Chapter 5 Groundwater Potential in the target communes/towns

5.1 Water balance

In general, water balance study in a certain river basin for long years can be determined in the following formulas, if groundwater in-flow to the area and out-flow from the area are negligible and the storages water of surface and sub-surface are constant:

$$P = S + G + E$$

$$S + G = R$$

Where P: precipitation, S: surface runoff, G: groundwater runoff
E: evaporation, R: total runoff

According to the "Vietnam National Atlas (1996)", the average annual surface runoff in the central highlands is estimated to be from 400 to 1500mm/year. In the northern and southern parts of the central highlands, the average annual surface runoff is more than 1,200mm/year at the mountain area.

The minimum value of the average annual surface runoff is less than 400mm/year in the Cheo Reo-Phu Tuc lowland/depression. The average annual surface runoff in the Buon Ma Thuot and Plei Ku highlands ranges from 600 to 1,000mm/year.

The average annual groundwater runoff in the central highlands is estimated as 200-600mm/year. The minimum of the average annual groundwater runoff is found in the An Khe Lowland and Buon Ma Thuot highland. The average annual groundwater runoff is estimated to be mostly from 200 to 400mm/year.

The water balance equation in certain area is also expressed as the following equation. If the water balance is calculated for several ten years, δS (=F) can be neglected.

$$P - E = I + U + \delta S$$

where P: precipitation, E: evaporation,
I: river runoff in-flow to the area and out-flow from the area
U: underground in-flow to the area and out-flow from the area
δS: change in storage

According to DANIDA study, the annual rainfall, evaporation and river runoff in the Krong Buk river basin can be estimated as 1,400mm, 713mm and 685mm, in ascending river course. The Krong Buk river basin has a catchment area of 510 km^2. The groundwater flow at the river gauging station can also be calculated to be 730,000 m^3/year as the cross section is 2,000 km, which is equivalent to 2 mm/year.

There is no hydro-meteorological data on the surface runoff, precipitation and evaporation in the target communes/towns. Even if there are several hydro-meteorological stations in the central highlands, these hydro-meteorological data have not yet published by the authorities.

The groundwater recharge on the Buon Ma Thuot highland is assessed and estimated at 510 mm/year on a basis of the discharge data of the Ea Co Tam spring with a catchment of 7 km^2, which was monitored from 1978 to 1981 according to the Srepok water action plan report by DANIDA. The amount results in a base flow contribution to the streams of 165 mm (12.8 l/sec/km^2) in dry season and 345 mm (18.5 l/sec/km^2) in rainy season.

5.2 Water Balance Analysis

The southwestern part of the Plei Ku Highland is included in the Srepok river basin, which lies over the Buon Ma Thuot Highland mostly. The eastern part of the Gia Lai province is locted in the Ba river basin. Even if there are several hydro-meteorological stations in the Ba river basin, these hydro-meteorological data have not yet published by the authorities. Therefore, the water balance analysis in the Ba river basin is impossible.

It can be recognized that the Plei Ku Highland has same hydrogeological characteristics of the Buon Ma Thuot Highland. Therefore, the result of the water balance analysis in the Srepok river basin can also be applied to that in the Plei Ku Highland.

Sugawara's tank model, which is one of the most effective runoff model, is applied in order to make clear a hydrological cycle in the Srepok river basin and to estimate recharge of precipitation to groundwater aquifer.

5.2.1 Tank Model and Procedure

The tank model is composed of four tanks vertically in series. Each tank corresponds to each runoff component. The top tank represents the ground surface and the outflow from the top tank corresponds to a surface runoff. The second tank represents the soil layer and the outflow from the second tank corresponds to an intermediate runoff. The third and fourth tanks represent groundwater layer and the outflow from these tanks corresponds to a base flow. The top tank is attached with soil structure in order to consider the effect of initial rainfall loss.

The characteristics of the tank model are described as follows:

- The tank model can analyze both flood and low flows.
- The tank model expresses non-linear relationship between rainfall and runoff.
- The time lag between rainfall and runoff is automatically calculated.
- The tank model is not necessary for complicated procedure of calculation.
- The tank model has to find coefficients of four tanks by trial and error.

5.2.2 Srepok River Basin

The Srepok river is one of the major tributaries of the Mekong river and has a total basin area of 17,300 km^2, and 11,830 km^2 inside Vietnam, alone. The basin lies over the Buon Ma Thout highland and the southwestern part of the Plei Ku Highland. The basin is located at coordinates of 11^{o}30' to 13^{o}00'N and 107^{o}30' to 108^{o}30'E as shown in Figure 5.1. The Srepok river is composed of two tributaries of Krong Kno and Krong Ana. The Krong Kno river originates from the Truong Son range along the southern border of Dak Lak province and has a length of 156 km, a basin area of 3,920 km^2, an average elevation of 917 m and a basin slope of 17.6 %. The Krong Ana river is composed of three tributaries of Krong Buk, Krong Pak and Krong Bong. The Krong Ana river originates from the Haom Roang range and the East Truong Son range and has a length of 215 km and a basin area of 3,960 km^2.

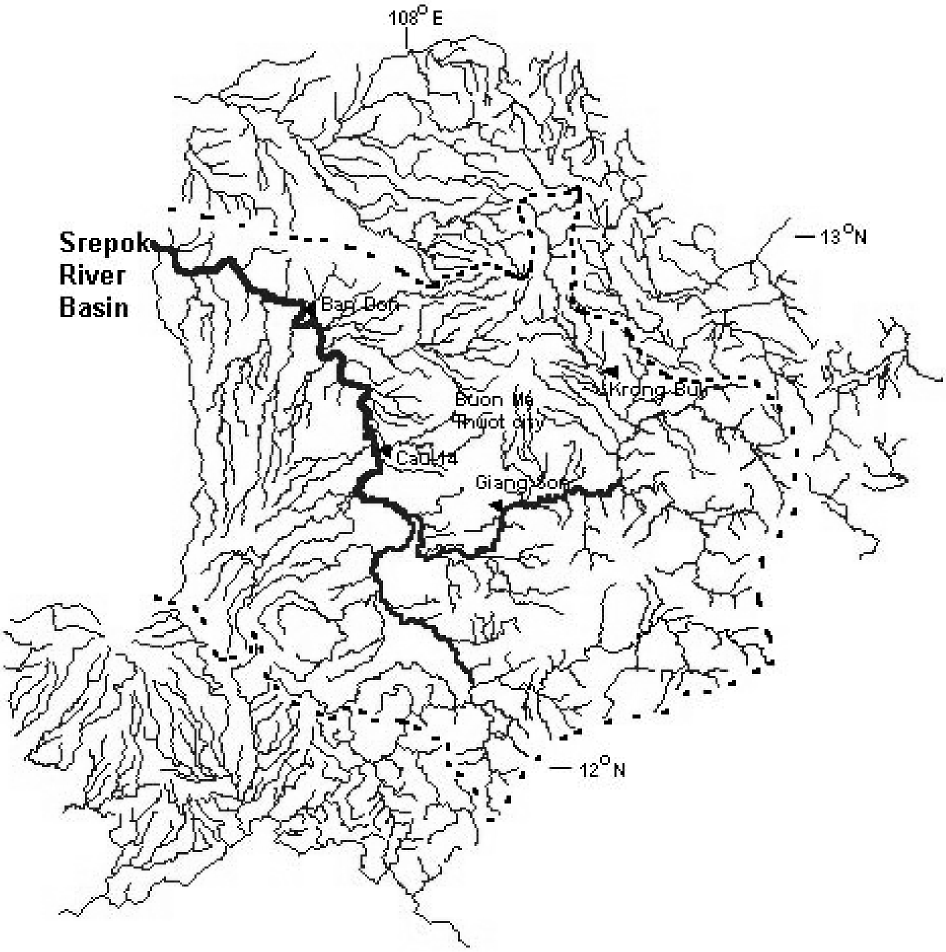


Figure 5.1 Srepok River Basin and Gauging Stations

5.2.3 Basic Meteorological Data

There are twenty-four (24) rainfall stations in the Srepok river basin. The rainfall at the Buon Ma Thuot station has been observed since 1928. There are nine (9) rainfall stations with at least ten (10) years of records since 1977 in Dak Lak province as shown in the following table.

Table 5.1 Annual rainfall (mm/year).

Year	Annual rainfall (mm/year)					
	Ban Don	Cau 14	B.M Thuot	Lak	Giang Son	Kr Buk
1977	1427.5	1423.1	1655.8	1654.9	1473.8	1106.6
1978	1658.0	2012.6	1926.9	2207.1	2069.1	1373.8
1979	1779.5	1662.6	1984.4	2017.9	1944.3	1448.8
1980	1571.4	1582.0	1875.6	2431.7	1935.7	1608.9
1981	1498.9	2290.8	2598.0	2331.1	2193.1	1734.8
1982	1521.8	1699.9	1560.5	1887.2	1715.2	1097.9
1983	1515.5	1707.3	1648.3	1357.0	1517.3	1594.6
1984	1723.6	1460.4	2046.4	2035.1	2392.2	1379.5
1985	1671.3	1730.9	1679.1	1773.1	1862.9	1356.0
1986	1563.6	1633.8	1772.1	1604.3	1840.7	1396.4
1987	1928.3	1733.5	1746.5	1873.9	2094.6	1523.3
1988	1487.0	1490.4	2096.7	1939.3	1916.9	1253.6
1989	1491.1	1551.3	1804.7	2880.7	1540.6	1147.7
1990	1721.4	2123.5	2298.0	2569.1	2147.0	1409.4
1991	1302.2	1404.5	1248.9	1277.9	1245.4	1139.8
1992	1551.2	1709.6	2420.4	2748.6	2095.2	1699.7
1993	1735.8	1798.0	1711.1	2064.4	1898.0	1725.2
1994	1091.9	1441.5	1669.8	1535.1	1684.6	1177.2
1995	1540.5	1766.3	1388.3	1645.7	1542.3	1432.5
1996	2166.8	2216.2	2188.4	1607.6	2126.9	1762.2
1997	-	-	1504.9	-	-	1421.9
1998	-	-	2161.5	-	-	1619.5
Average	1597.4	1721.9	1863.4	1972.1	1861.8	1427.7
Standard deviation.	223.7	258.9	335.7	446.0	291.9	213.1
Var. coefficient	0.14	0.15	0.18	0.23	0.16	0.15

(Source:DANIDA)

The rainy season lasts six (6) months from May to October in the north-western part of the Srepok basin and seven (7) months from May to November in the south-eastern part as shown below.

Table 5.2 Average monthly rainfall (mm/month).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Buôn Ho	1	2	24	87	191	222	186	225	248	224	86	22	1487
Krong Buk*	3.6	5.4	39.2	78.3	168.2	157.6	150.4	166.7	227.1	225.2	156.6	49.3	1427.7
Dak Ea Mil	0	5	36	126	218	222	238	231	279	222	73	13	1663
Giang Son	0	4	18	100	215	253	263	300	298	261	103	29	1848
Duc Xuyen	1	2	28	105	227	283	277	308	303	225	75	11	1846
Cau 14	2	4	17	796	261	256	226	267	291	239	72	11	1696
Ban Don	1	4	25	95	200	248	235	242	264	200	60	10	1568
B.M.Thuôt*	3.6	5.1	23.3	85.8	240.5	272.9	257.3	316.5	302.6	244.8	91.4	19.6	1863.4
M'Drak	32	15	31	73	163	111	122	118	207	400	377	158	1825
Lak	0	3	18	72	219	286	307	378	302	272	92	250	1991

Data : 1977-1995 except for Krong Buk (1977-1998) and B.M.Thuot (1977-1998)

During the period 1977-1995, the mean monthly rainfall at Buon Ma Thuot has been a maximum of 311 mm in August, and a minimum of 2.0 mm in February, at Giang Son 300.0 mm in August and 0.4 mm in January, at Duc Xuyen, 308.0 mm in August and 1.3 mm in January, respectively.

There are three (3) evaporation measurement stations in Dak Lak province as shown below. The evaporation at the Buon Ma Thuot station has been measured since 1977 by a standard Piche tube. In general, actual evaporation values are approximately fifty (50) to seventy (70) % of the values measured by the standard Piche tube in subtropical zones.

Table 5.3 Average monthly Piche Tube evaporation (mm/month)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Buôn Ho	92	123	164	159	134	94	81	71	64	62	62	71	1189
B.M.Thuôt	175	185	220	187	117	74	68	63	53	73	97	129	1441
M'Drak	73	85	116	121	116	144	146	141	88	63	52	57	1201

Data : 1977-1995 except for B.M.Thuot (1977-1998)

There are twenty-nine (29) river gauging stations in Dak Lak province. Out of twenty-nine (29) river gauging stations, there are four (4) key discharge measurement stations for the Srepok river basin at Ban Don, Cau 14, Gian Son and Duc Xuyen as shown below. The discharge data at these key river gauging stations have been measured since 1977.

Table 5.4 River Gauging Stations of Srepok River Basin

No.	Name	River gauging station	Catchment area (km^2)	Aggregate area (km^2)
1	Krong Pac	Krong Pac	256	-
2	Krong Bong	Krong Bong	788	-
3	Upper Krong Buk	Buon Ho	178	-
4	Lower Krong Buk	Cau 42	280	458
5	Upper Krong Ana	Giang Son	1,678	3,180
6	Krong Kno	Duc Xuyen	3,080	-
7	Srepok	Cau 14	2,410	8,670
8	Ea Knir	Doan Ket	224	-
9	Srepok	Ban Don	1,806	10,700
10	Border	None	1,130	11,830

(Source:DANIDA)

The mean annual runoff (1977-1995) of the Srepok river at Ban Don station is 247 m^3/sec, at Giang Son is 64 m^3/sec, and at Duc Xuyen is 97.4 m^3/s as shown below. The maximum annual runoff at Ban Don is 360 m^3/sec in 1981 and minimum is 154 m^3/sec in 1977; at Giang Son it is 118 m^3/sec in 1981 and 39 m^3/sec in 1982, and at Duc Xuyen is 131 m^3/sec in 1990 and 60 m^3/sec in 1977, respectively.

Table 5.5 Mean Annual Discharge of Srepok River (m^3/s)

Year	Measured annual discharge (m^3/sec)		
	Giang Son	Cau 14	Ban Don
1977	44.7	127.9	154.1
1978	61.0	197.8	247.0
1979	64.4	205.6	232.4
1980	73.0	247.6	275.9
1981	118.3	310.5	359.7
1982	38.9	184.5	236.9
1983	44.4	165.0	199.4
1984	61.9	238.5	268.3
1985	56.5	179.4	205.3
1986	57.1	190.6	215.0
1987	47.0	176.8	212.5
1988	65.9	216.3	250.6
1989	64.1	245.0	255.4
1990	92.1	262.2	329.7
1991	40.5	154.4	183.3
1992	89.1	241.2	316.6
1993	90.7	251.2	301.5
1994	57.3	197.5	249.4
1995	49.5	178.2	206.0
Average	64.0	209.0	247.3
Standard deviation	20.77	44.22	52.51
Var. coefficient	0.32	0.21	0.21

(Source:DANIDA)

The lowest mean monthly discharge occurs in April as shown below. The lowest mean monthly discharge values at Ban Don, Cau 14, Gian Son and Duc Xuyen are 61.3, 55.5, 13.6 and 25.1 m^3/sec, respectively.

Table 5.6 Average monthly discharges (m^3/s).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Buôn Ho	3.0	1.9	1.5	1.3	1.8	2.7	2.9	4.5	6.7	8.5	7.2	4.7	3.9
Krong Buk	5.6	3.0	2.1	2.1	3.8	6.2	6.2	10.3	15.9	21.7	17.3	10.4	8.7
Krong Pac	4.9	2.6	1.6	1.3	2.1	3.4	3.5	4.2	7.2	17.3	20.9	12.4	6.8
Krong Bong	14.4	8.4	5.9	5.1	7.0	11.8	12.1	15.0	23.2	45.5	56.6	39.2	20.3
Giang Son	40.1	22.8	15.5	13.6	22.0	39.2	41.9	56.5	82.6	150	161	111	64.0
Duc Xuyen	47.8	32.7	25.6	25.1	38.2	75.7	98.7	172	205	224	137	86.3	97.4
Cau 14	118	76.0	56.7	55.5	86.7	155	204	285	380	468	350	238	209
Ban Don	129	82.9	62.4	61.3	103	196	249	357	483	574	403	267	247
Ea Knir	2.2	1.5	1.3	1.3	2.1	3.9	4.4	6.0	7.9	9.1	6.2	4.3	4.2

Data : 1977-1995 except for Ban Don (1977-1998)

5.2.4 Verification of Simulated Runoff and Water Balance in the Srepok River Basin

The drainage basin of the Srepok river is composed of highlands of basalts and plains of Jurassic sandstone and shale. The discharge of the Srepok river at Ban

Don with a drainage basin area of 10,700 km^2 is selected and verified for the purpose of water balance analysis.

The daily discharge at Ban Don is calculated for twenty-one (21) years from 1978 to 1998. The rainfall data at Buon Ma Thuot and Krong Buk and the evaporation data at Buon Ma Thuot are used in the calculation.

The simulated daily, monthly and annual runoffs of the Srepok river at Ban Don are verified by comparing with the observed runoffs for twenty-one (21) years from 1978 to 1998. The following table shows the identified flow parameters of the tank model and Figure 5.2 describes comparison with the observed and computed monthly discharges of the Srepok river at Ban Don.

Table 5.7 Identified Flow Parameters of Tank Model for Srepok River

Tank	Parameter			
First tank	Outflow coefficient	Upper hole	A2	0.1
		Lower hole	A1	0.1
	Infiltration coefficient		A0	0.2
Second tank	Outflow coefficient		B1	0.01
	Infiltration coefficient		B0	0.02
Third tank	Outflow coefficient		C1	0.001
	Infiltration coefficient		C0	0.002
Fourth tank	Outflow coefficient		D1	0.0002
	Infiltration coefficient		D0	0

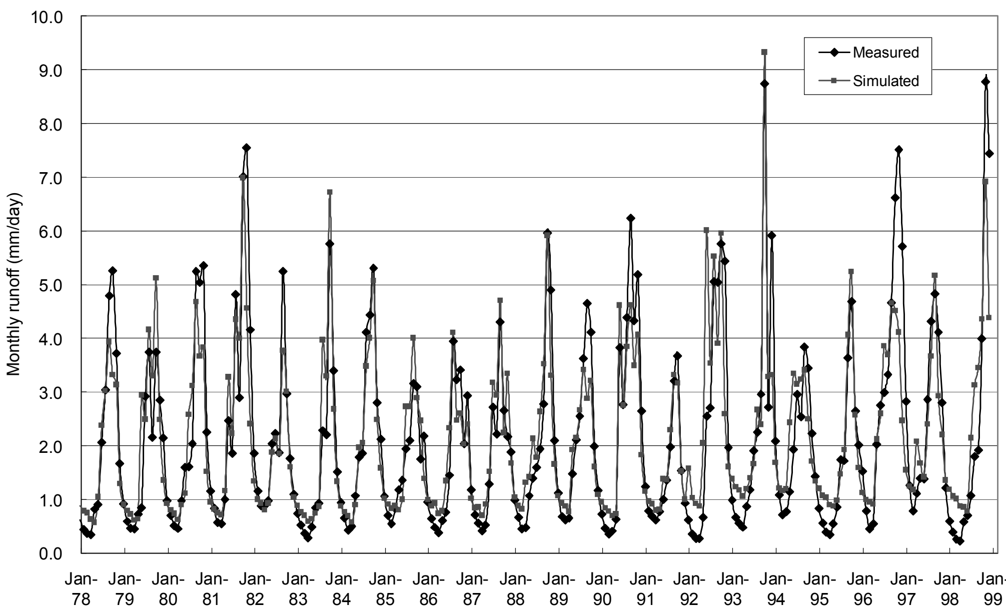


Figure 5.2 Runoff Simulation of Srepok River at Ban Don by Sugawara's Tank Model

The water balance calculation of the Srepok river basin for twenty-one (21) years from 1978 to 1998 at the Ban Don gauging station is summarized as shown below.

Table 5.8 Water Balance of Srepok River Basin for 21 years from 1978 to 1998 at Ban Don (10,700 km^2) identified by Sugawara's Tank Model

Precipitation (mm/year)	Evaporation (mm/year)	Runoff (mm/year)	Groundwater recharge (mm/year)	Groundwater recharge / Precipitation (%)
1658.1	886.1	784.5	535.5	32.3

The recharge in basalt area of the Buon Ma Thuot highland is calculated to exceed more than 30 % of precipitation. The basalt area of the Buon Ma Thuot highland makes a good groundwater aquifer.

5.3 Safe Well Yields

According to the water balance calculation as discussed in section 5.2, the basin-wide (macro-scale) water balance calculation shows that the annual groundwater recharge is estimated as 535.5 mm/year (1.5 mm/day) in the Srepok river basin as shown in Table 5.8 and that the groundwater recharge fluctuates from 437.4 in 1991 to 685.7 mm/year in 1992. The groundwater recharge of 1.5 mm/day is equivalent to an amount of 1500 m^3/day/km^2.

The relationship between discharge and drawdown of the step-drawdown test shows a specific line on a log-log graph as discussed in section 4. The critical yield (discharge) of the test wells is estimated to be more than the maximum discharge of the step-drawdown test. An optimum yield can generally be recognized to be seventy (70) % of the critical yield. The optimum yield of the test wells can be assumed to be nearly equal to the maximum discharge of the step-drawdown test. When the test wells produce an extraction rate of 300 m^3/day for future water supply, the extraction rate can be recognized to be much lower than a groundwater recharge of 1.5 mm/day. From a macroscopic viewpoint of the water balance in the Srepok river basin, several production wells can extract groundwater within 1 km^2.

Therefore, the safe well yield of each test well can be recognized to be equal to the optimum yield. The following table shows the safe well yields of each test well by commune/town.

Table 5.9 Safe Well yield of Each Commune/Town

Target commune/town		Safe well yield (m^3/day) (liter/sec)		Permissible dynamic groundwater level (m below ground surface)
Gia Lai province				
G1	Kong Tang	322	3.7	57
G2	Nhon Hoa	173	2.0	71
G3	Chu Ty	317	3.7	62
G4	Thang Hung	259	3.0	54
G5	Nghia Hoa	173	2.0	62
G6	Ia Rsiom	406	4.7	50
G7	Kong Yang	432	5.0	44

5.4 Groundwater Level Monitoring

5.4.1 Observation Wells Monitored by the Geological & Mineral Resources Survey of Vietnam

In general, groundwater level monitoring is indispensable to detect problems of groundwater over-exploitation. According to the National Program of Groundwater Monitoring in the central highlands under the Ministry of Industry, the groundwater level monitoring in the three provinces of Dac Lac, Gia Lai and Kon Tum has been conducted since 1993 at 73 monitoring wells. The purpose of these monitoring wells is to measure the groundwater levels of aquifers in Quaternary sediments, Basalts, Neogene sediments, Jurassic rocks, metamorphic rocks and granites.

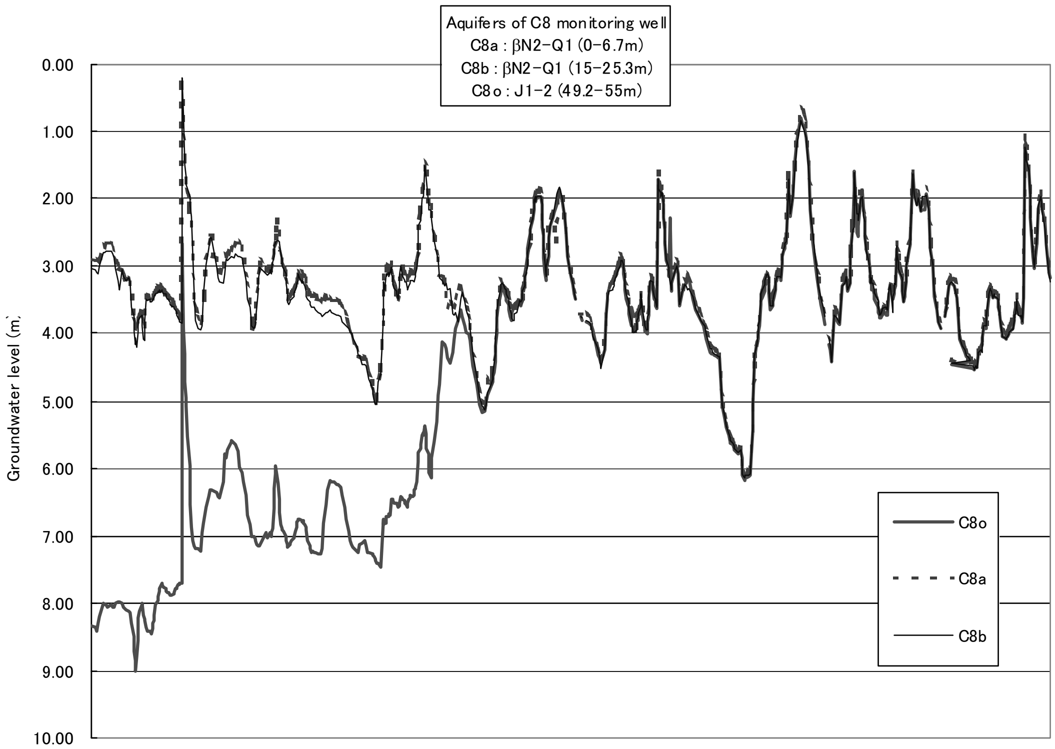
The following four monitoring wells exist within and in the vicinity of the target communes/towns. The following table shows aquifers of the monitoring wells within and in the vicinity of the four target communes/towns, Ea Drang (D2), Krong Buk (D3), Nhon Hoa (G2) and Nghia Hoa (G5).

Table 5.10 Existing Monitoring Wells within and in the Vicinity of the Target Communes

Commune/town	Monitoring well	Aquifer	Screen (m)
G2, Nhon Hoa	LK67T	Basalt (βN_2-Q_1)	0 - 20
G5, Nghia Hoa	C2a	Basalt (βN_2-Q_1)	0 - 22.7
	C2b	Basalt (βN_2-Q_1)	33 - 58.5
	C2c	Basalt (βN_2-Q_1)	62 - 75
	C2o	Basalt (βN_2-Q_1)	89.6 - 190.8

The LK67T and C2 monitoring wells are located within the target communes of Nhon Hoa (G2) and Nghia Hoa (G5), respectively. The aquifers of these monitoring wells are composed of basalt and the groundwater level measurement has been carried out. The monitoring data do not show lowering of groundwater level at these monitoring wells as shown in Figure 5.3 and Figure 5.4.

It can be recognized that groundwater exploitation from the deep aquifers has just started recently in the rural area according to the field survey. When groundwater development is planned properly with adequate intervals between wells to avoid local groundwater level lowering (cone effect), it is judged to be sustainable and to contribute to the improvement of the living standards of the people by supplying clean and safe water. Monitoring of groundwater level for the existing and newly constructed wells is essential for management of groundwater resources.



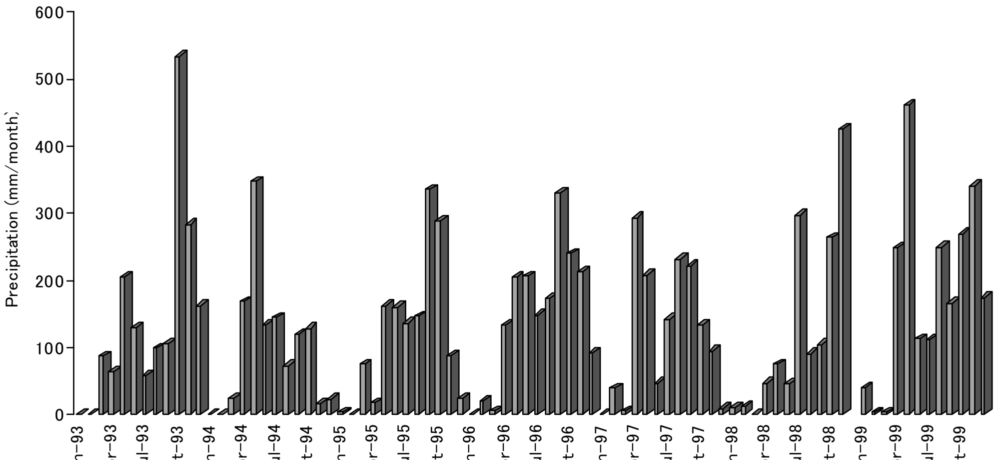
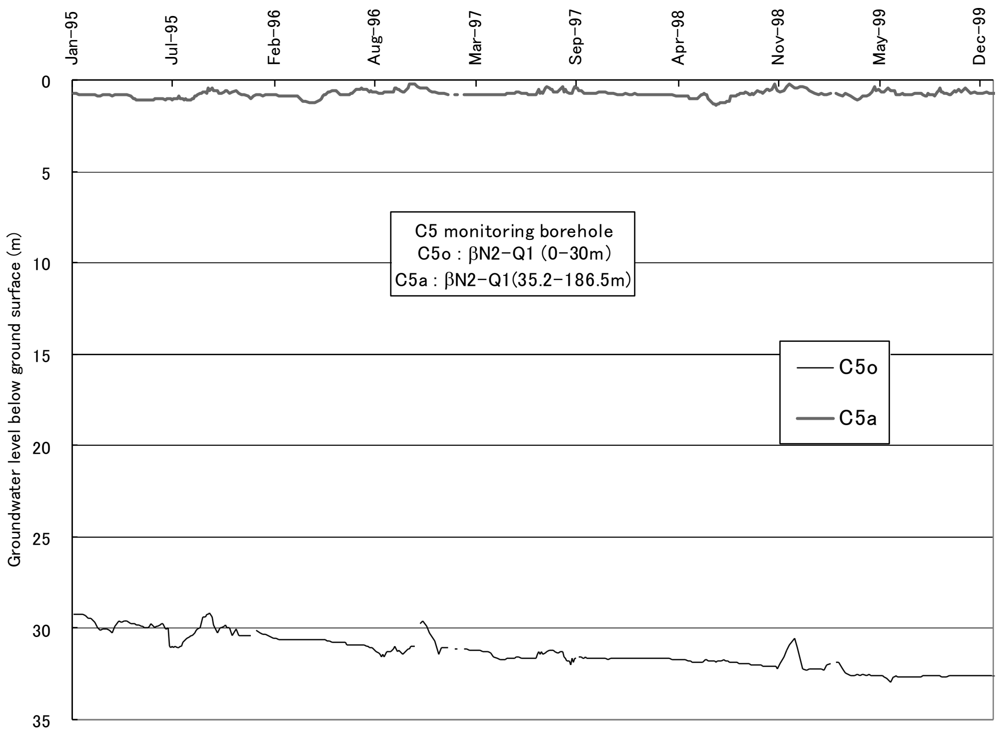


Figure 5.3 Groundwater Level of C8 Monitoring Well at Phuc An, Krong Pak, Dac Lac



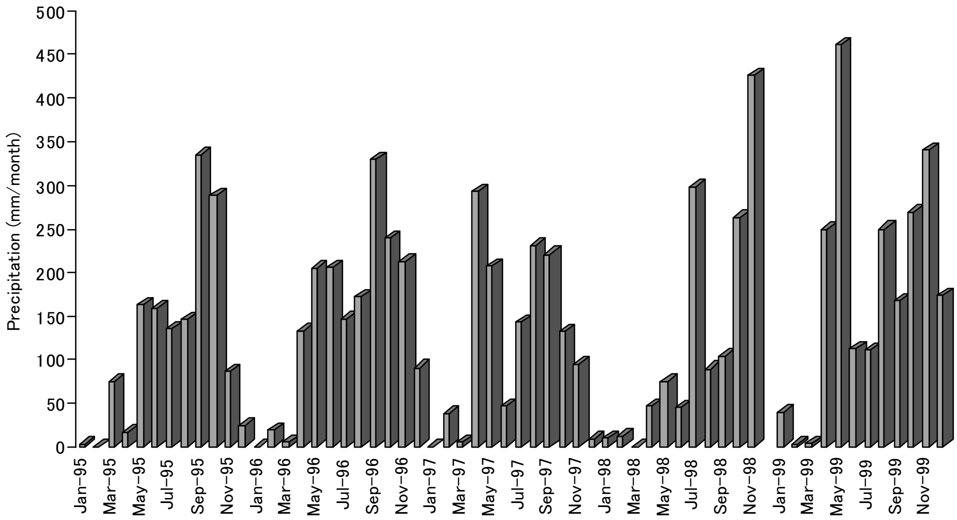
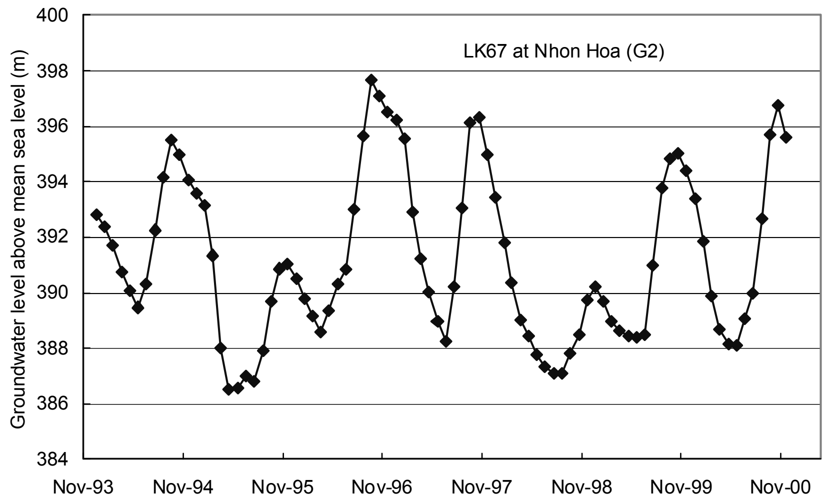


Figure 5.4 Groundwater Level of C5 Monitoring Well in TP, Buon Ma Thuot



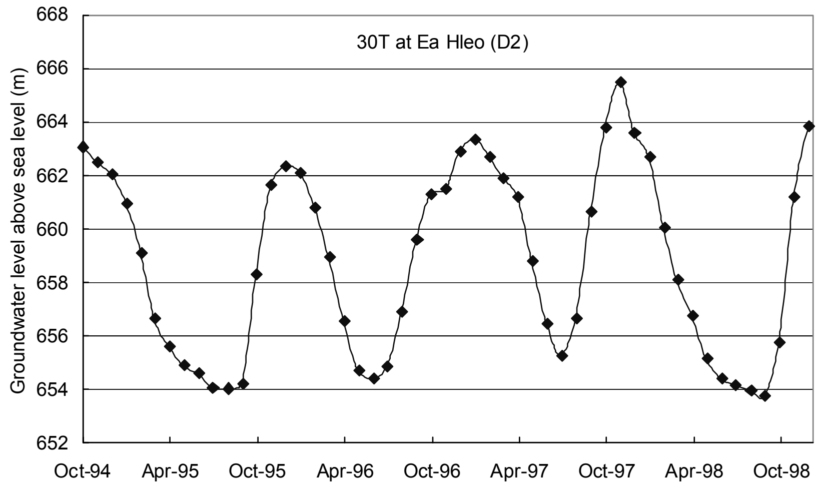


Figure 5.5 Groundwater Levels of 30T and LK67 Monitoring Wells at Ea Hleo (D2) and Nhon Hoa (G2)

5.4.2 Test Wells

Automatic groundwater level recorders were installed for the 7 test wells at June 2001. PCERWASS has been continuing the monitoring work. Figure 5.6 shows the fluctuation of groundwater levels in the test wells from June 2001 to June 2002. It is one hydrological year records including wet and dry seasons. According to the hydro-meteorological station in Buon Ma Thuot, it was a drought from September 2001 to March 2002. Unfortunately the data for G4 was not fully recorded.

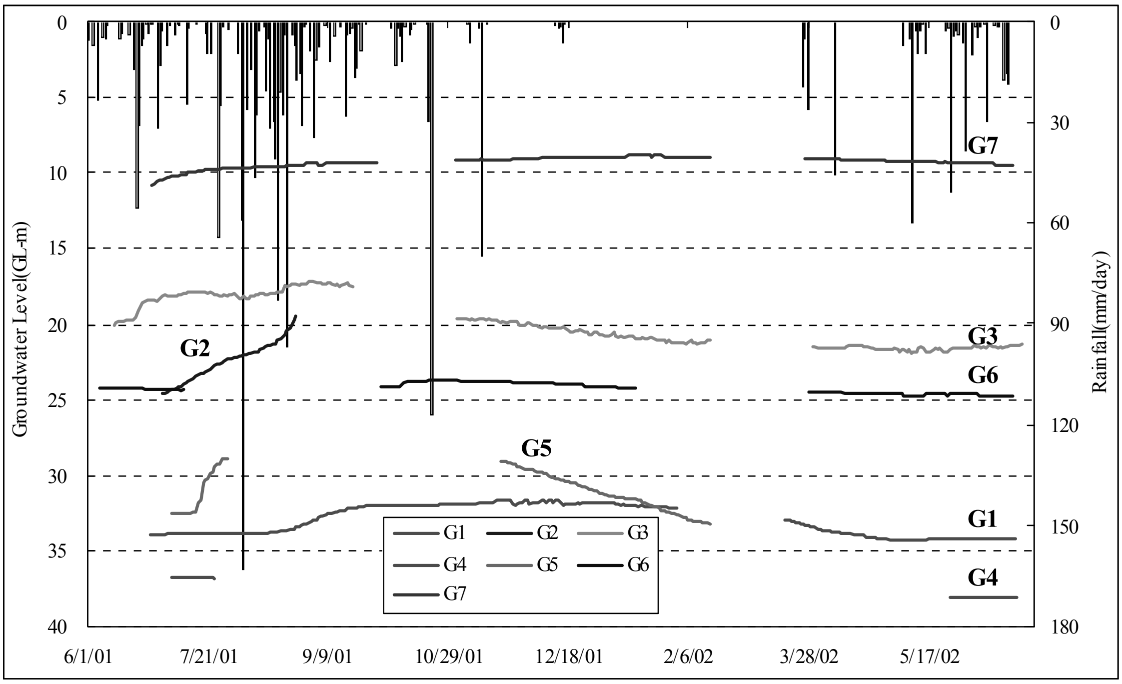


Figure 5.6 Groundwater Levels of Test Wells

The data do not reveal lowering of groundwater levels from the result. The groundwater level of G1 test well had began to rise from September 2001 to December 2001 with approximately 2 m. The groundwater level had lowered from January 2002 to May 2002.

There is a production well in Chu Ty town (G3) water supply system about 200 m apart from G3 test well. The pumping usually starts in every early morning and stops by evening. The groundwater level of G3 test well shows a lowering of about 1 m in afternoon and recovers groundwater level in midnight. Therefore, the groundwater levels of every early morning before pumping were analyzed. The groundwater level at G3 test well had risen from July 2001 to September 2001 with approximately 3 m. The groundwater level had lowered from October 2001 to May 2002.

The groundwater level of G5 test well had risen from July 2001 to September 2001 with approximately 5 m. The groundwater level had lowered from October 2001 to May 2002. The groundwater level of G2 test well is nearly same fluctuation as G5 test well. The groundwater levels at G6 and G7 test wells show a small fluctuation of about 1 m only.

5.5 Groundwater Potential Map

The most promising areas for wells drilled for future groundwater development of each target commune/town are shown in Figure 5.6 - 5.12. The most promising areas for the future development of groundwater are circled excluding the present JICA well fields. The results will be reviewed and revised at the F/S phase and feedback to the master plan in consideration of the layout of each water supply system.

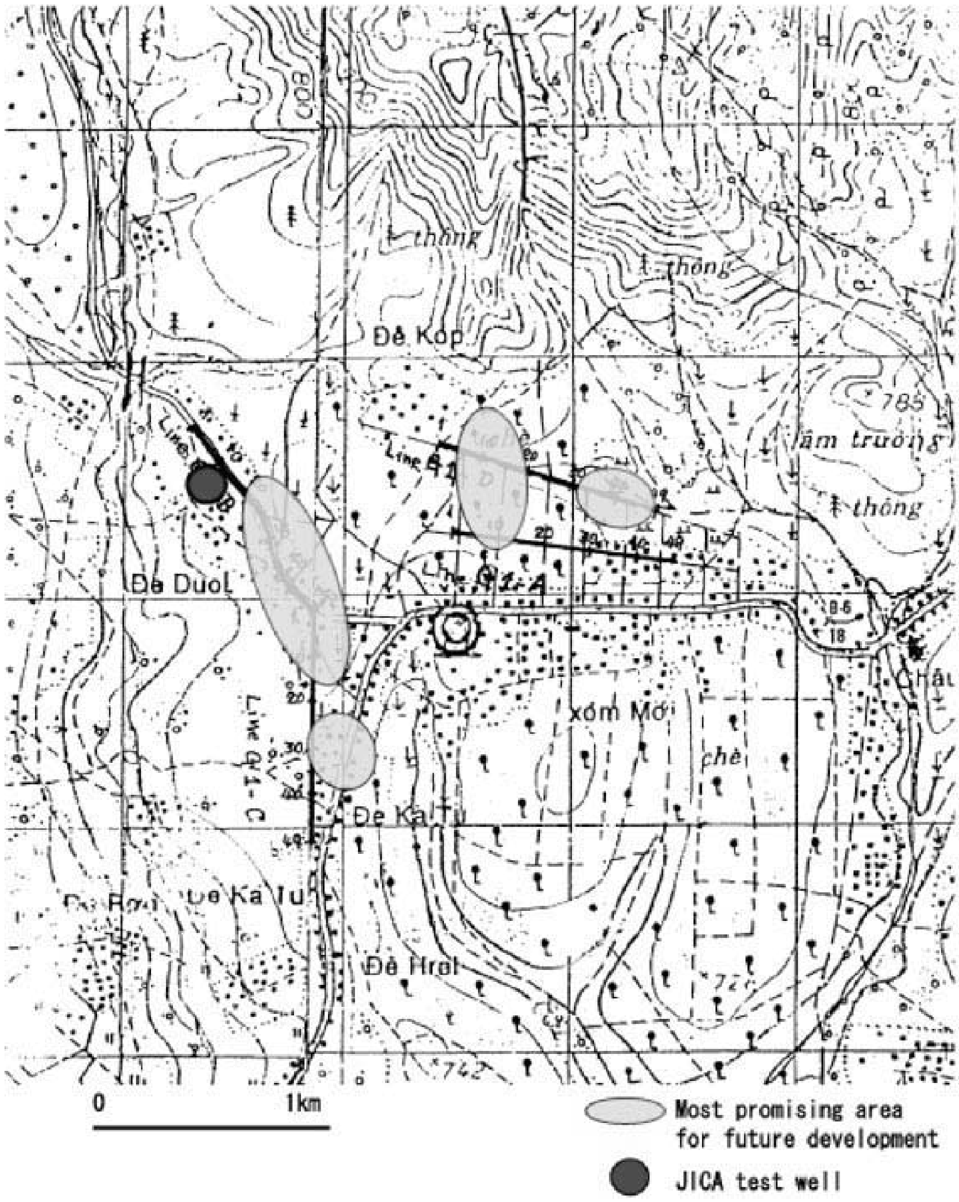


Figure 5.7 Most Promising Area for Future Groundwater Development at Kong Tang Twon

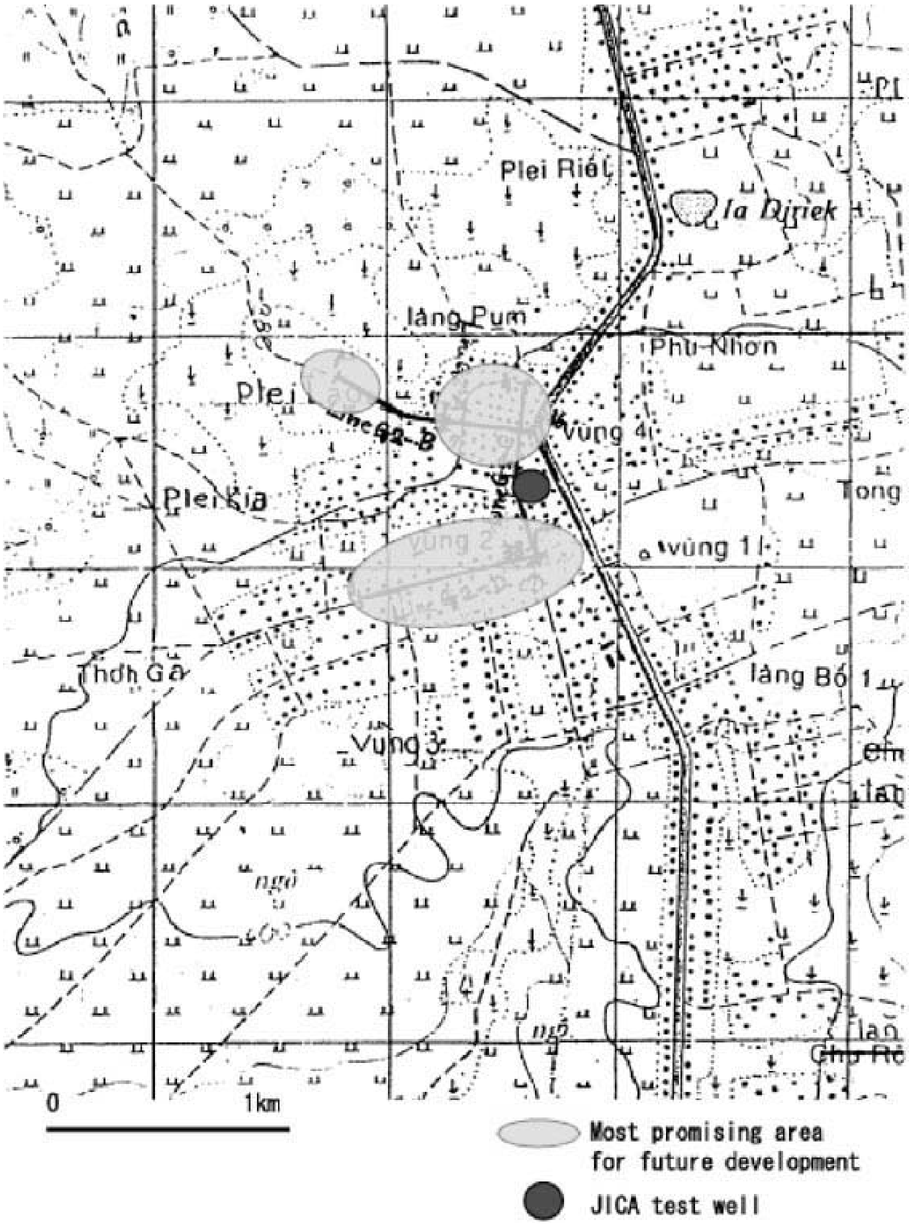


Figure 5.8 Most Promising Area for Future Groundwater Development at Nhon Hoa Commune

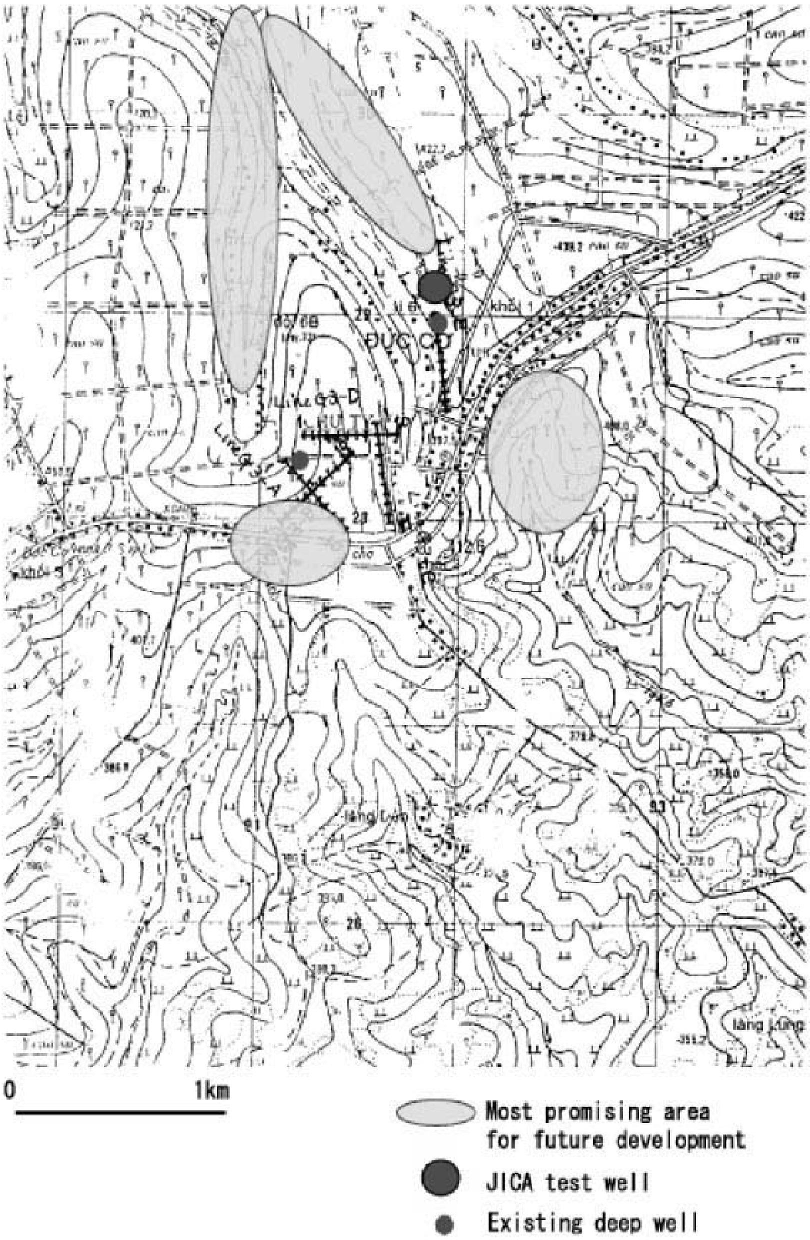


Figure 5.9 Most Promising Area for Future Groundwater Development at Chu Ty Town

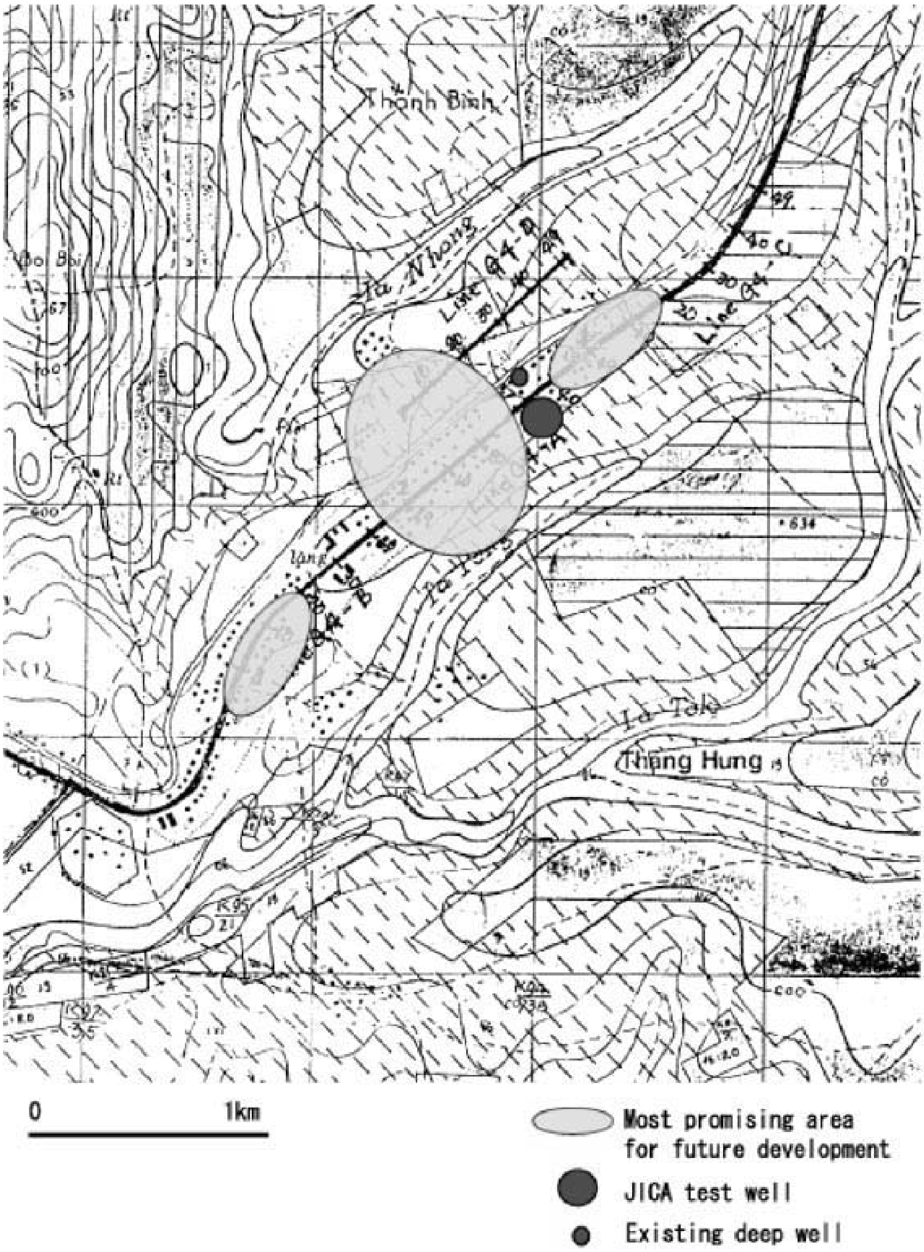


Figure 5.10 Most Promising Area for Future Groundwater Development at Thang Huang Commune

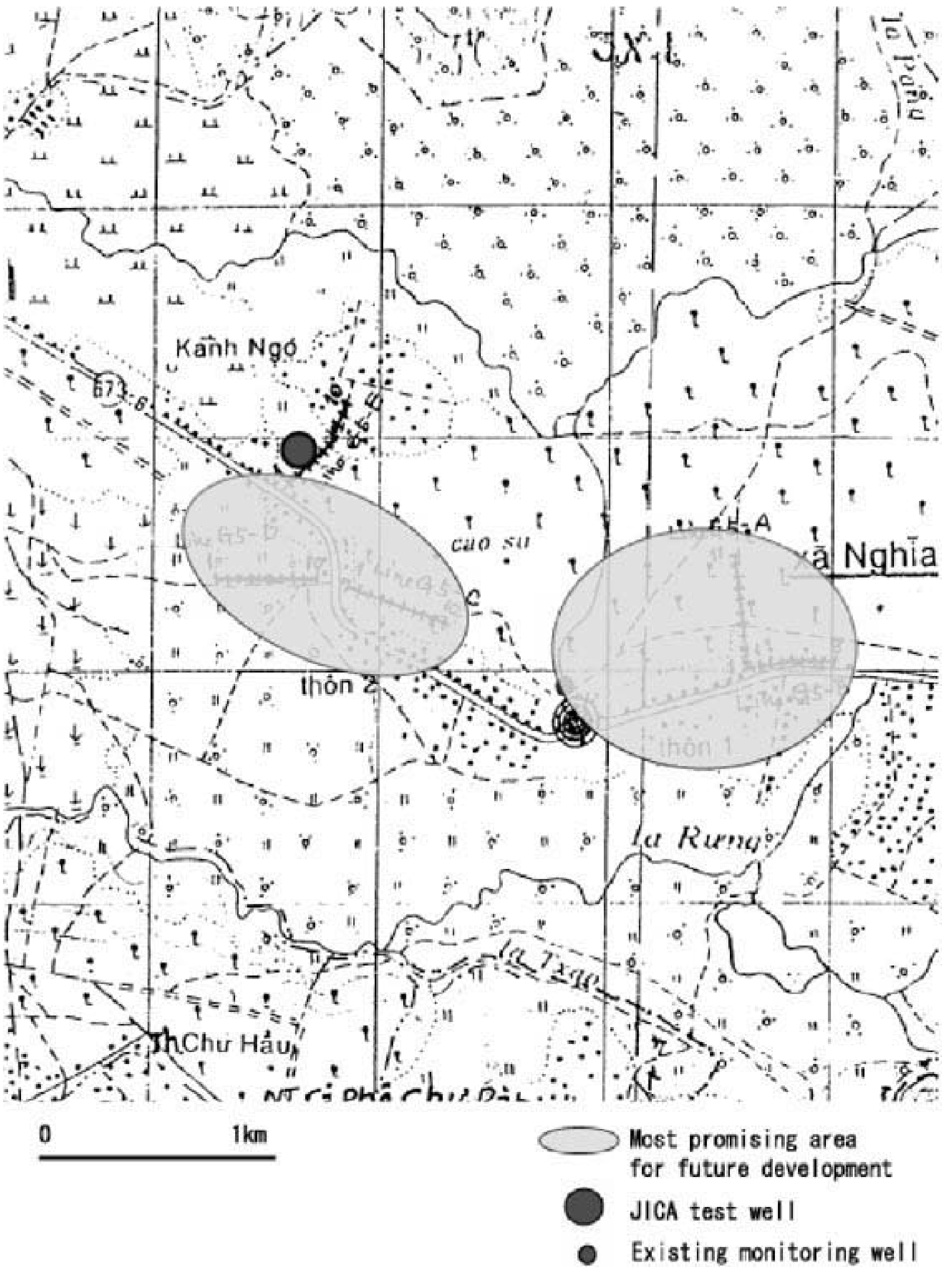


Figure 5.11 Most Promising Area for Future Groundwater Development at Ghia Hoa Commune

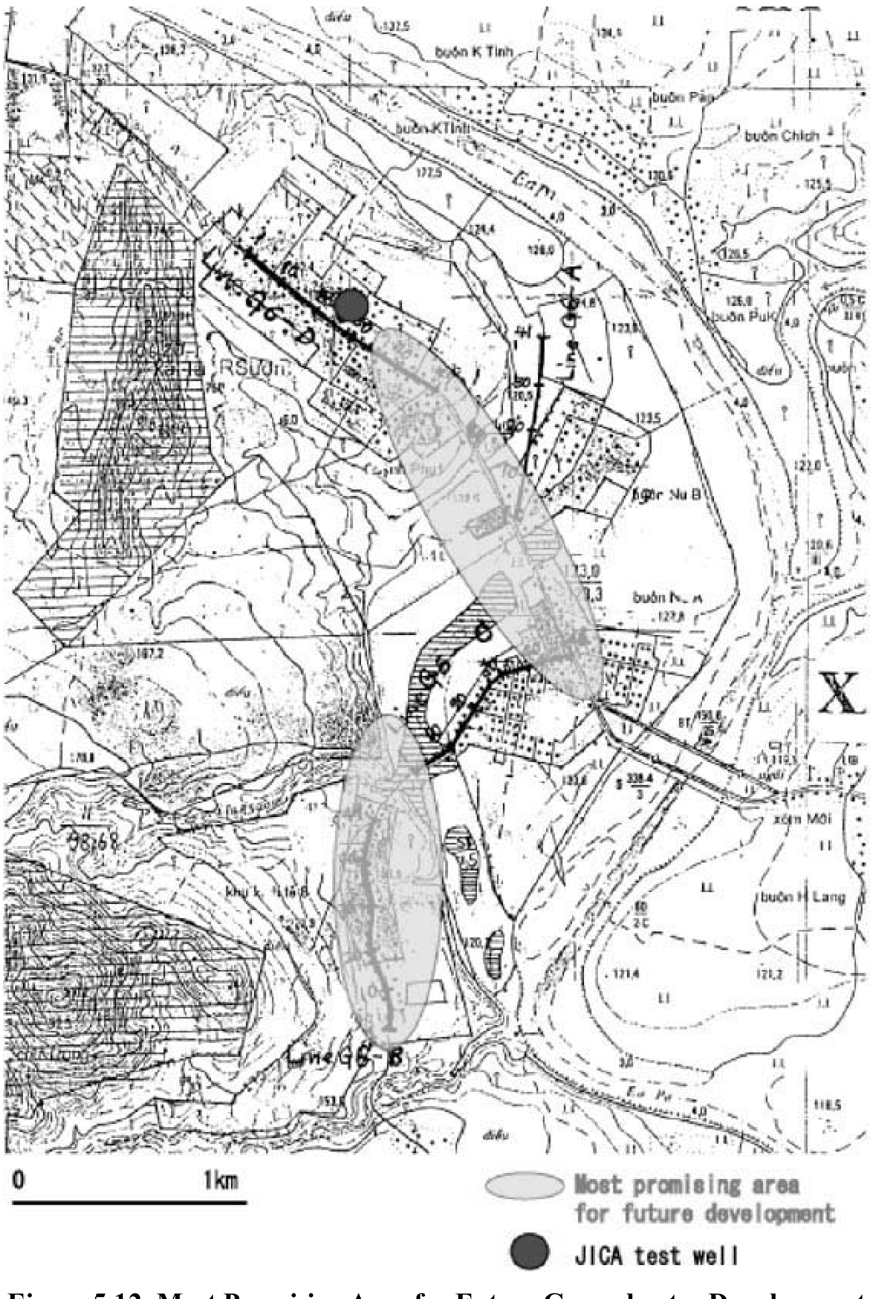


Figure 5.12 Most Promising Area for Future Groundwater Development at Ia Rsiom Commune

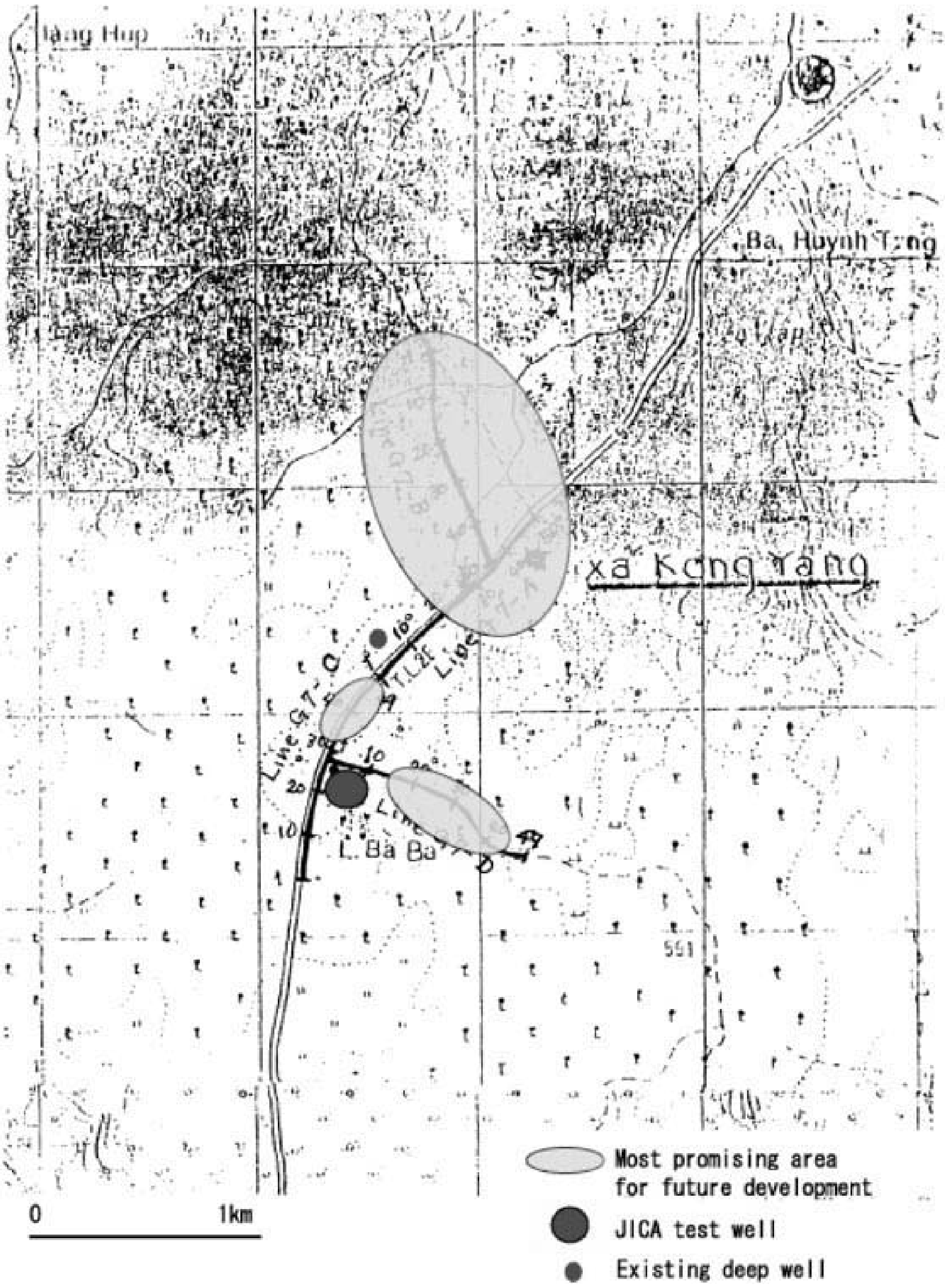


Figure 5.13 Most Promising Area for Future Groundwater Development at Kong Yang Commune