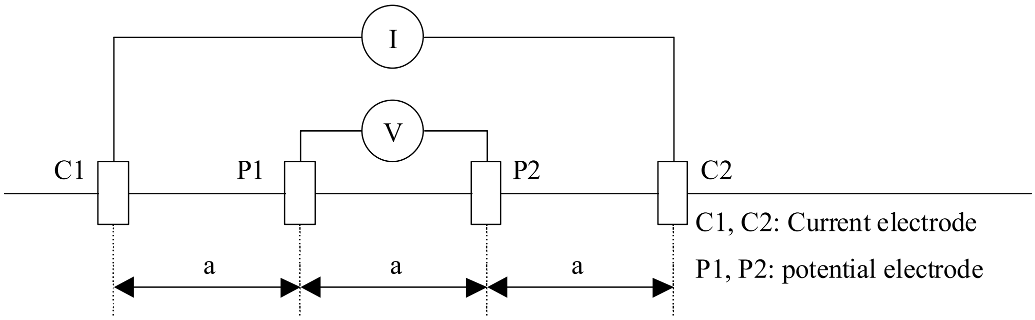

Figure 2.1　Wenner Electrode Array

2.1.2 Field Works

Electrical sounding was made by two-dimensional measurement, with Wenner electrode array along 19 survey lines as shown in Table 2.1. The instruments used in the electrical sounding were a resistivity survey system OYO McOHM-21(model-2116), a power booster (model-2919), and A.0 pairs of geo-electric nodes(model-2A.16) and cables. The system of the instruments is shown below.

Table 2.1 Quantity of Geophysical Prospecting Work

Province	Commune	Electrical sounding Line	Electro-magnetic sounding
Gia Lai	Kong Tang	4	-
	Nhon Hoa	3	7
	Chu Ty	-	51
	Thang Hung	4	-
	Nghia Hoa	-	49
	Ia Rsiom	4	-
	Kong Yang	4	-
Total		19	107

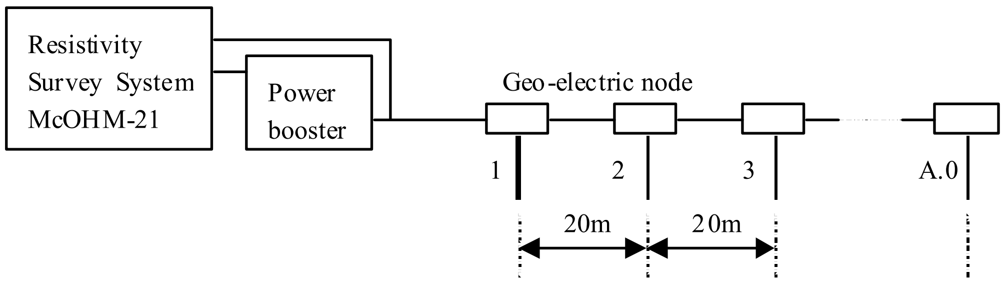

Figure 2.2 Configuration of Instruments for Electrical Sounding

Fifty electrodes made of stainless steel rods were placed in a linear array at a spacing of 20 m to form a survey line. In electrical sounding, electrode spacing is increased to obtain the resistivity from successively deeper depths. Measurements in the survey were made at 1A steps of electrode spacing expanding from 20 to 300 m. For 50 electrodes, the total number of array patterns for measurement in a survey line is 390. All measurements were made automatically by turning switches of the electrodes with a preset array pattern. In order to reduce resistance between electrodes and the earth, all electrodes were watered with a saturated salt solution. The electric current transmitted was a maximum 400 mA.

2.1.3 Data Analysis

The electrical sounding data were interpreted by two-dimensional model inversion method using interpretation software "ElecImager/2D" from OYO Corporation. This analysis assumes that the structure is two dimensional, and determines the optimum resistivity distribution of a two-dimensional model for each line. The distribution of apparent resistivity calculated for the optimum model is best matched to that of the observed apparent resistivity. The finite element method is applied to the forward analysis and the non-linear least squares method with a smoothness constraint is applied to the optimization of resistivity distribution. Figure 2.3 shows observed apparent resistivity and calculated apparent resistivity profiles as an example of the result of the inversion. In the section, apparent resistivity is plotted at the depth of a (=electrode spacing) below the middle point of the electrodes used for each line.

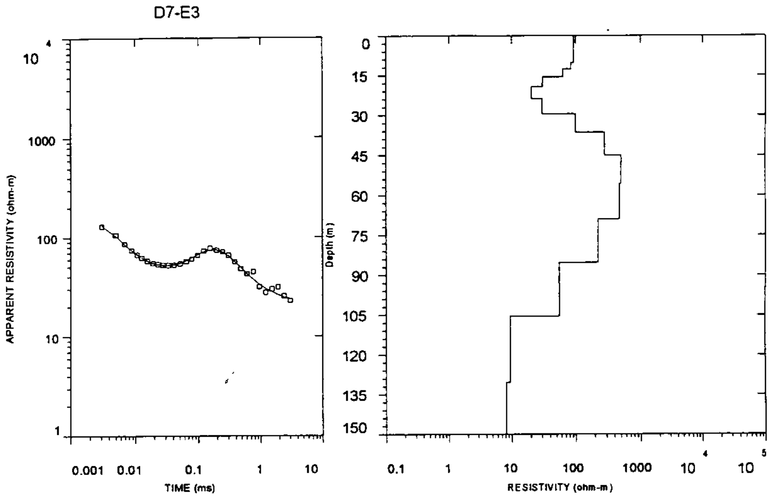

Figure 2.3 Result of One-Dimensional inversion

2.2 Electro-magnetic Sounding

2.2.1 Introduction

Electro-magnetic sounding was applied by the transient electro-magnetic method (TEM). Transient electro-magnetic method is often referred to as time-domain electro-magnetic method (TDEM), in which the ground is energized by an artificial magnetic field and its response is measured as a function of time to determine the resistivity of the earth beneath the observation point at a target depth. In this method, a steady current is passed through a loop of wire situated on the surface of the earth that is inductively linked to the earth. The fact that loop sources that have no direct contact with the earth can be used, makes this method suitable in areas where high surface resistivity prohibits the use of the conventional direct current method. The direct current is abruptly interrupted and the secondary fields created by an induced eddy current can be measured in the absence of the primary field. The current migrates from the transmitter into the earth and the pattern resembles a 'smoke ring' as shown in the following figure.

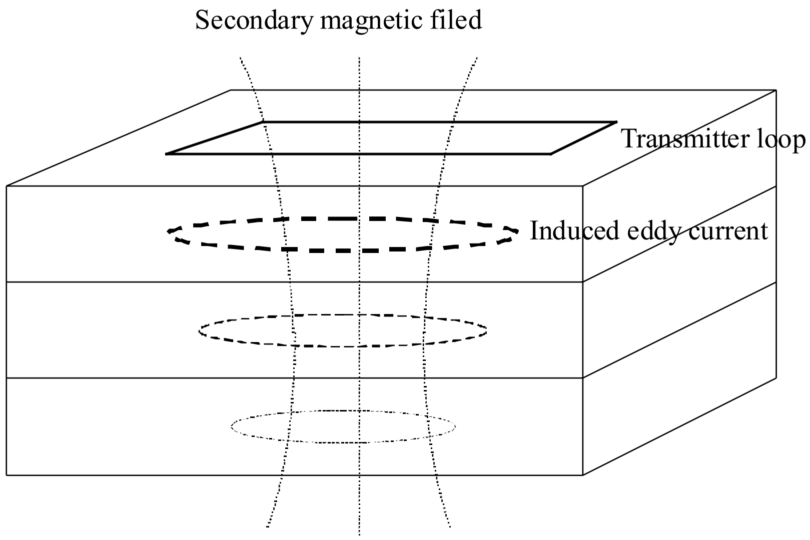

Figure 2.4 Schematic of Transient Electro-Magnetic Method

The decay of the magnetic field depends upon the underground resistivity structures. For a poor conductive medium, the receiver coil output voltage, which is proportional to the rate of change of the secondary magnetic field, is initially large but decays rapidly. The response of a good conductor is initially lower, but the voltage decays more slowly. A coil sensor can measure the time derivative of the transient magnetic field which results from these currents. The decay of the secondary field measured at the surface, can be analyzed to determine the resistivity of the earth at depths.

2.2.2 Field Work

Electromagnetic sounding was made at 107 points along 11 survey lines with about A.0 m interval for the survey lines as shown in Table 4.6. The instruments for electromagnetic sounding consist of a receiver ZONGE GDP-16 and a battery-powered transmitter NT-20, for the signal source. The transmitter and receiver array used in the measurement was the in-loop (central-loop) configuration shown below. The configuration was a 20 x 20 m loop for the transmitter and a 5 x 5 m loop for the receiver.

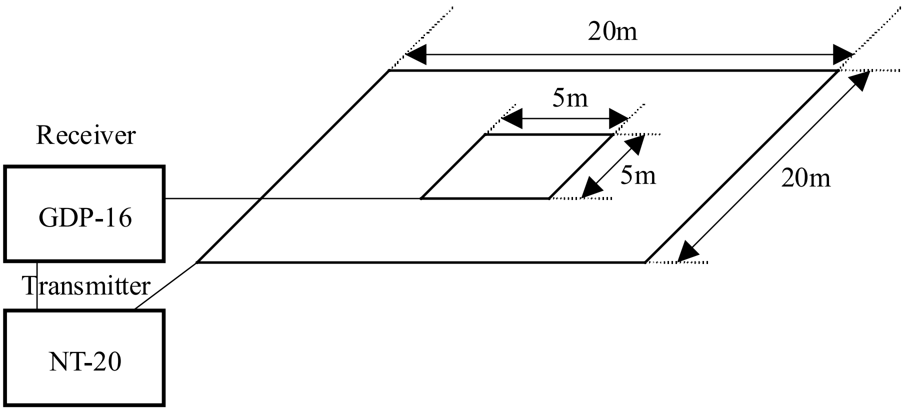

Figure 2.5 In-Loop Configuration

Transmitter current was about 3.0 amperes and was cycled on and off in pulses of alternating polarity 32 times per second. Sampling time of the decay of the secondary magnetic field was from 0.0031 milliseconds to 3.0153 milliseconds.

2.2.3 Data Analysis

The electro-magnetic sounding data were interpreted by one dimensional layered model inversion method using interpretation software "TEMIX-GL" from INTERPEX Limited. Based on the inversion method, a model that best fitted the sounding data was obtained by iteratively adjusting the parameters (resistivity and thickness of layers) after inputting an initial model.

2.3 Results of Geophysical Prospecting

Location maps of geophysical prospecting are shown in Chapter 4 and resistivity sections analyzed for each commune are shown in Data Book. In the resistivity profiles, the darker color indicates higher resistivity and the lighter color shows lower resistivity.

As above-mentioned, electrical resistivity of earth materials is an indicator of the lithology and the characteristics of aquifers. Fresh rocks generally show higher resistivity, and compact volcanic rocks especially have high resistivity more than 1,000 ohm-m. The resistivity of weathered or fractured saturated rocks and sedimentary rocks become lower. Water along faults and fractures in the rock will demonstrate low resistivity anomalies against the compact and fresh rock. Very low resistivity, less than 10 ohm-m, possibly points to a high content of clay.

The promising zone, that could be recognized to be an aquifer in the area, ranges from 30 to 100 ohm-m in resistivity by reflecting on the geological and hydrogeological conditions.

Chapter 3 Present Groundwater Use Survey

The field survey for existing water sources and groundwater use was carried out from February to May 2001. During the field survey, 362 locations of existing water sources were investigated in the Gia Lai province. The investigated locations are classified into the following 7 categories and the detailed description is shown in Table 3.1:

Table 3.1 Existing Water Sources

Commune	Surface Water	Spring Water	Shallow Well (Dug Well)	Shallow Well (Unicef HP Well)	Deep Well (Dug+Dri Well)	Deep Well (Drilling Well)	Existing Water Supply System	Total
G-1	3	2	29	–	–	–	–	34
G-2	2	1	27	–	–	–	–	30
G-3	5	2	19	–	–	2	1	29
G-4	1	2	90	–	–	1	–	94
G-5	–	3	26	–	–	4	–	33
G-6	–	–	50	29	–	–	–	79
G-7	4	1	51	6		1	–	63
Sub Total	15	11	292	35	0	8	1	362

3.1 Present Water Sources

Based on the results of field survey, the present water sources in the 7 communes were divided into the following 4 types:

- water from an existing water supply system,
- surface water,
- spring water,
- groundwater.

Water supply systems can be sub-divided into the following two types depending on their water sources. One is the bamboo piped gravity flow system with sources of spring water or rivulet water and the other’s source is groundwater.

The bamboo piped gravity flow system is found in target commune. The other system with a source of groundwater is found in Chu Ty commune (G-3).

Among the 4 water sources mentioned above, groundwater is the most popular source in this study area. Groundwater is mainly used for domestic purpose and also for irrigation of coffee and pepper plants.

The ethnic minority people do not prefer to groundwater for domestic use, but the majority people prefer to groundwater especially for drinking. Rubber companies, tea factories and large-scale coffee plantations have dug deep wells. They also use groundwater for irrigation though deep wells, which are very limited in number.

3.2 Method of Groundwater Abstraction

The 3 types of groundwater exploitation methods, dug wells, UNICEF hand pump wells and deep wells, are the most common in the area.

3.2.1 Sallow Well (Dug Well)

A shallow well (dug well) is a general method to get groundwater. The purposes are mostly for drinking, washing and cooking.

For the investigated 362 shallow wells, groundwater level (SWL) and portable water quality tests were carried out at site. The SWL ranged from 0 to 31m. It is inferred that approximately 57 % of investigated household use groundwater.

Groundwater levels of dug wells are mostly shallower than 10 m as shown in Figure 3.1. The investigated groundwater fluctuation ranges from 0 to 10 m. According to the well inventory survey, approximately 60 percent of the wells are less than 4 m of the fluctuation as shown Figure 3.2. These wells of small fluctuation are dug in the Quaternary sediments and/or near the boundary between the sediments and weathered parts of basement rock.

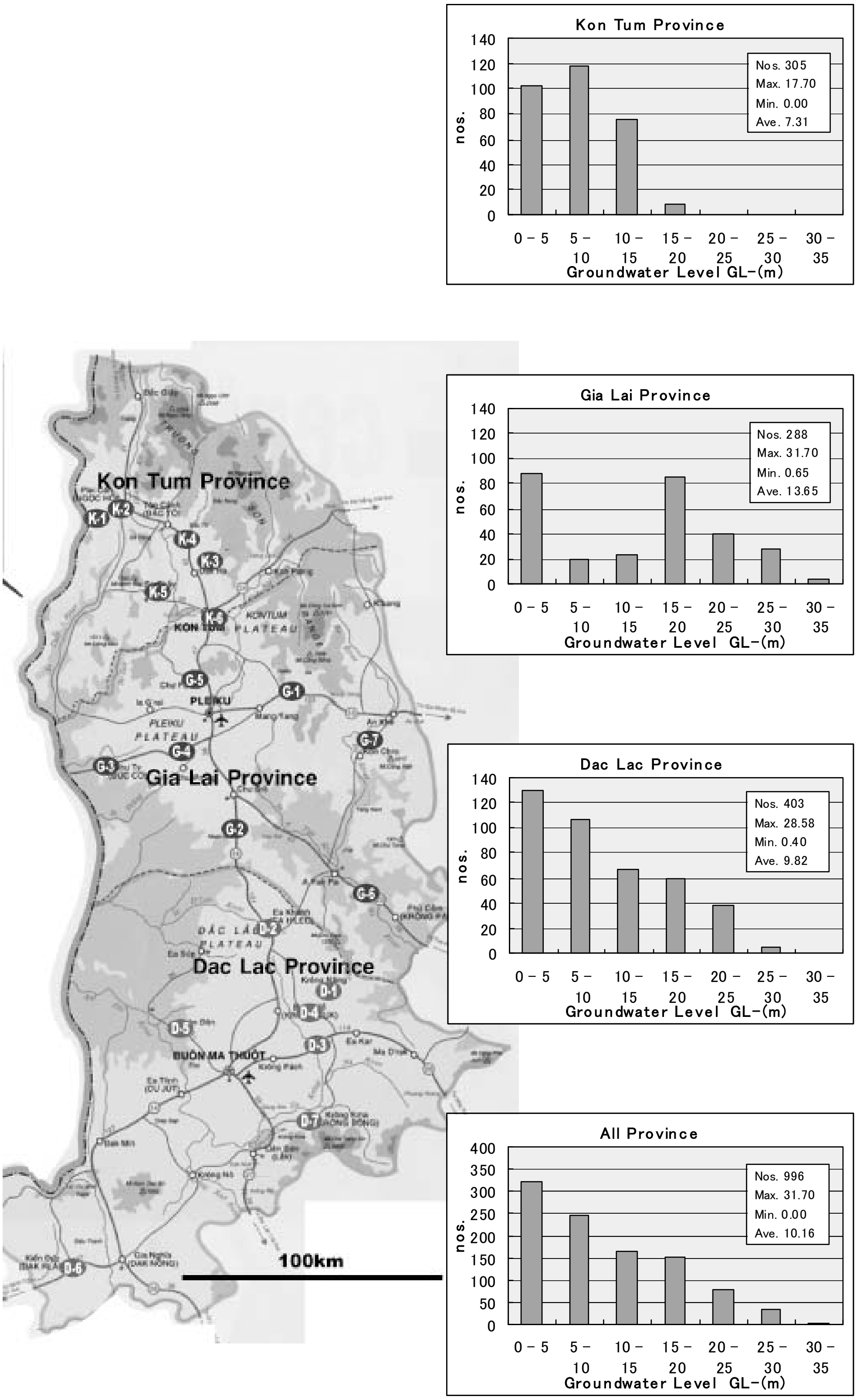

Figure 3.1 Groundwater Level of Existing Dug Well in Three Provinces

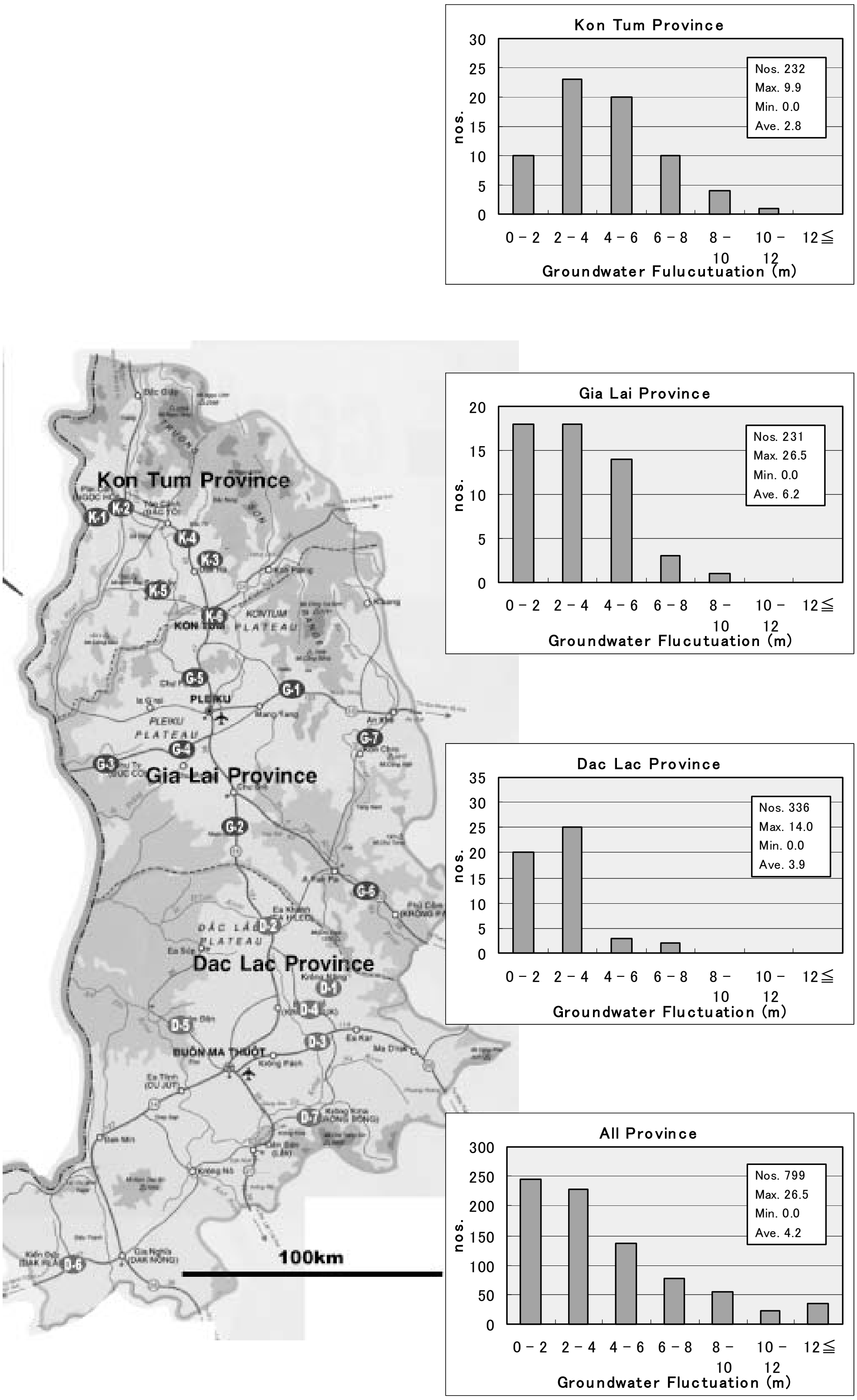

Figure 3.2 Groundwater Flucutuation of Existing Dug Well in Three Provinces

Electric motor pumps are installed for approximately 62 % of the shallow wells as presented in Table 3.2. Power sources are mostly supplied by public power. The installation rate of electric pumps in Nhon Hoa commune (G-2) is the highest and 74 % as shown in Table 3.2. While, the lowest percentages (10 ~ 20%) were in Ia Rsiom commune (G-6) and Kong Yang commune (G-7). The installation rate of electric pumps is much dependent on the depth of SWL and pumping water level (PWL) as shown in Figure 3.3.

Table 3.2 Installation Rate of Electric Pump and Groundwater Level

Commune	Shallow Well	With Pump	Percentage	Average of Groundwater Level (m)
G-1	29	14	48%	16.11
G-2	27	20	74%	15.42
G-3	19	10	53%	18.45
G-4	90	57	63%	20.32
G-5	26	17	65%	20.27
G-6	(50)	-	(10~20%)	3.85
G-7	(51)	-	(10~20%)	3.31
Sub Total	191	118	62%	13.65

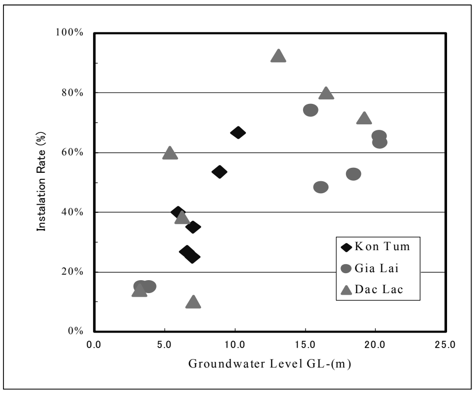

Figure 3.3 Installation Rate of Electric Pump

3.2.2 Shallow Well (UNICEF hand pump wells)

UNICEF hand pump wells are common in many houses after dug wells, and these wells are popular in Ia Rsiom commune (G-6) and Kong Yang commune (G-7). The depth of UNICEF hand pump wells is inferred as 7 – 30 m with an average of 12.2m, judging from the investigated of the 35 exiting wells as shown in Figure 3.4. Approximately 80 % of the investigated wells are shallower than 20 m in depth as shown below. These wells are dug in Quaternary sediments and/or near the boundary between the sediments and basement rock.

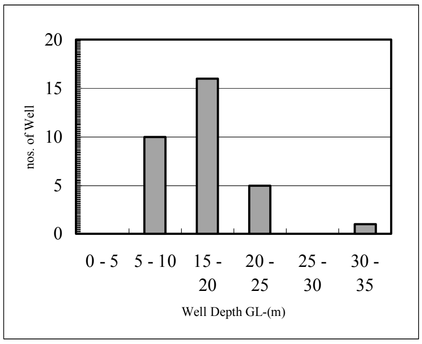

Figure 3.4 Depth of UNICEF Hand Pump Wells

3.2.3 Deep Well

There are 8 deep wells in the target communes. These are mainly developed in Gia Lai province except Kong Tang commune (G-1), Nhon Hoa commune (G-2) and Ia Rsiom commune (G-6).

The depths of investigated deep wells range from 25 to 195m with an average of 84.7m as shown in Figure 3.5. Approximately 54 % of the investigated wells are shallower than 75m as shown below. The deep wells were drilled and constructed by several drilling companies under a contract basis in the Central Highlands. According to interviews with the drilling companies on the contract system, the drilling works were conducted under a full responsibility of the contractors. This means that the contractors have a high risk of drilling works. Hence, the contract price for drilling work will be high. Submersible motor pumps are installed for some of the existing deep tube wells. It is not easy to procure the motor pumps for the well owner himself because of high cost of the pumps and their scarcity in local markets. Submersible pumps are available from dealers in Ho Chi Minh. The pumps from Italy, France and Japan are imported and available in Vietnam.

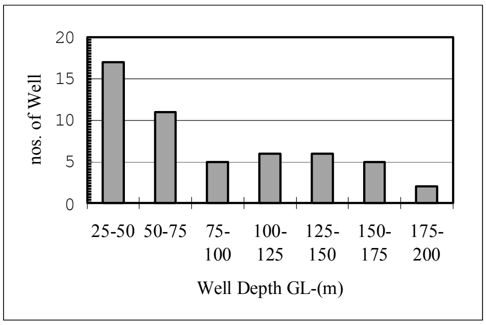

Figure 3.5 Depth of Deep Well

Chapter 4 Exploratory Well Drilling

4.1 Observation and Exploratory Wells

The 7 exploratory (test) wells were planned and 7 drilling works were carried out on time during Phase I and II of the study. The drilling points and depths were determined based on the analyses of geophysical prospecting and hydrogeological investigation, in order to evaluate hydrogeological condition at the target communes. Each drilling site was determined through discussion among the study team, CERWASS engineers and authorities of the target communes/ towns. The drilling result was used for evaluation of the production capacity of well, possibility of groundwater development plan and water quality check.

The seven (7) test wells were drilled in Dac Lac province, seven (7) test wells in Gia Lai province and six (6) plus two (2) additional test wells in Kon Tum province. The coordinates and elevations of the test wells were measured using GPS.

Table 4.1 General Features of Test Wells

Target commune/town		Coordinate (UTM)		Elevation (m)	Drilling depth (m)	Reaming depth (m)
		Latitude	Longitude			
G1	Kong Tang	1554896	202592	736	150	112
G2	Nhon Hoa	1499742	185766	421	170	110
G3	Chu Ty	1528374	791729	417	150	85
G4	Thang Hung	1630373	813129	633	180	150
G5	Nghia Hoa	1562211	814529	682	160	135
G6	Ia Rsion	1474169	238141	140	180	158
G7	Kong Yang	1531378	234391	472	160	110

Figures 4.1 to 4.7 show the exact locations of the test wells and lines of the geophysical prospecting at the 7 target communes/towns. Each drilling site was determined through discussion among the study team, CERWASS engineers and the authorities of the target communes/towns. The geographical conditions, accessibility to the drilling spot and the conditions of the land use, were also considered.

4.2 Geology and Well Structure

The existing wells of the target communes are mostly shallow dug wells or hand pump shallow wells. The people usually take shallow groundwater from the dug wells for domestic use. There is almost no hydrogeological information on deep aquifers, particularly metamorphic rocks and granites. Therefore, the drilled wells in this study were important to evaluate hydrogeological characteristics of basalts, sedimentary rocks, and metamorphic rocks and granites.

Through the course of the drilling and well construction, the geology of each test well was carefully recorded through observation of core samples and geophysical logging data were interpreted. The geology and well structure of each well are shown in the following table and interpretation graphs of geophysical logging tests are presented in Data Book.

Table 4.2 Geology of Test Wells

Commune/Town		Geology
G1	Kong Tang	Basalt (β N_2-Q_1)
G2	Nhon Hoa	Basalt (β N_2-Q_1)
G3	Chu Ty	Basalt (β N_2-Q_1)
G4	Thang Hung	Basalt (β N_2-Q_1)
G5	Nghia Hoa	Basalt (β N_2-Q_1)
G6	Ia Rsiom	Quaternary sediment (Q), Jurassic sandstone (N)
G7	Kong Yang	Basalt (β N_2-Q_1)

The test wells were so designed that screen pipes should not be installed in the first aquifer so as to avoid interaction between the first and deeper aquifers.

4.2.1 Pumping test

The pumping test in this Study is composed of four (4) types, namely 1) a preliminary yield test during four (4) hours pumping, 2) Six (6) step-drawdown tests during a total of twelve (12) hours, 3) constant continuous pumping test during seventy-two (72) hours and 4) recovery test during twelve (12) hours. The step-drawdown test was conducted in six (6) steps of two (2) hours pumping for each step prior to the constant continuous pumping test. After casing and screen pipes were installed and well development was performed, the pumping tests at the 18 test wells were carried out. The procedures for the pumping test are presented in Data Book. In the case that the preliminary yield tests were conducted several times, the last test results are shown in the report.

4.2.2 Step-drawdown test

The step-drawdown tests were carried out at seventeen (17) test wells except for Kien Duc town (D6), Dak Hring commune (K4) and Sa Nghia commune (K5). The step-drawdown test is conducted at six (6) steps of two (2) hours pumping for each step. Two (2) steps of the step-drawdown test were performed at Chu Hreng commune (K6) because its yield was too small to conduct the four (4) steps of the step-drawdown test, based on the result of the preliminary yield test.

Table 4.3 shows the results of step-drawdown tests for each test well. The values of aquifer loss, well loss and well efficiency for each step and the averages were calculated for each test well.

Table 4.3 Step-Drawdown Tests of JICA Test Wells

Well No.	Commune / town	Coordinates		Elevation	Drilling Depth	Reaming Depth	Screen Length	Static Water Level	Step-drawdown test						Aquifer loss coefficient [B]	Well loss coefficient [C]	Average well efficiency
		Latitude North	Longitude East						1st	2nd	3rd	4th	5th	6th			
									Discharge(m3/h)								
		UTM	UTM	(m)	(m)	(m)	(m)	(m)	Drawdown (m)						(hr/m^2)	(hr^2/m^5)	(%)
D1	Krong Nang	1432676	212271	714	140	100	40	11.80	1.8	7.2	12.6	18	14.4	10.8	5.13E-01	2.88E-02	64
									1.01	5.36	10.6	18.86	13.9	9.14			
D2	Ea Drang	1461593	196617	644	180	120	48	24.00	0.5	0.9	1.3	1.6	1.1	0.7	8.57E+00	2.69E+00	78
									5.67	9.29	14.92	21.42	11.05	7.41			
D3	Krong Buk	1412609	217070	484	140	70	30	9.00	4.3	8.6	13	17.3	10.8	7.2	5.58E-01	3.10E-02	58
									3.06	6.92	13.03	19.05	13.5	8.45			
D4	Ea Drong	1427255	209295	615	180	116	58	15.89	3.2	6.1	9	11.9	7.9	5.4	3.11E+00	3.82E-02	110
									10.05	16.89	23.97	32.87	22.03	15.76			
D5	Ea Wer	1418900	813607	255	150	35	22	2.00	3.6	7.2	10.8	13.3	10.1	6.5	3.22E-01	9.64E-02	30
									2.25	7.83	14.67	21.09	12.33	7.5			
D6	Kien Duc	1325577	772292	691	170	120	40	32.20	-	-	-	-	-	-	-	-	-
									-	-	-	-	-	-	-	-	
D7	Krong Kmar	1384752	210996	436	39	39	28	3.80	7.2	12.6	18	23	18	12.6	1.05E-01	5.70E-03	52
									1.07	2.13	3.94	5.37	4.33	2.95			
G1	Kong Tang	1554896	202592	736	150	112	40	34.00	3.6	6.6	9.6	13.2	9.6	6.6	1.57E+00	1.70E-03	101
									5.65	10.27	14.9	20.49	16.2	11.64			
G2	Nhon Hoa	1499742	185766	421	170	110	34	21.00	1.9	3.6	5.2	6.8	5.4	3.9	1.97E+00	5.37E-01	47
									5.84	12.96	24.77	39	26.75	15.89			
G3	Chu Ty	1528374	791729	417	150	85	22	22.40	4.2	7.2	10.8	13.2	10.8	7.2	8.27E-01	1.23E-01	52
									5.79	11.78	24.11	32.06	26.2	14.96			
G4	Thang Hung	1630373	813129	633	180	150	50	34.10	2.7	5.4	8.1	10.8	8.4	5.7	5.51E-01	9.60E-03	110
									1.45	2.62	3.78	4.93	4.4	3.25			
G5	Nghia Hoa	1562211	814529	682	160	135	52	32.50	1.5	3	4.2	6	5.1	3.6	3.42E+00	4.44E-02	93
									5.13	11.02	15	22	19.16	14.57			
G6	Ia Sion	1474169	238141	140	180	158	38	24.15	3.6	8.4	13.2	17	13.2	8.4	8.28E-01	3.50E-03	91
									3.07	6.97	11.73	15.08	13.25	8.96			
G7	Kong Yang	1531378	234391	472	160	110	34	10.80	4.5	9	13.8	18	14.4	10.2	1.07E+00	4.00E-04	104
									4.8	9.7	14.67	19.19	14.63	9.29			
K1	Bo Y	1623379	782270	683	170	50	24	0.88	0.8	1.8	2.7	3.6	2.8	2.0	7.78E+00	9.35E-02	101
									6.63	14.17	21.86	29.18	19.18	14.51			
K2A	Dak Su	1610205	783252	670	80	50	32	0.80	1.6	3.1	4.7	6.1	4.8	3.3	3.33E+00	9.60E-03	100
									5.21	10.53	15.83	20.72	15.8	10.59			
K3	Dak Ui	1613032	177275	685	160	38	28	1.35	3	6.6	9.6	12.6	9	6	9.89E-01	3.35E-02	84
									3.18	8.2	12.9	17.36	9.59	6.28			
K6	Chu Hreng	1584716	177337	590	98	40	14	12.50	0.12	0.24	-	-	-	-	3.5E+01	1.7E+01	92
									4.42	9.34	-	-	-	-			

The drawdown of a well generally consists of aquifer loss and well loss. According to Jacab (1947), well loss is proportional to some power of the well discharge. The drawdown is given as follows;

$$s = B*Q + C*Q^n$$

Where B: aquifer loss coefficient
C: well loss coefficient
n: constant

The n value of the above equation is assumed to be two (2) in this Study.
The well efficiency is defined as the percentage of (BQ/s) for a specified duration of pumping in order to evaluate well performance. If the total drawdown is caused by the aquifer loss only, the well efficiency should be 100 %.

The value of the aquifer loss coefficient (B) at the test wells of G5 (Nghia Hoa) is higher than the others and almost 3 hr/m^2. The value at G5 is caused by the aquifers consisting of basalt with low permeability. The value of the aquifer loss coefficient (B) at the test wells of G5 (Nghia Hoa) and G6 (Ia Rsiom) are lower than the others and almost 1 hr/m^2. The value at G3 is caused by the aquifers consisting of basalt with high permeability.

The values of the well loss coefficient (C) at the test wells of G1 (Kong Tang) and G7 (Kong Yang) are lower than the others and almost 0.001 hr^2/m^5. This shows that the well structure of G1 and G7 did not affect the drawdown more than the others. The values of the well loss coefficient (C) at the test well of G2 (Nhon Hoa) is higher than the others and almost 1 hr^2/m^5. This shows that the well structure of G2 affected the drawdown as much as the others.

The performance of a well can be evaluated based on the well efficiency value. If the total drawdown is equal to the drawdown caused by the aquifer loss, the well efficiency is 100 %. The values of the well efficiency at the test wells of G1 (Kong Tang), G5 (Ngia Hoa) and G6 (Ia Rsiom) are more than ninety (90) %. The value of the well efficiency at the test well of G3 (Chu Ty) is less than sixty (60) %.

The relationship between discharge (Q) and drawdown (s) is plotted on a log-log graph. If the Q-s curve vended upward, the Q value at the turning point can be recognized to be critical discharge rate of the well. This means that the discharge rate over the turning point would not be suitable for continuous pumping. The Q-s curves show specific straight lines on log-log graphs.

4.2.3 Constant Continuous Pumping Test and Recovery Test

The constant continuous pumping test was carried out during seventy-two (72) hours and the recovery test was conducted during twelve (12) hours after the constant continuous test. The values of transmissivity and storage coefficient can be estimated based on the results of the tests. The values of transmissivity can be calculated by Cooper-Jacob analysis method, Theis analysis method and recovery analysis method and the values of storage coefficient are obtained by the Cooper-Jacob analysis method and the Theis analysis method.

The graphs of the constant continuous pumping test analyzed by the Theis analysis method are shown in Data Book. The results of the constant continuous pumping test and recovery test analyzed by the Theis analysis method are summarized in Table 4.4.

Table 4.4 Results of the Constant Continuous Test and Recovery Test Analyzed by Theis Analysis Method

Well No.	Commune / town	Coordinates		Elevation	Drilling depth	Reaming depth	Screen length	Static water level	Pumping discharge	Drawdown	Specific capacity	Theis method						
		Latitude North UTM	Longitude East UTM									Match point				Transmissivity	Storage coefficient	Hydraulic conductivity
												u	W(u)	r2/t (m2/s)	s (m)			
				(m)	(m)	(m)	(m)	(m)	(l/s)	(m)	(l/s/m)					(m2/day)		(m/day)
D1	Krong Nang	1432676	212271	714	140	100	40	11.80	4.00	15.89	0.25	1.0E-10	22.0	1.0E-04	13.0	4.7E+01	1.3E-07	1.2E+00
D2	Ea Drang	1461593	196617	644	180	120	48	24.00	0.45	20.56	0.02	1.0E-06	13.0	1.0E-04	17.5	2.3E+00	6.4E-05	4.8E-02
D3	Krong Buk	1412609	217070	484	140	70	30	9.00	4.80	21.26	0.23	1.0E-07	15.0	1.0E-05	16.0	2.6E+01	7.2E-04	8.6E-01
D4	Ea Drong	1427255	209295	615	180	116	58	15.89	3.10	30.20	0.10	1.0E-10	21.0	1.0E-04	23.5	1.9E+01	5.3E-08	3.3E-01
D5	Ea Wer	1418900	813607	255	150	35	22	2.00	3.70	21.42	0.17	1.0E-10	21.0	1.0E-04	17.0	3.1E+01	8.7E-08	1.4E+00
D6	Kien Duc	1325577	772292	691	170	120	40	32.20	0.25	22.23	0.01	-	-	-	-	-	-	-
D7	Krong Kmar	1384752	210996	436	39	39	28	3.80	6.40	6.50	0.98	1.0E-06	11.5	1.0E-04	4.0	1.3E+02	3.5E-03	4.5E+00
G1	Kong Tang	1554896	202592	736	150	112	40	34.00	3.73	21.73	0.17	1.0E-10	22.0	1.0E-04	19.0	3.0E+01	8.2E-08	7.4E-01
G2	Nhon Hoa	1499742	185766	421	170	110	34	21.00	2.00	40.34	0.05	1.0E-10	20.0	1.0E-04	37.0	7.4E+00	2.1E-08	2.2E-01
G3	Chu Ty	1528374	791729	417	150	85	22	22.40	3.67	32.22	0.11	4.0E-05	12.0	4.0E-03	13.5	2.2E+01	6.2E-04	1.0E+00
G4	Thang Hung	1630373	813129	633	180	150	50	34.10	3.00	9.66	0.31	1.0E-05	11.0	1.0E-03	3.5	6.5E+01	1.8E-03	1.3E+00
G5	Nghia Hoa	1562211	814529	682	160	135	52	32.50	2.00	26.13	0.08	1.0E-06	13.0	1.0E-04	20.0	8.9E+00	2.5E-04	1.7E-01
G6	Ia Sion	1474169	238141	140	180	158	38	24.15	4.70	15.83	0.30	1.0E-10	22.0	1.0E-04	12.6	5.6E+01	1.6E-07	1.5E+00
G7	Kong Yang	1531378	234391	472	160	110	34	10.80	5.00	22.96	0.22	1.0E-07	15.0	1.0E-05	20.0	2.6E+01	7.2E-04	7.6E-01
K1	Bo Y	1623379	782270	683	170	50	24	0.88	1.00	31.73	0.03	1.0E-02	4.2	1.0E-04	19.0	1.5E+00	4.2E-01	6.3E-02
K2A	Dak Su	1610205	783252	670	80	50	32	0.80	1.73	21.34	0.08	1.0E-05	12.0	4.0E-05	18.0	7.9E+00	5.5E-03	2.5E-01
K3	Dak Ui	1613032	177275	685	160	38	28	1.35	3.00	16.90	0.18	1.0E-06	13.0	1.0E-04	13.0	2.1E+01	5.7E-04	7.4E-01
K6	Chu Hreng	1584716	177337	590	98	40	14	12.50	0.07	22.50	0.003	-	-	-	-	-	-	-

Table 4.5 shows the results of the constant continuous test and recovery test analyzed by the Cooper-Jacob analysis method and recovery method. The graphs analyzed by the Cooper-Jacob analysis method and recovery tests are shown in the Data Book.

Table 4.5 Results of the Constant Continuous Test and Recovery Test Analyzed by Cooper-Jacob and Recovery Analysis Methods

Well No.	Commune / town	Coordinates Latitude North UTM	Coordinates Longitude East UTM	Elevation (m)	Drilling depth (m)	Reaming depth (m)	Screen length (m)	Static water level (m)	Pumping discharge (l/s)	Drawdown (m)	Specific capacity (l/s/m)	Cooper-Jacob analysis method: Transmissivity (m2/day)	Cooper-Jacob analysis method: Storage coefficient	Hydraulic conductivity (m/day)	Recovery analysis: Transmissivity (m2/day)	Recovery analysis: Hydraulic conductivity (m/day)
D1	Krong Nang	1432676	212271	714	140	100	40	11.80	4.00	15.89	0.25	4.2E+01	2.0E-06	1.1E+00	3.2E+01	7.9E-01
D2	Ea Drang	1461593	198617	644	180	120	48	24.00	0.45	20.58	0.02	2.4E+00	3.3E-04	4.9E-02	4.0E+00	8.2E-02
D3	Krong Buk	1412609	217070	484	140	70	30	9.00	4.80	21.26	0.23	1.4E+01	6.4E-01	4.6E-01	1.3E+01	4.2E-01
D4	Ea Drong	1427255	209295	615	180	116	58	15.89	3.10	30.20	0.10	1.6E+01	7.6E-06	2.8E-01	1.6E+01	2.8E-01
D5	Ea Wer	1418900	813607	255	150	35	22	2.00	3.70	21.42	0.17	2.3E+01	1.1E-05	1.1E+00	2.3E+01	1.1E+00
D6	Kien Duc	1325577	772292	691	170	120	40	32.20	0.25	22.23	0.01	2.9E-01	4.1E-01	7.3E-03	2.8E-01	7.0E-03
D7	Krong Kmar	1384752	210996	436	39	39	28	3.80	6.40	6.50	0.98	6.7E+01	3.1E-01	2.4E+00	8.4E+01	3.0E+00
G1	Kong Tang	1554896	202592	736	150	112	40	34.00	3.73	21.73	0.17	3.0E+01	1.4E-07	7.4E-01	2.1E+01	5.3E-01
G2	Nhon Hoa	1499742	185766	421	170	110	34	21.00	2.00	40.34	0.05	3.5E+00	3.3E-03	1.0E-01	6.3E+00	1.9E-01
G3	Chu Ty	1528374	791729	417	150	85	22	22.40	3.67	32.22	0.11	1.7E+01	7.7E-03	7.5E-01	7.0E+00	3.2E-01
G4	Thang Hung	1630373	813129	633	180	150	50	34.10	3.00	9.66	0.31	4.8E+01	2.2E-02	9.6E-01	6.8E+01	1.4E+00
G5	Nghia Hoa	1562211	814529	692	160	135	52	32.50	2.00	26.13	0.08	9.0E+00	4.2E-04	1.7E-01	1.1E+01	2.0E-01
G6	Ia Sion	1474169	238141	140	180	158	38	24.15	4.70	15.83	0.30	3.7E+01	1.7E-04	9.8E-01	6.2E+01	1.6E+00
G7	Kong Yang	1531378	234391	472	160	110	34	10.80	5.00	22.96	0.22	2.8E+01	1.3E-03	8.3E-01	5.3E+01	1.6E+00
K1	Bo Y	1623379	782270	683	170	50	24	0.88	1.00	31.73	0.03	1.9E+00	2.7E-01	8.0E-02	1.7E+00	7.2E-02
K2A	Dak Su	1610205	783252	670	80	50	32	0.80	1.73	21.34	0.08	3.9E+00	3.6E-02	1.2E-01	9.1E+00	2.9E-01
K3	Dak Ui	1613032	177275	685	160	38	28	1.35	3.00	16.90	0.18	1.7E+01	2.4E-03	6.1E-01	1.6E+01	5.6E-01
K6	Chu Hreng	1584716	177337	590	98	40	14	12.50	0.07	22.50	0.00	6.0E-02	2.9E-01	4.3E-03	1.3E-01	9.3E-03

The hydrogeological characteristics of the test wells in the target communes/towns are shown in Table 4.6.

Table 4.6 Hydrogeological Parameters of Test Wells

Target commune /town		Aquifer geology	Aquifer length (m)	Static water level (m)	Transmissivity (m^2/day)	Storage coefficient
Kon Tum province						
Gia Lai province						
G1	Kong Tang	Basalt	40	34.00	3.0E+1	8.2E-8
G2	Nhon Hoa	Basalt	34	21.00	7.4E+0	2.1E-8
G3	Chu Ty	Basalt	22	22.40	2.2E+1	6.2E-4
G4	Thang Hung	Basalt	50	34.10	6.5E+1	1.8E-3
G5	Nghia Hoa	Basalt	52	32.50	8.9E+0	2.5E-4
G6	Ia Rsiom	Quaternary sediments and Jurassic sandstone	38	24.15	5.6E+1	1.6E-7
G7	Kong Yang	Basalt and granite	34	10.80	2.6E+1	7.2E-4

During the constant continuous pumping tests, groundwater levels of several dug wells were observed and monitored as shown in Data Book, although any observation well was not distributed nearby the test well at G3 (Chu Ty). The groundwater levels of the dug observation wells did not decline during seventy-two

4.2.4 Aquifer Constants

Aquifer constants including transmissivity and storage coefficients are essential hydrogeological parameters.

Transmissivity describes the ability of the aquifer to transmit groundwater and is defined as the flow in volume per unit time through an aquifer section of unit width under a unit hydraulic gradient. The results of the constant continuous pumping test and recovery test analyzed by the Theis analysis method are shown in Table 4.4. The transmissivity values, which are analyzed by the Theis analysis method, range from 1.5 to 126.3 m^2/day. The results of the constant continuous test and recovery test analyzed by the Cooper-Jacob analysis method are expressed in Table 4.5. The transmissivity values, which are analyzed by Cooper-Jacob analysis method, range from 0.1 to 67.5 m^2/day. The transmissivity values analyzed by the Theis analysis method are proportional to the Cooper-Jacob analysis method as shown in Figure 4.1.

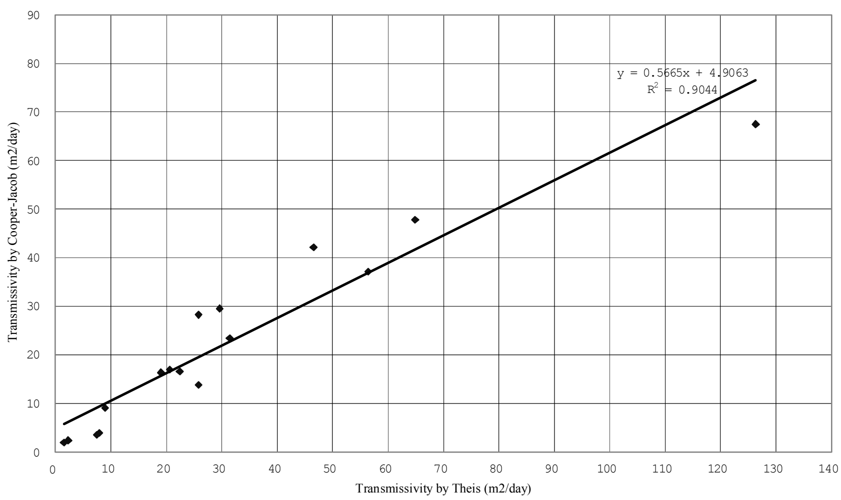

Figure 4.1 Relationship between Transmissivity Analyzed by Theis and Cooper-Jacob Analysis Methods

Specific capacity defines the rate at which it is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Specific capacity values are obtained from pumping discharge and final drawdown of the constant continuous pumping test. The specific capacity values of aquifers of the test wells range from 0.3 to

85.1 m^3/day/m. Figure 4.2 shows the relationship between transmissivity (T) and specific capacity (Sc) of the test wells. The relationship between transmissivity (T) and specific capacity (Sc) is proportional especially for confined aquifers. According to Logan (1964), the mathematical relationship can be expressed as T = 1.22Sc.

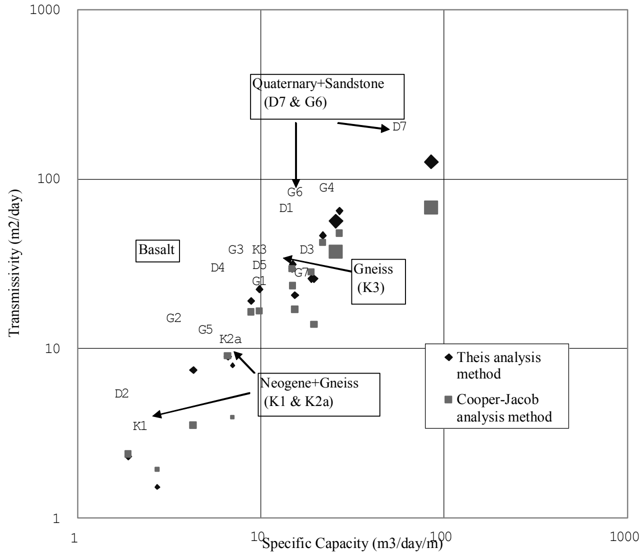

Figure 4.2 Relationship between Transmissivity and Specific Capacity

The Quaternary sediments and Jurassic sandstone aquifer of G6 (Ia Rsiom) has higher transmissivity and the specific capacity values as shown in Figure 4.2. The basalt aquifers show wide range of transmissivity and specific capacity values.

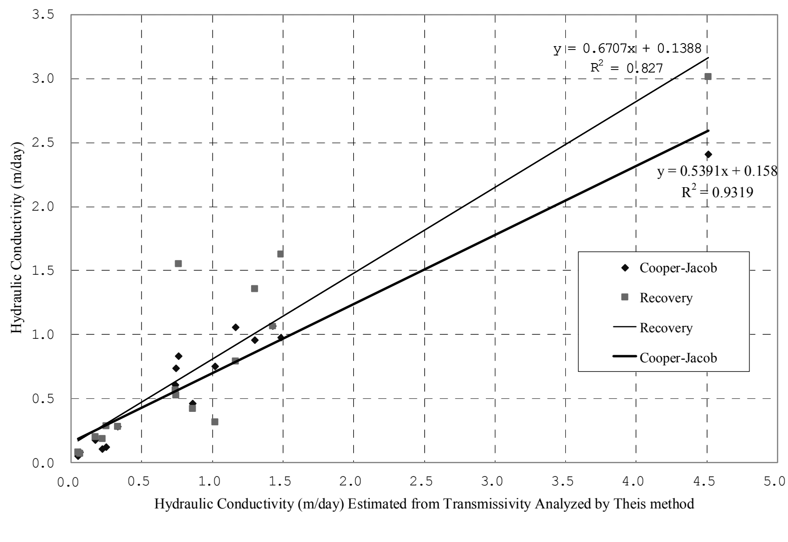

Figure 4.3 Hydraulic Conductivity Values Estimated from Transmissivity Values Analyzed by Theis, Cooper-Jacob and Recovery Analysis Methods

Hydraulic conductivity (k) can be estimated from the relationship between transmissivity (T) and aquifer thickness (b), k = T/b. Table 4.4 shows hydraulic conductivity values estimated from transmissivity values analyzed by the Theis method, based on the assumption that aquifer thickness is equivalent to a total length of screen pipes. Table 4.5 expresses hydraulic conductivity values estimated from transmissivity values analyzed by Cooper-Jacob and recovery methods. The hydraulic conductivity values estimated from transmissivity values analyzed by the Theis method are nearly equal to those by the Cooper-Jacob analysis method as shown in Figure 4.3.

Storage coefficient means the water volume, which an aquifer releases from or takes into storage, per unit surface area of the aquifer per unit change in head. In this study the storage coefficient values are obtained from the Theis method as shown in Table 4.4 and the Cooper-Jacob method as shown in Table 4.5. The almost all aquifers of test wells belong to a category of confined aquifer. The storage coefficient of G4 (Thang Hung) is 0.0018 in Table 4.4 and 0.022 in Table 4.5 and the aquifer of G4 (Thang Hung) can be recognized to belong to a category of semi-confined aquifer.