CHAPTER V

RESULTS AND DISCUSSION

5.1 Vertical groundwater flow velocity

The results of β value and vertical groundwater velocity of each selected hydrogeological unit in 20 wells in Chiang Mai Basin were calculated and are listed in Table 5.1 (see details in appendix A and B). This chapter will describe and discuss the results of those values in relation to the geological and hydrological conditions of the area.

Table 5.1 Summary of β values and vertical groundwater velocities

Well No.	Depth (m)	Hydro-geological Unit	Approx. % Clays	Thickness (m)	*β* Values	Thermal gradient (°C/100m)	Vertical Groundwater Velocities (cm/yr)	Geological Setting
2	20-50	Sandy clays	60	30	0.27	1.28	7.91	Qcr
	50-66	Sands	<5	16	0.06		4.68	
	66-84	Sandy clays	60	18	0.09		4.44	
4	54-94	Sands	<5	40	0.88	2.91	27.85	Qcm
	144-196	Sands	<5	52	0.13		3.10	
5	10-34	Clayey sands	30	24	0.33	3.15	14.64	Qcr
	34-80	Gravels	<5	46	-0.26		-7.14	
	80-130	Sandy clays	70	50	-0.49		-8.06	
6	28-96	Sandy clays	70	68	1.36	2.65	16.44	Qcm
8	38-148	Sands	<5	110	0.36	3.01	4.16	Qcr
9	24-68	Sands	5	44	-0.01	4.51	-0.24	Qcr
	68-112	Sands	<5	44	0.10		2.76	
	112-168	Sands	10	56	0.01		1.11	
11	72-96	Clayey sands	30	24	0.15	1.97	6.91	Qcp
12	36-84	Sands	<5	48	0.37	2.16	9.91	Qcp
13	34-104	Clayey sands	20	70	1.16	2.21	18.76	Qcm
14	32-56	Sands	<5	24	0.62	2.41	32.81	Qcm
	58-90	Sandy clays	80	32	0.19		4.58	
	106-130	Sands	5	24	0.17		8.61	

Well No.	Depth (m)	Hydro-geological Unit	Approx. % Clays	Thickness (m)	*β* Values	Thermal gradient (°C/100m)	Vertical Groundwater Velocities (cm/yr)	Geological Setting
15	24-126	Sands	<5	102	0.95	2.65	11.80	Qcr
	126-174	Clayey sands	40	48	0.15		3.11	
16	44-70	Sands	<5	26	0.53	2.63	25.96	Qcm
	78-202	Sands	<5	124	0.22		2.33	
19	22-168	Sands	<5	146	0.91	2.93	7.80	Qcp
21	20-96	Sands	10	76	0.98	5.51	15.10	Qcr
	98-180	Sandy clays	70	82	0.09		0.47	
24	26-60	Sandy clays	70	34	0.84	1.36	20.19	Qcm
	62-96	Clayey sands	20	34	0.50		16.80	
	116-150	Sandy clays	70	34	0.68		16.43	
	150-202	Sands	<5	52	0.50		12.06	
27	38-72	Clayey sands	20	34	0.60	2.30	19.90	Qcm
	72-108	Sands	<5	36	0.28		9.64	
	112-170	Sands	<5	58	0.11		2.30	
29	20-96	Clayey sands	15	76	0.23	3.50	3.58	Qcp
	96-196	Sandy clays	70	100	-0.17		-1.38	
30	30-174	Sands	<5	144	0.77	2.73	6.73	Qcp
31	28-116	Sandy clays	80	88	-0.02	3.45	-0.21	Qcp
	116-144	Sands	<5	28	-0.19		-8.46	
	144-180	Sandy clays	60	36	0.28		6.89	
42	58-106	Clayey sands	42	48	0.08	2.87	1.62	Qcp
	106-300	Sands	<5	194	0.09		0.60	

Details of each well are described as follows:

Well 2 is located in Mond Huay Kaew temple, Doi Lor district, Chiang Mai province. The geological setting of the area is low terrace deposits (Qcr). Three hydrogeological units in this well were selected for calculation from upper to lower units.

The upper hydrogeological unit was chosen at 20-50 meters depth consisting of sandy clays (~60% clays). The calculated result gives a positive β value of 0.27 indicating that groundwater moves downward and the calculated vertical velocity is 7.91 cm/yr.

The middle hydrogeological unit was selected at 50-66 meters depth which consists mostly of sands (~<5% clays). The calculated β value is 0.06 indicating a downward movement of groundwater at a calculated vertical velocity of 4.68 cm/yr.

The lower hydrogeological unit in this well was selected at 66-84 meters depth which consists of sandy clays (~60% clays). The calculated β value is 0.09 indicating a downward movement of groundwater at a vertical velocity of 4.44 cm/yr.

The above result reveals that the area in the vicinity of this well is a recharge zone in which the groundwater moves downward at a faster vertical velocity rate in the upper aquifer and slow down slightly in the lower two aquifers.

This well is situated in low terrace deposits (Qcr) consisting of sands and sandy clays near the Mae Ping river on the lower part of the basin. The upper most units represent low range of vertical groundwater velocity.

Well 4 is located in Mai Nong Hoy temple, Doi Lo district, Chiang Mai province. The geological setting of the area is high terrace deposits (Qcm). Two hydrogeological units in this well were selected for calculation from upper to lower units.

The upper hydrogeological unit was chosen at 54-94 meters depth consisting mostly of sands (<5% clay). The calculated β value is 0.88 indicating that groundwater moves downward at a very fast vertical velocity is 27.85 cm/yr.

The lower hydrogeological unit was selected at a 144-196 meters depth which consists essentially of sands (<5% clays). The calculated β value is 0.13 indicating a downward movement of groundwater at a vertical velocity is 3.10 cm/yr.

From the above result it suggests that this area is a recharge zone in which the groundwater descents at rather high vertical velocity in the shallow level and decrease rapidly in the deeper level.

This well is situated on topographically high terrace deposits on the lower part of the basin and near the rim of the basin. The high terrace area represents high hydraulic gradient which allows surface water to replenish aquifer at high rate. However, the rapid decrease of recharge rate in the lower unit may be due to the presence of interbedded clay-rich layers (having low hydraulic conductivity) at 94-144 and 135-144 meters depth.

Well 5 is located in Mai Sun Tung temple, Jom Tong district, Chiang Mai province. The geological setting of the area is low terrace deposits (Qcr). There are three hydrogeological units selected for evaluation in this well from upper to lower units.

The upper hydrogeological unit was chosen at 10-34 meters depth which consist of clayey sands and clayey gravels (~30% clays). The calculated results show β value of 0.327 indicating groundwater moves downward and give vertical velocity rate of 14.64 cm/yr.

The middle hydrogeological unit was selected at 34-80 meters consisting mostly of gravels (<5% clays). The calculated result gives a negative β value of -0.26 indicating that groundwater moves upward and the calculated (upward) vertical velocity is -7.14 cm/yr (as indicated by negative sign).

The lower hydrogeological unit was selected at 80-130 meters depth which consist of sandy clays (~70% clays). The calculated β value is -0.49 indicating an upward movement of groundwater at a vertical velocity rate of -5.58 cm/yr.

From the above result it suggests that the upper hydrogeological unit in this area is a recharge zone but the lower two hydrogeological units are discharge zones.

This well is situated in low terrace deposits (Qcr) consisting of clayey sands and gravels in upper unit. The well is also located in the medium high land area on the lower part of the basin that shows the medium hydraulic gradient. This could allow surface water to replenish aquifers moderately well as shown by medium recharge rate in the upper unit. On the contrary, the discharge zone of lower two units could be explained by the following facts. Based on the DGR data in 2006 (Adisai Charuratna, 2008) the total of groundwater usage from government and private wells in this area was around 1,200 cu.m./day for industrial and household consumption. From the record of well, the depth of well screen is between 30-200 meters that are exactly in the zones giving upward groundwater movement of the lower two units.

Well 6 is located in the Sri Boon Ruang Mausoleum, Mae Rim district, Chiang Mai province. The geological settling of the area is high terrace deposits (Qcm). Only one hydrogeological unit was selected for evaluation in this well.

The selected hydrogeological unit was chosen at 28-96 meters depth consisting of sandy clays (~70% clays). The calculated β value is 1.36, indicating that the groundwater moves downward at a vertical velocity rate of 16.44 cm/yr.

The result shows rather high vertical velocity. This may be because this well is situated on the upper part and near the rim of the basin. According to its setting in high terrace area which represents the high hydraulic gradient, this allows surface water to replenish to aquifer at high rate.

Well 8 is located in the Jum Long Temple, Mae Rim District, Chiang Mai Province. The geological setting of the area is low terrace deposits (Qcr). Only one hydrogeological unit was selected for evaluation in this well.

The hydrogeological unit was chosen at 38-148 meters depth which consists of gravels and sands (<5% clay). The calculated result gives β value of 0.36 indicating downward movement of groundwater at a vertical velocity of 4.16 cm/yr. This area is therefore a recharge zone.

This well is situated in low terrace deposits. The well is also located in the medium high land area on the middle part of the basin that shows the medium hydraulic gradient. This could allow surface water to replenish aquifers moderately well but the calculated recharge rate is rather low by unknown reason.

Well 9 is located in the Wat Dong Kee Lek school, San Kamphang district, Chiang Mai province. The geological setting of the area is low terrace deposits (Qcr). Three hydrogeological units in this well were selected for evaluation from upper to lower units.

The upper hydrogeological unit was chosen at 24-68 meters depth which consists mostly of sands (~5% clays). The calculated results show a small negative β value of -

0.01 indicating groundwater almost stand still or moves upward at a very slow vertical velocity rate (-0.24 cm/yr).

The middle hydrogeological unit was selected at 68-112 meters depth consisting of sands (<5% clays). The calculated result gives a positive β value of 0.01 indicating that groundwater moves downward at a vertical velocity of 2.76 cm/yr.

The lower hydrogeological unit was chosen between 112-168 meters depth consisting mostly of sands (~10% clays). The calculated result gives a positive β value of 0.01 indicating a downward movement of groundwater at a vertical velocity of 0.29 cm/yr.

From the above result it suggests that the upper aquifer in this area is a discharge zone but the lower two aquifers are recharge zones.

Based on the DGR data in 2006 (Adisai Charuratna, 2008) most wells in area have screen between10-60 meters depth (roughly at the upper unit) for supplying groundwater at a total rate of about 2,700 cu. m/day for agricultural purposes, especially for longan plantation. Such high pumping rate however may be slightly more than the natural local recharge from the surface water which, as a result, have given a small negative β value. On the contrary, the downward movement of the lower two units may be influenced by regional recharge from rim of the basin rather than from local discharge.

Well 11 is located in the Je Di Mae Kruew temple, San Saey district, Chiang Mai province. The geological setting of the area is younger alluvial deposits (Qcp). In this well only one hydrogeological unit was selected for calculation.

The hydrogeological unit was picked at 72-96 meters depth which consists of clayey sands (~30% clays). The calculated β value is 0.15 indicating a downward movement of groundwater at a calculated vertical velocity of 6.91 cm/yr. Hence this area is a recharge zone.

This well is situated in the Mae Ping floodplain deposits on the upper part and near the Mae Ping River. According to its setting in the low land area which represents low hydraulic gradient, this allows surface water to replenish the aquifer at rather low rate.

Well 12 is located in the San Na Meng village, San Saey district, Chiang Mai province. The geological setting of the area is younger alluvial deposits (Qcp). Only one hydrogeological unit was selected for evaluation in this well.

The hydrogeological unit was chosen at 36-84 meters depth which consists of sands (<5% clays). The calculated β value is 0.37 indicating that groundwater moves downward and the vertical velocity rate is 9.91 cm/yr. Again this area is a recharge zone.

This well is situated in the Mae Kuang River floodplain deposits on the upper part and near the Mae Kuang River. According to its setting in the low land area which represents low hydraulic gradient, this allows surface water to replenish the aquifer at rather low rate.

Well 13 is located in the Tha Kwean temple, San Saey district, Chiang Mai province. The geological setting of the area is high terrace deposits (Qcm). Only one hydrogeological unit was selected for calculation in this well.

The hydrogeological unit is chosen at 34-104 meters depth which consists of clayey sands (~20% clays). The calculated β value is 1.16 indicating a downward movement of groundwater at a very high vertical velocity of 18.76 cm/yr. Hence this area is located in a recharge zone.

This well is situated in an alluvial complex area on the upper part of the basin and near the rim of the basin. The high terrace area represents high hydraulic gradient which allows surface water to replenish aquifer at high rate.

Well 14 is located in the Wi Wak Wa Na Ram temple, San Saey district, Chiang Mai province. The geological condition of the area is high terrace deposits (Qcm). Three hydrogeological units were selected for calculation in this well from upper to lower units.

The upper hydrogeological unit was chosen at 32-56 meters depth which consists of sands (<5% clays). The calculated β value is 0.62 indicating a downward movement of groundwater at a very high vertical velocity rate of 32.81 cm/yr.

The middle hydrogeological unit was selected at 58-90 meters depth consisting of sandy clays (~80% clays). The calculated β value is 0.19 indicating a downward movement of groundwater at a vertical velocity rate of 4.58 cm/yr.

The lower hydrogeological unit was selected at 106-130 meters depth which consists of sands (~5% clays). The calculated β value is 0.17 indicating a downward movement of groundwater at a vertical velocity rate of 8.61 cm/yr.

The above result reveals that the area around this well is a recharge zone in which the groundwater descents at a faster vertical rate in the upper level and slow down in the lower levels in particular in the sandy clay layer.

This well is situated in topographically high terrace deposits on the upper part of the basin and near the rim of the basin. The high terrace area represents high hydraulic gradient which allows surface water to replenish aquifer at high rate. However, the flow rates decrease rapidly in the lower levels because of the presence of middle clay-rich layer.

Well 15 is located in the Tung Tom subdistrict, San Pa Tong district, Chiang Mai province. The geological setting of the area is low terrace deposits (Qcr). Two hydrogeological units were selected for calculation in this well from upper to lower units.

The upper hydrogeological unit was chosen at 24-126 meters depth which consists of sands (<5% clays). The calculated β value is 0.95 indicating a downward movement of groundwater at a vertical velocity rate of 11.80 cm/yr.

The lower hydrogeological unit was selected 126-174 meters depth consisting of clayey sands (~40% clays). The calculated β value is 0.15 indicating a downward movement of groundwater at a vertical velocity of 3.11 cm/yr.

The area around this well is therefore a recharge zone in which the groundwater moves downward at a faster vertical velocity rate in the upper aquifer and slow down somewhat in the lower sandy clay layer.

This well is situated in low terrace deposits. Well is also located in the medium high land area on the middle part of the basin that shows the medium hydraulic gradient. This could allow surface water to replenish aquifers moderately well as shown by medium recharge rate in the upper unit.

Well 16 is located in Jom Jeng temple, San Pa Tong district, Chiang Mai province. the geological setting of the area is high terrace deposits (Qcm). Two hydrogeological units were selected for calculation in this well from upper to lower units.

The upper hydrogeological unit was chosen at 44-70 meters depth which consists of sands (<5% clays). The calculated β value is 0.53 indicating a downward movement of groundwater at a very high vertical velocity of 25.69 cm/yr.

The lower hydrogeological unit was selected at 78-202 meters depth consisting of sands (<5% clays). The calculated β value is 0.22 indicating a downward movement of groundwater at a vertical velocity of 2.33 cm/yr.

Hence the area around this well is a recharge zone in which the groundwater descents at a very fast vertical rate in the upper unit and slow down in the lower unit.

This well is situated in topographically high terrace deposits on the central part of the basin and near the rim of the basin. The high terrace area represents high hydraulic gradient which allows surface water to replenish aquifer at high rate. However the rapid decrease of flow rate in the lower unit may be due to the presence of clay barrier at 70-74 meters depth.

Well 19 is located in the Te Pa Ram temple, Sa Ra Pi district, Chiang Mai province. The geological settling of the area is younger alluvial deposits (Qcp). Only one hydrogeological unit was selected for calculation in this well.

The hydrogeological unit was chosen at 22-168 meters depth which consists mainly of sands (<5% clays). The calculated β value is 0.91 indicating a downward movement of groundwater at a vertical velocity of 7.80 cm/yr. This well is therefore a recharge zone.

This well is situated in the floodplain deposits on the central part and near the Mae Kuang River. According to its setting in the low land area which represents low hydraulic gradient, this allows surface water to replenish the aquifer at rather low rate.

Well 21 is located in the Su Wan Pra Dit temple, Hang Dong district, Chiang Mai province. The geological settling of the area is low terrace deposits (Qcr). Two hydrogeological units were selected for calculation in this well from upper to lower units.

The upper hydrogeological unit was chosen at 20-96 meters depth which consist of sands (~10% clays). The calculated β value is 0.98 indicating a downward movement of groundwater at a rather high vertical velocity of 15.10 cm/yr.

The lower hydrogeological unit was selected at 98-180 meters depth consisting of sandy clays (~70% clay). The calculated β value is 0.09 indicating a downward movement of groundwater at a vertical velocity of 0.47 cm/yr.

Hence the area around this well is a recharge zone in which the groundwater descents at a fairly fast vertical rate in the upper aquifer and slow down considerably in the lower layer.

This well is situated in a rather high slope of the low terrace deposits. The well is also located in the medium high land area on the middle part of the basin that shows the medium hydraulic gradient. This could allow surface water to replenish aquifers moderately well as shown by fairly well recharge rate in the upper unit. However the lower unit contains up to 70% clay component causing the flow rate to slow down considerably. This well is located near basin rim which may also influenced by active depositional environment; a characteristic of sediment deposition in active area from tectonic force and heat source below.

Well 24 is located in the Sri Tear village. Ban Hong district, Lamphun province. The geological settling of the area is high terrace deposits (Qcm). There are four hydrological units chosen for calculation in this well from upper to lower levels.

The upper most hydrogeological unit was selected at 26-60 meters depth which consists of sandy clays (~70% clays). The calculated β value is 0.84 indicating a downward movement of groundwater at a very high vertical velocity of 20.19 cm/yr.

The next lower hydrogeological unit was selected at 62-96 meters depth which consists of clayey sands (~20% clays). The calculated β value is 0.50 indicating a downward movement of groundwater at a vertical velocity of 16.80 cm/yr.

The next lower hydrogeological unit was chosen at 116-150 meters depth consisting of sandy clays (~70% clays). The calculated β value is 0.68 indicating a downward movement of groundwater at a vertical velocity of 16.43 cm/yr.

The lower most hydrogeological unit was selected at 150-202 meters depth which consists of sands (<5% clay). The calculated β is 0.50 indicating a downward movement of groundwater at a vertical velocity of 12.06 cm/yr.

Therefore the area around this well is a recharge zone in which the groundwater moves downward at rather high velocity and decrease slightly downward.

This well is situated in high terrace deposits on the lower part of the basin and near the rim of the basin. The high terrace area represents high hydraulic gradient which allows surface water to replenish aquifer at high rate.

Well 27 is located in Jom Jeng temple, San Pa Tong district, Chiang Mai province. geological settling of the area is high terrace deposits (Qcm). Three hydrogeological units were selected for calculation in this well from upper to lower levels.

The upper hydrogeological unit was chosen at 38-72 meters depth which consists of clayey sands (~20% clays). The calculated β value is 0.60 indicating a downward movement of groundwater at a fairly high vertical velocity of 19.90 cm/yr.

The middle hydrogeological unit was selected at 72-108 meters depth consisting of sands (<5% clays). The calculated β value is 0.28 indicating a downward movement of groundwater at a vertical velocity of 9.64 cm/yr.

The lower hydrogeological unit was selected at 112-170 meters depth consisting of sands (<5% clays). The calculated β value is 0.11 indicating a downward movement of groundwater at a vertical velocity of 2.30 cm/yr.

Hence the area around this well is a recharge zone in which the groundwater descents at a fairly fast vertical rate in the upper unit and slow down in the lower units.

This well is situated in topographically high terrace deposits on the lower part of the basin and near the rim of the basin. The high terrace area represents high hydraulic gradient which allows surface water to replenish aquifer at high rate. The flow rates in the middle and lower units decrease rapidly because of the presence of clay barriers, particularly at 108-112 meters depth.

Well 29 is located in the Pa Sang Noi temple, Meung district, Lamphun province. The geological settling of the area is younger alluvial deposits (Qcp). Two hydrogeological units were selected for calculation in this well from upper to lower levels

The upper hydrogeological unit was chosen at a 20-96 meters depth which consists of clayey sands (~15% clays). The calculated β value is 0.23 indicating a downward movement of groundwater at a vertical velocity of 3.58 cm/yr.

The lower hydrogeological unit was selected at 96-196 meters depth consisting of sandy clays (~70% clays). The calculated β value is -0.17 indicating an upward movement of groundwater at a vertical velocity of -1.38 cm/yr.

From the above result it suggests that the upper aquifer in this area is a recharge zone but the lower aquifer is discharge zone.

The upper unit gives downward groundwater flow velocity but the lower unit gives upward groundwater flow velocity. There are two explanations for this result. Firstly, the upper unit represent local recharging which the lower unit represents regional upward flow direction. Secondly, based on the DGR data in 2006 (Adisai Charuratna, 2008), there were large groundwater abstraction by the government and private wells at the rate approximately 2,000 cu.m./day for agricultural purpose and household consumption. The depths of abstraction were between 50-120 meters depth (roughly in between the upper and the lower units). These depths were at the same range of the depth of discharge zone or upward groundwater velocity.

Well 30 is located in the Nong Chang Kleun temple, Meung, Lamphun province. The geological settling of the area is younger alluvial deposits (Qcp). Only one hydrogeological unit was selected for calculation in this well.

The hydrogeological unit was chosen at 30-174 meters depth which consists mainly of sands (<5% clays). The calculated β value is 0.77 indicating a descending groundwater at a vertical velocity of 6.73 cm/yr. This well is therefore recharge zone.

This well is situated in floodplain deposits on the central part and near the Mae Kuang River and Mae Ping River. According to its setting in the low land area which represents low hydraulic gradient, this allows surface water to replenish the aquifer at rather low rate.

Well 31 is located in the Pa Yang Ping temple, Meung district, Lamphun province. The geological settling of the area is younger alluvial deposits (Qcp). Three hydrogeological units were selected for calculation in this well from upper to lower levels.

The upper hydrogeological unit is chosen at 28-116 meters depth which consists of sandy clays (~80% clays). The calculated β value is -0.02 indicating an upward movement of groundwater at a vertical velocity of -0.21 cm/yr.

The middle hydrogeological unit was selected at 116-144 meters depth consisting mostly of sands (<5% clays). The calculated β value is -0.19 indicating an upward movement of groundwater at a vertical velocity of -8.46 cm/yr.

The lower hydrogeological unit was selected at 144-180 meters depth consisting of sandy clays (~60% clays). The calculated β value is 0.28 indicating a downward movement of groundwater at a vertical velocity of 6.89 cm/yr.

From the above result it suggests that the upper two layers in this area are discharge zones whereas the lower layer is a recharge zone.

The two upper units give upward groundwater flow velocity but the lower unit gives downward groundwater flow velocity. There are two explanations for these results. The two upper units represent regional upward flow direction that follows the regional flow model proposed by Toth (1963) as shown in Figure 5.9. Secondly, based on the DGR data in 2006 (Adisai Charuratna, 2008), there were large groundwater abstraction by the government and private wells at the rate approximately 1,700 cu.m./day for longan plantation, and household consumption. The depths of abstraction were between 30-150 meters depth. These depths were at the same range of the depth of discharge zone or upward groundwater velocity. However, the reason that the lower unit show downward groundwater flow with high thermal gradient at 3.45 °C/100 m was not known.

Well 42 is located in the Po Thi Mong Kol temple, Sa Ra Pi district, Chiang Mai Province. The geological settling of the area is younger alluvial deposits (Qcp). Two hydrogeological units were selected for calculation in this well from upper to lower levels.

The upper hydrogeological unit was chosen at 58-106 meters depth which consists of clayey sands (~42% clays). The calculated β value is 0.08 indicating a downward movement of groundwater at a vertical velocity of 1.62 cm/yr.

The lower hydrogeological unit was selected at 106-300 meters depth consisting mainly of sands (<5% clays). The calculated β value is 0.09 indicating a downward movement of groundwater at a vertical velocity of 0.60 cm/yr.

Hence the area around this well is a recharge zone in which the groundwater descents at a rather slow vertical rate.

This well is situated in river floodplain deposits on the central part and near the Mae Kuang River. According to its setting in the low land area which represents low hydraulic gradient, this allows surface water to replenish the aquifer at low rate.

5.2 Recharge rate variation in different geological units

There is a significant difference in the downward flow velocity or recharge rate in different types of unconsolidated geological unit, namely, young alluvial deposits (Qcp), low terrace deposits (Qcr) and high terrace deposits (Qcm) as shown in Figure. 5.1 (see also Table 5.1).

Firstly, considering all observation wells located in unconsolidated aquifers of young alluvial deposits (Qcp), each of those wells shows a similar trend in which the top unit gives the recharge rate less than 10 cm/yr (Figure 5.1 or range from 1.62-9.91 cm/yr with an average of 6.07 cm/yr). Apparently, wells in the Qcp consistently give the lowest recharge rates among those three types of unconsolidated geological unit. This can be explained by the fact that the Qcp is young alluvial deposits of Mae Ping and Mae Kuang flood plains and located in lowest elevation level in the Chiang Mai Basin; then possess the least hydraulic gradient in which the groundwater can percolate through at the slowest vertical velocity.

Secondly, considering all observation wells located in unconsolidated aquifers of low terrace deposits (Qcr), each of those wells also shows a similar trend in which the top unit gives the recharge rate less than 15 cm/yr (range from 4.16-15.1 cm/yr with an average of 10.72 cm/yr) and the rates decrease downward in the deep layers (Figure. 5.1). The wells in the Qcr give the intermediate recharge rates among those three types of unconsolidated geological unit. The deposits are located at the intermediate elevation level in the Chiang Mai Basin; and possess the intermediate hydraulic gradient in which the groundwater can percolate through at the intermediate vertical velocity.

Thirdly, considering all observation wells located in unconsolidated aquifers of high terrace deposits (Qcm), again each of those wells also shows a similar trend in which the top unit gives the recharge rate more than 15 cm/yr (range from 16.44-32.81

cm/yr with an average of 23.13 cm/yr) and the rates decrease consecutively downward in the deep layers (Figure 5.1). The wells in the Qcm give the highest recharge rates among those three types of unconsolidated geological unit. The deposits are also located at the highest elevation level in the Chiang Mai Basin; and possess the highest gradient in which the groundwater can percolate through at the most quickest vertical velocity.

Fourthly, considering the overall recharge rates of the top units of all recharge wells, the rates range from 1.62-32.81 cm/yr with an average of 14.0 cm/yr. The average value is approximately 12 % of the annual rainfall (116 cm/yr). This average recharge rate is also in the same range to the recharge rate of 12.6 cm/yr estimated from water balance calculation (Sirirat Uppasit, 2004), or consistent with the values of 6-21 % of the annual rainfall estimated from other previous studies by the different approaches (Fongsaward Suvagondha, 1979; Fongsaward Suvagondha and Santichai Jitapunkul, 1982; Teerawash Intrasuta, 1983; Pisanu Wongpornchai, 1990; Tinnakorn Tatong, 2000). Therefore this groundwater temperature method can also be used for efficient groundwater resources management in this basin. Lastly the sources of recharge water could be derived from both basin rim and inner area of the basin (Qcp); however, this study show that high magnitude of recharge rate occur at the basin rim (Qcm, Qcr). This could be explained by the variation in hydraulic gradient and thermal gradient. The method of calculation of groundwater recharge rate and direction from groundwater temperature is acceptable and the method of data acquisition and interpretation is not difficult.

5.3 Variation of temperature depth profiles

The next aspect worth consideration is the variation of the shape of temperature-depth profile in comparison with the theoretical subsurface temperature shape. The slopes of temperature-depth profile of groundwater in the wells in the study area are different because of several factors, such as geology, hydrogeology and others. The profiles can be differentiated into 6 groups (Figure 5.2) based on the characteristics of the profile.

Classification of temperature-depth profile is summarized in Table 5.2. The wells with thermal gradient less than 3 °C/100 m represent downward movement of groundwater or recharge zone. On the other hand, the wells with thermal gradient higher than 3 °C/100 m represent upward movement of groundwater or discharge zone. The high thermal gradient also presents in Group 6 which caused by heat source from subsurface.

Group 1: There are seven wells included into this group (no. 8, 11, 12, 15, 19, 42, and 30). They are located in young alluvial deposits (Qcp) and low terrace deposits (Qcr) of Mae Ping flood plain (Figure 5.2). Those wells have the concave-upward temperature-depth profile indicating the recharge zones and they show a similar thermal gradient (or slope of the curve) at normal rates of about 1.97-3.01 °C/100 m (Figure 5.3). This type of vertical groundwater flow system is therefore normal in young alluvial deposits (Qcp) and low terrace deposits (Qcr) consisting of unconsolidated sediments with normal geothermal gradients (see Figures 5.4 and 5.5).

Group 2: There are two wells included into this group (no. 2 and 24). They are located in low terrace deposits (Qcr) and high terrace deposits (Qcm) in the lower part of basin (Figure 5.2). These two wells have the concave-upward temperature-depth profiles indicating recharge zone and they show a similar thermal gradient at somewhat lower rates of about 1.28-1.36 °C/100 m. (Figure 5.6). This type of groundwater replenishment is therefore normal in low terrace deposits (Qcr) and high terrace deposits (Qcm) consisting of unconsolidated sediments.

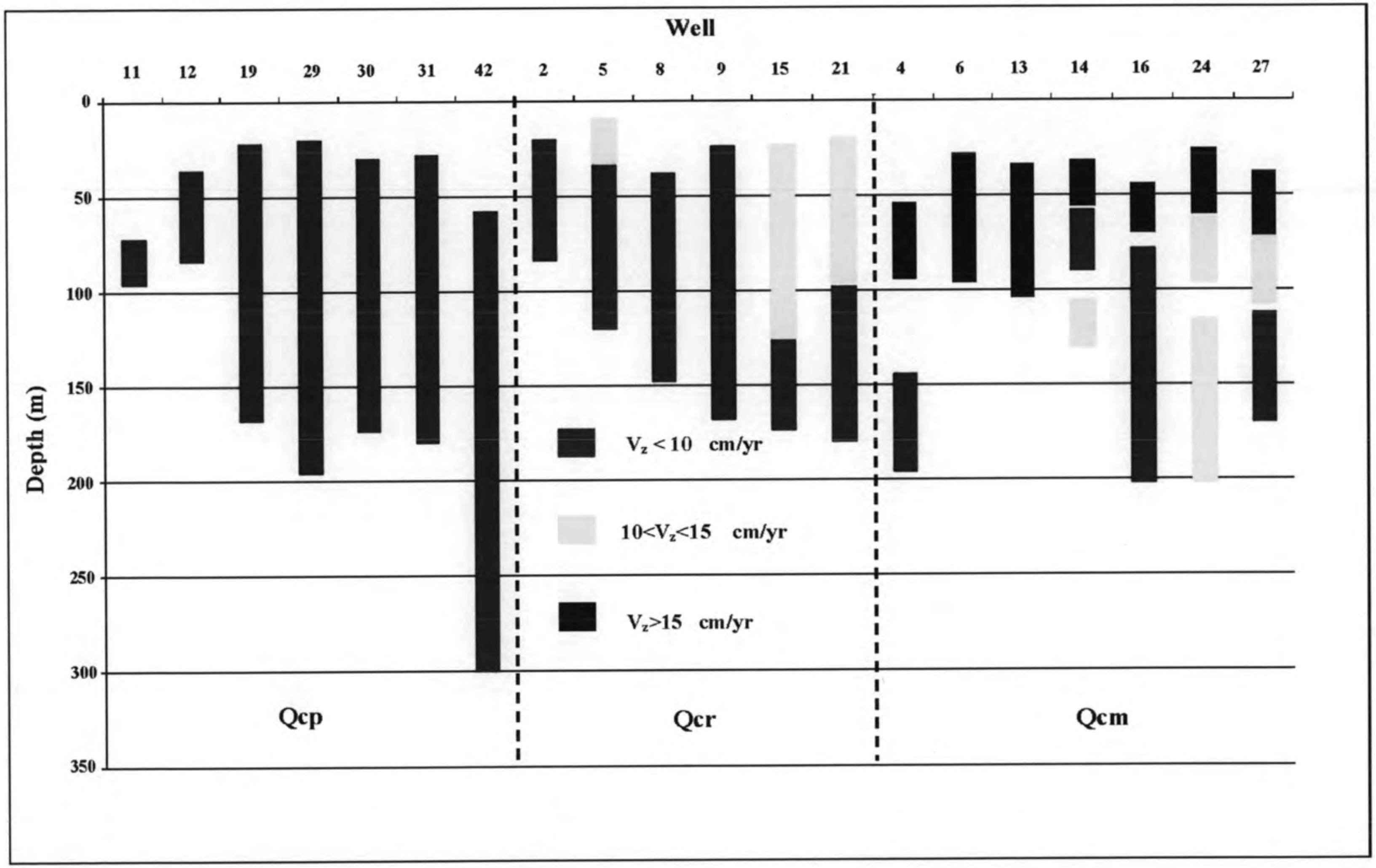

Figure 5.1: Composite bar chart of observation wells in study area showing recharge rates in different unconsolidated geologic units, namely, young alluvial deposits (Qcp), low terrace deposits (Qcr) and high terrace deposits (Qcm).

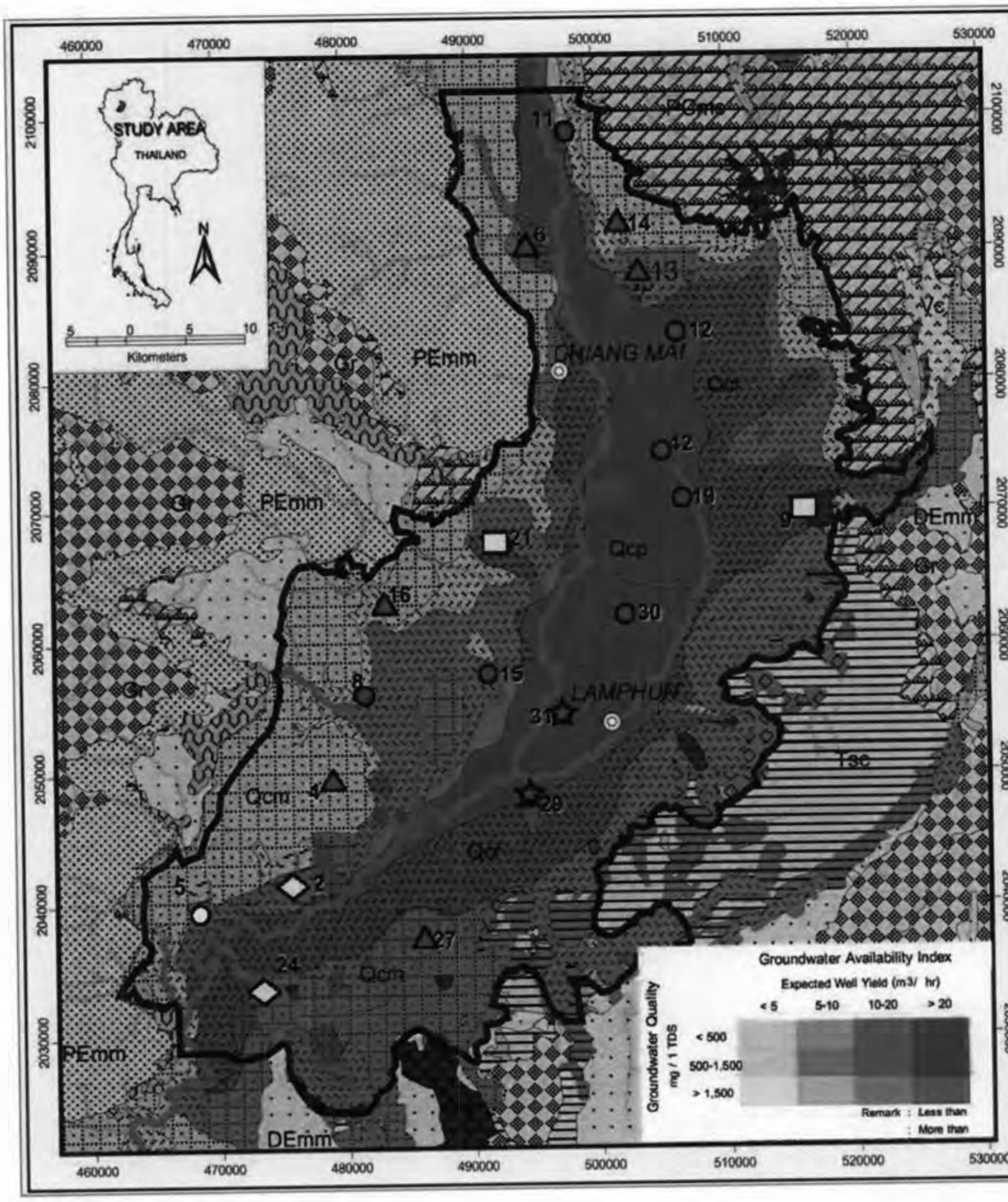

Figure 5.2 Location of observation wells in the Chiang Mai Basin showing 6 groups of temperature-depth profile.

Group 1: located on Mae Ping flood plain shown as ● Group 2: located on lower part of the basin shown as ◇ Group 3: located at basin rim shown as ▲. Group 4: located on central Mae Ping flood plain shown as ★ . Group 5: located on the lower basin rim shown in ○. Group 6: located on basin rim shown as □

Group 3: There are six wells included into this group (no. 4, 6, 13, 14, 16 and 27). They are located in high terrace deposits (Qcm) at the rim of basin (Figure 5.2). These six wells have the concave-upward temperature-depth profiles suggesting recharge zone and they show a similar thermal gradient at normal rates of about 2.21-2.91 °C/100 m (Figure 5.7). This type of vertical groundwater flow system is also normal in high terrace deposits (Qcm) consisting of unconsolidated sediments.

Table 5.2 Classification of thermal gradient into 6 groups.

Group	**Geological unit**	**Thermal gradient (°C/100 m)**	**Classification of temperature – depth profile**	***Average of Vertical groundwater velocity (cm/yr)**	**Well no.**	**Remark**
1	Qcp, Qcr	1.97- 3.01	Recharge zone	5.85	8, 11, 12, 15, 19, 30, 42	Well 8 and 15 in Qcr
2	Qcr, Qcm	1.28- 1.36	Recharge zone	11.89	2, 24	
3	Qcm	2.21- 2.91	Recharge zone	14.36	4, 6, 13, 14, 16, 27	
4	Qcp	3.45- 3.50	Discharge zone	0.07	29, 31	
5	Qcr	3.15	Discharge zone	-0.19	5	
6	Qcr	4.51- 5.51	Recharge and Discharge zones	3.84	9, 21	Active depositional environment

*average of every hydrogeological unit in the same Group

Group 4: There are two wells included into this group (no. 29 and 31). They are located in young alluvial deposits (Qcp) of central Mae Ping flood plain (Figure 5.2). These two wells have the convex-upward temperature depth profiles (opposite to the Group 1) indicating discharge zones and they show a similar thermal gradient at somewhat higher rates of about 3.45-3.50 °C/100 m. (Figure 5.8). The wells are situated near the river and Lamphun city. It is well understood that the river can interchange water with groundwater, hence it is possible that the river near these two wells could gain stream water from aquifers nearby (see model in Figure 5.9) and/or Lamphun municipal and agricultural consumptions may exploit excessive volume of the groundwater as discussed earlier on these two particular wells.

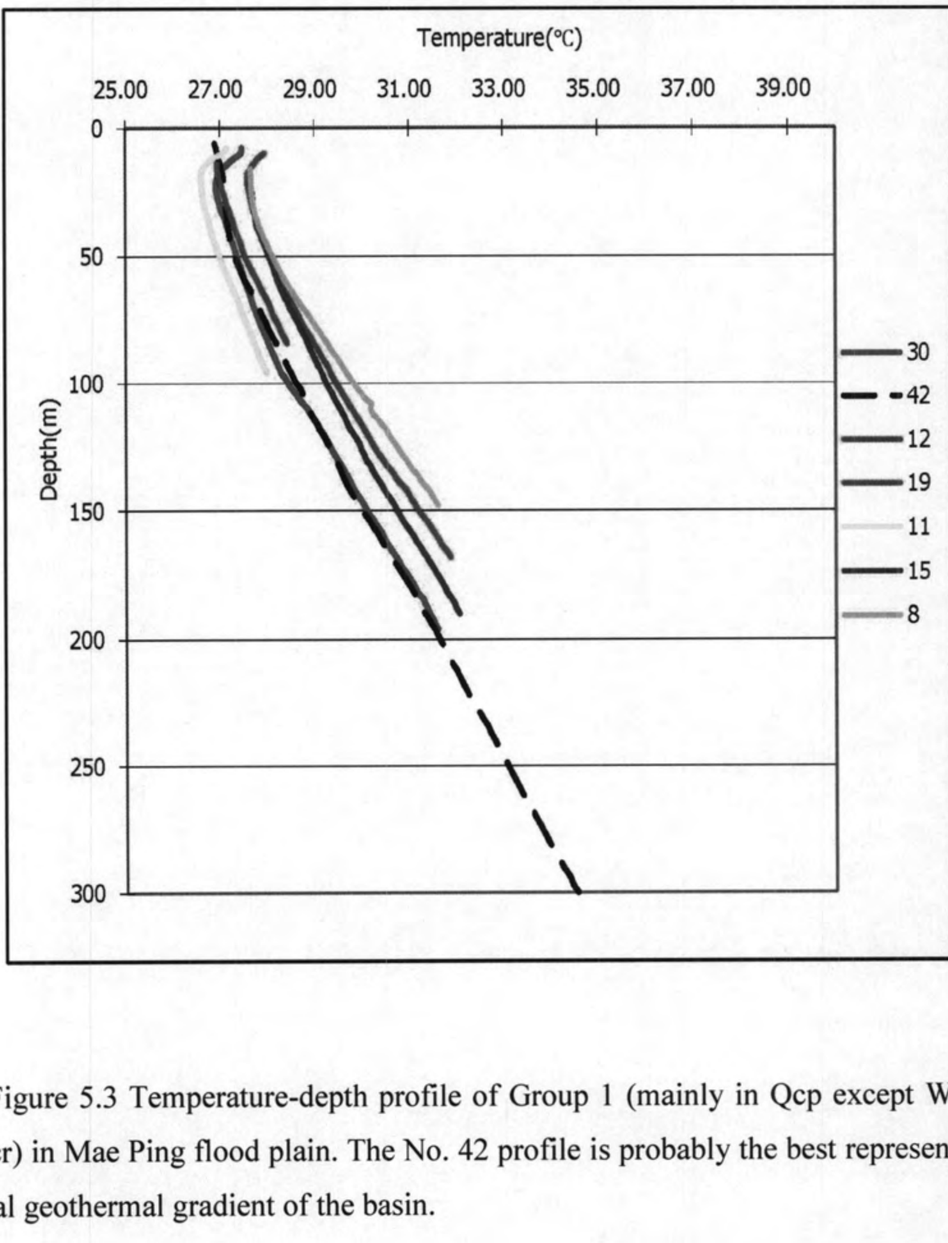

Figure 5.3 Temperature-depth profile of Group 1 (mainly in Qcp except Well 8, 15 in Qcr) in Mae Ping flood plain. The No. 42 profile is probably the best representative of normal geothermal gradient of the basin.

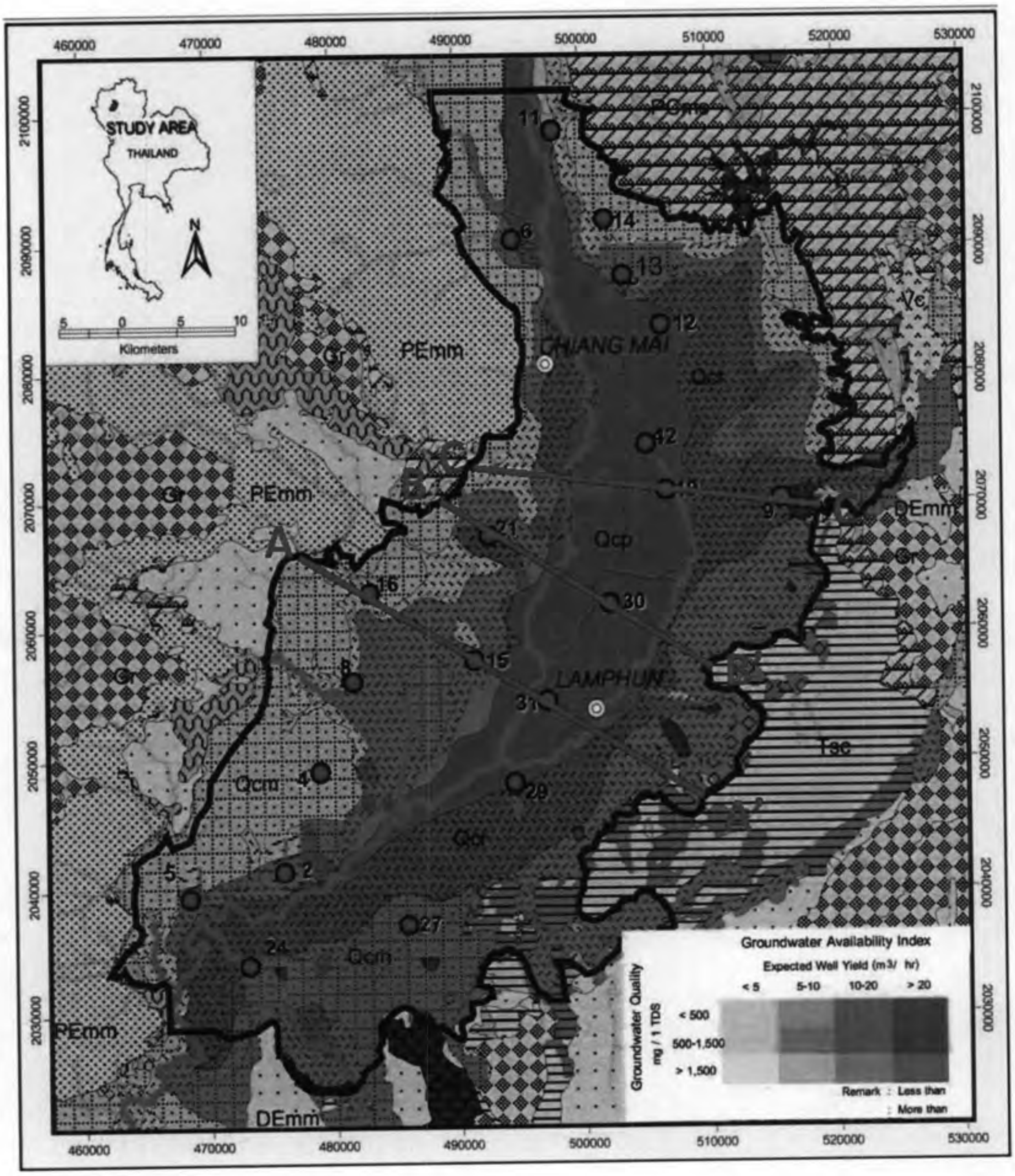

Figure 5.4 Showing cross-section lines in Chiang Mai Basin.

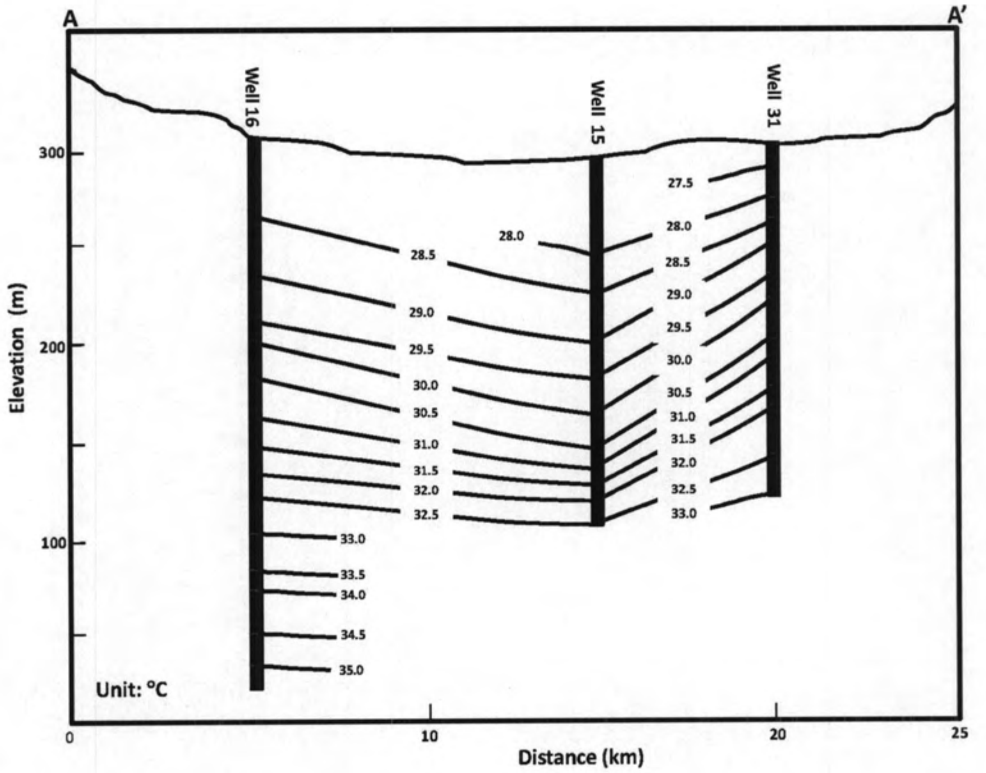

Figure 5.5 Cross-section line A-A' showing normal isotherm observed in the observation wells.

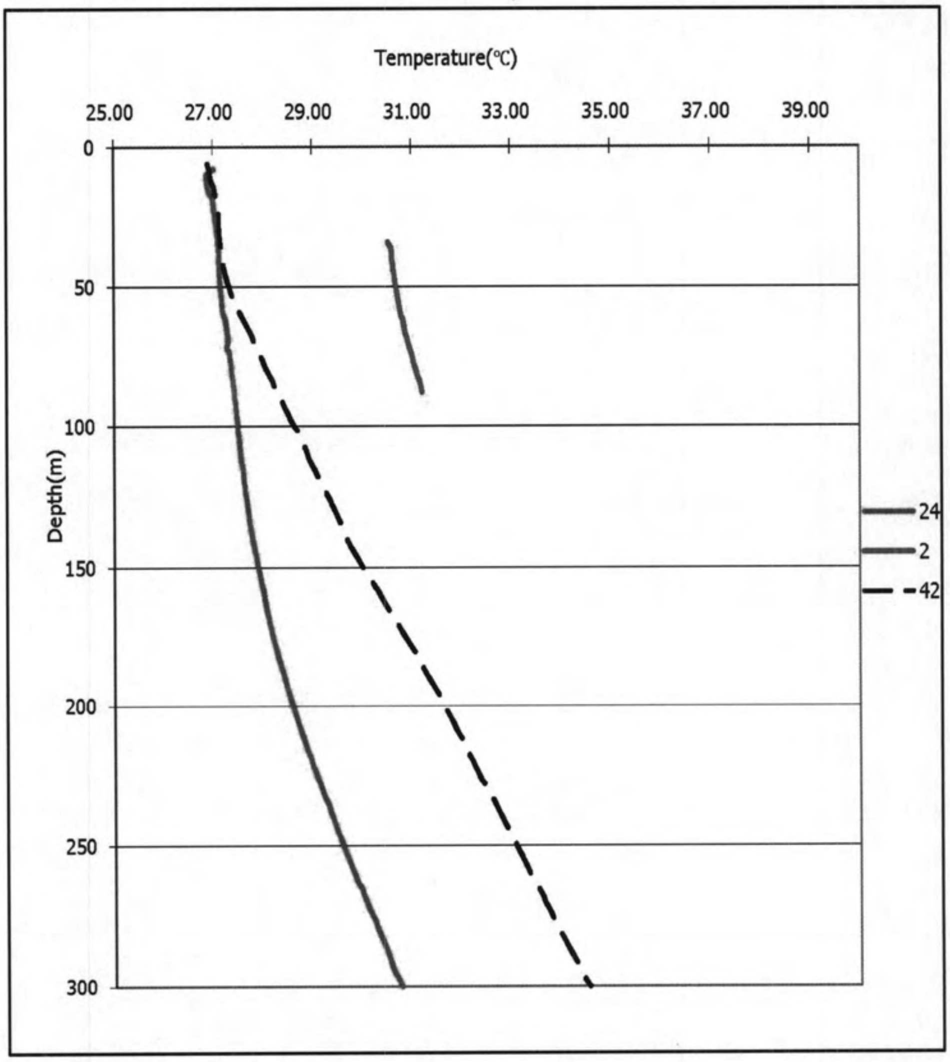

Figure 5.6 Temperature-depth profile of Group 2 (in Qcr and Qcm) in lower Mae Ping flood plain. The No. 42 is shown as the reference profile.

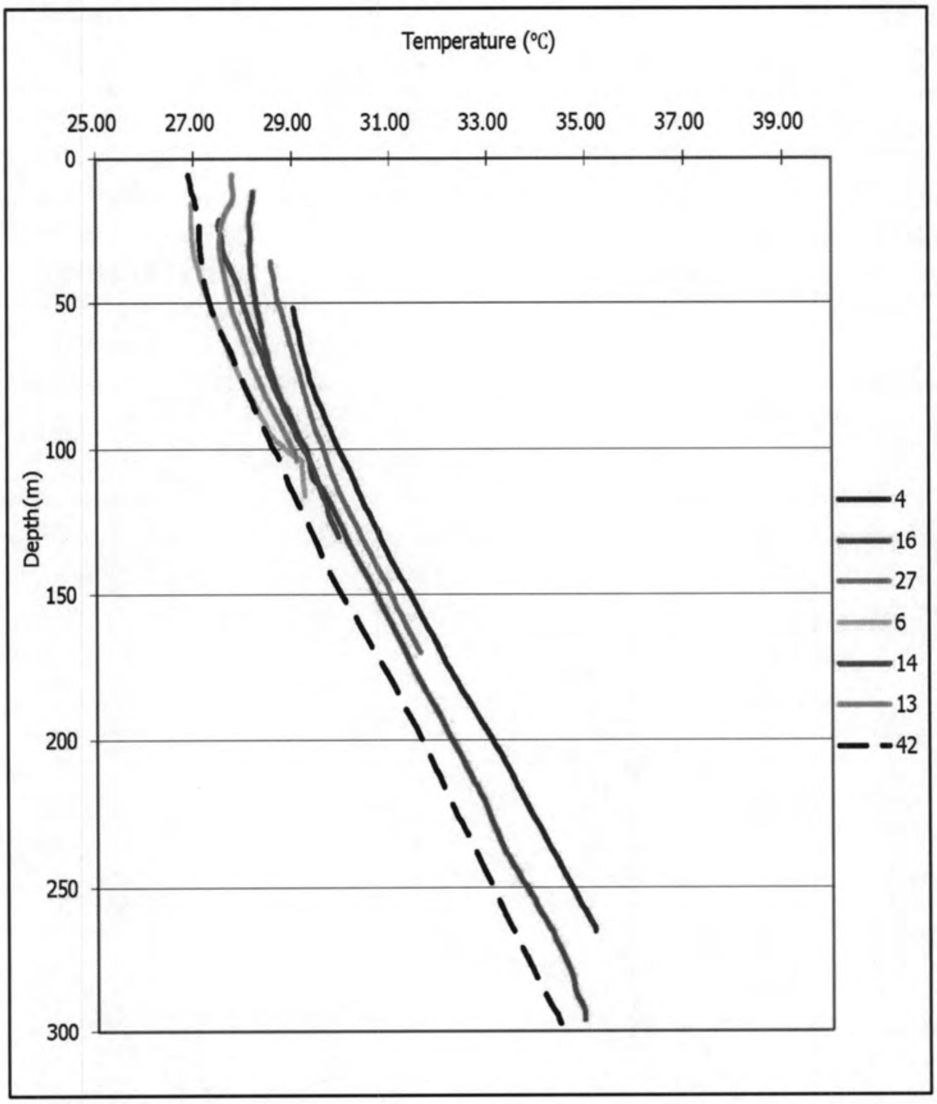

Figure 5.7 Temperature-depth profile of Group 3 (in Qcm) at basin rim. The No. 42 is shown as the reference profile.

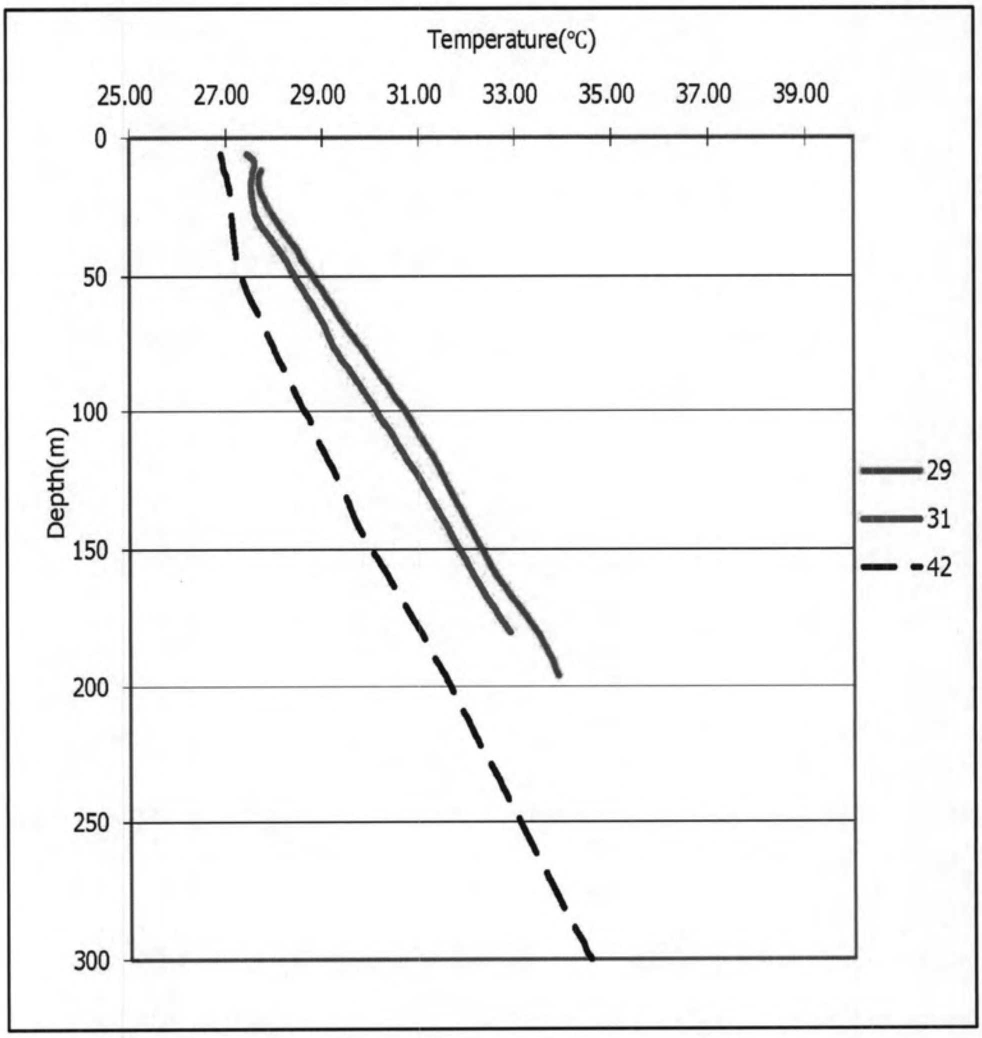

Figure 5.8 Temperature-depth profile of Group 4 (in Qcp) in central Mae Ping flood plain. The No. 42 is shown as the reference profile.

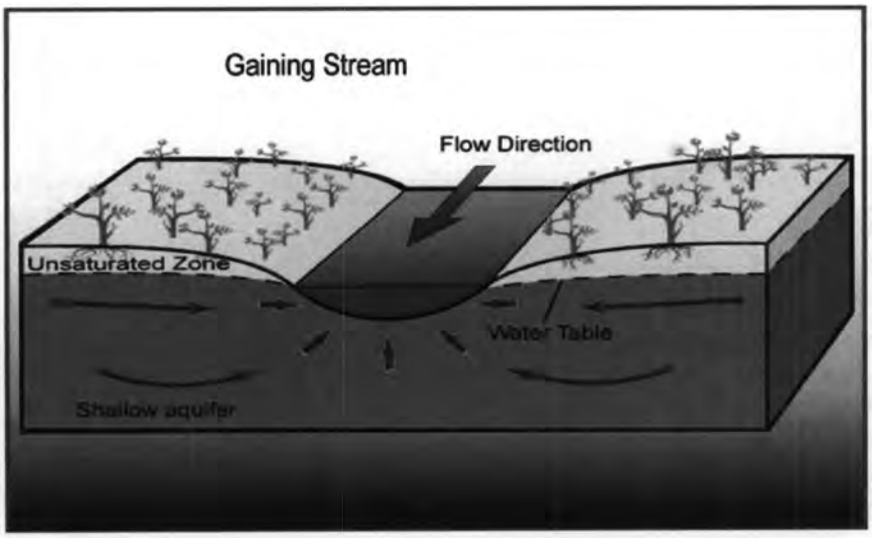

Figure 5.9 Schematic of stream water gained from nearby groundwater. (modified after Toth, 1963)

Group 5 is observed in only one well (no. 5) located in low terrace deposits (Qcr) at the lower rim of basin (Figure 5.2). The well has the convex-upward temperature-depth profile indicating a discharge zone in the lower hydrogeological units and the thermal gradient is at 3.15 °C/100 m. (Figure 5.10). As mentioned earlier the discharge zone may be due to excessive industrial and household consumptions at the rate about 1,200 cu.m./day in this area based on the DGR (Adisai Charuratna, 2008) data on government and private wells in 2006.

Group 6 is observed in two wells (no. 9 and 21) located in low terrace deposits (Qcr) at the rim of basin (Figure 5.2). The Well 9 has the convex-upward temperature-depth profile in the upper level but almost straight profile in the lower level suggesting a discharge zone near surface whereas the Well no. 21 has the concave-upward profile indicating a recharge zone. These two wells show the highest thermal gradients of about 4.51-5.51 C°/100 m (Figure 5.11). Hence the abnormally high thermal gradients in these two wells may be influenced by subsurface heating (see Figures 5.4, 5.12 and 5.13). In fact the Well 9 is situated near San Kamphang hot spring in which the area may be affected by deep active basement faults and heat source underneath in NE-SW direction parallel to the eastern basin edge (see Figure 2.2) and Mae Tha fault zone about 10 kilometers to the east of the basin. The presence of underneath hydrothermal activity is also support by rather high fluoride contents. Well 9 and 21 situated near the area of represent high fluoride content of water and most wells in NE-SW direction parallel to the eastern basin edge (Figure 5.14). As for the Well 21, it is located near basin rim which may also influenced by active depositional environment; a characteristic of sediment deposition in active area from tectonic force and heat source below.

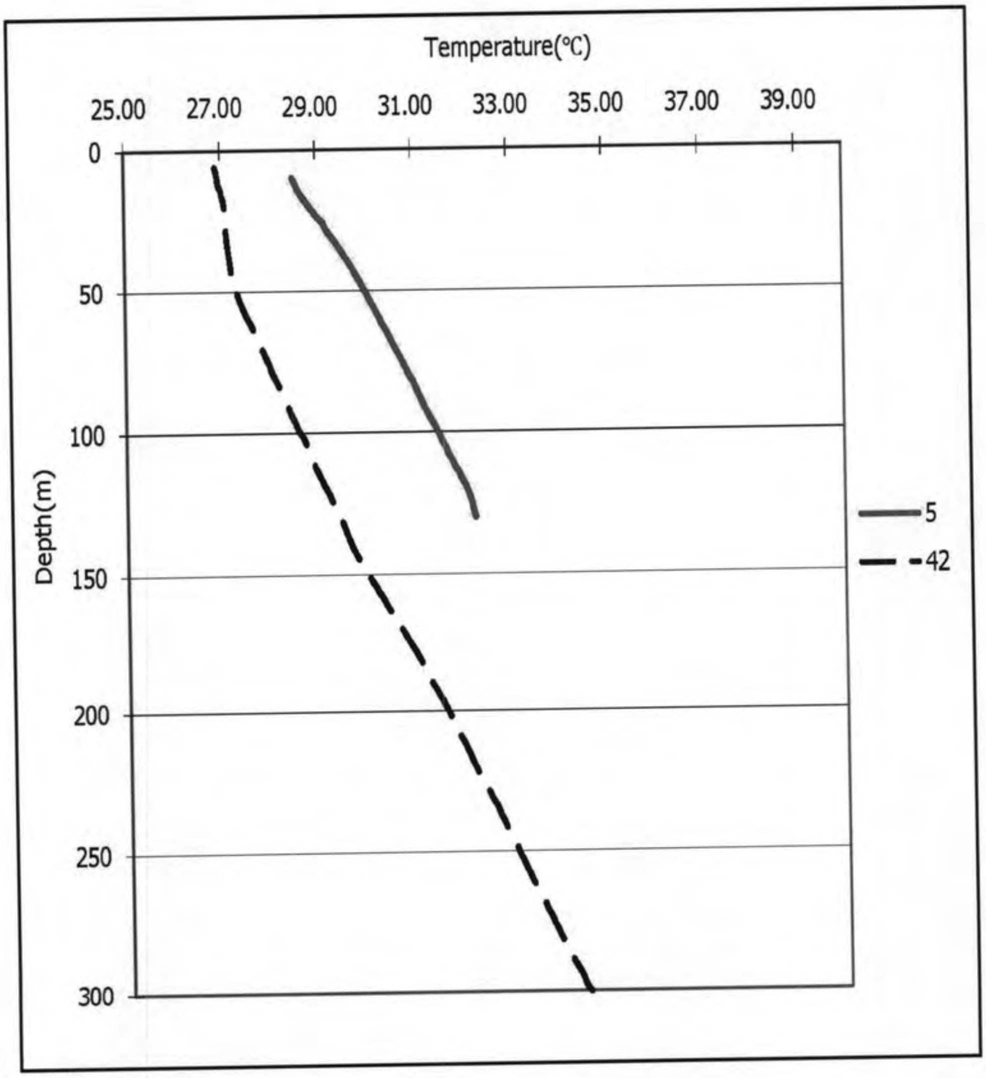

Figure 5.10 Temperature-depth profile of Group 5(Qcr) at lower basin rim. The No. 42 is shown as the reference profile.

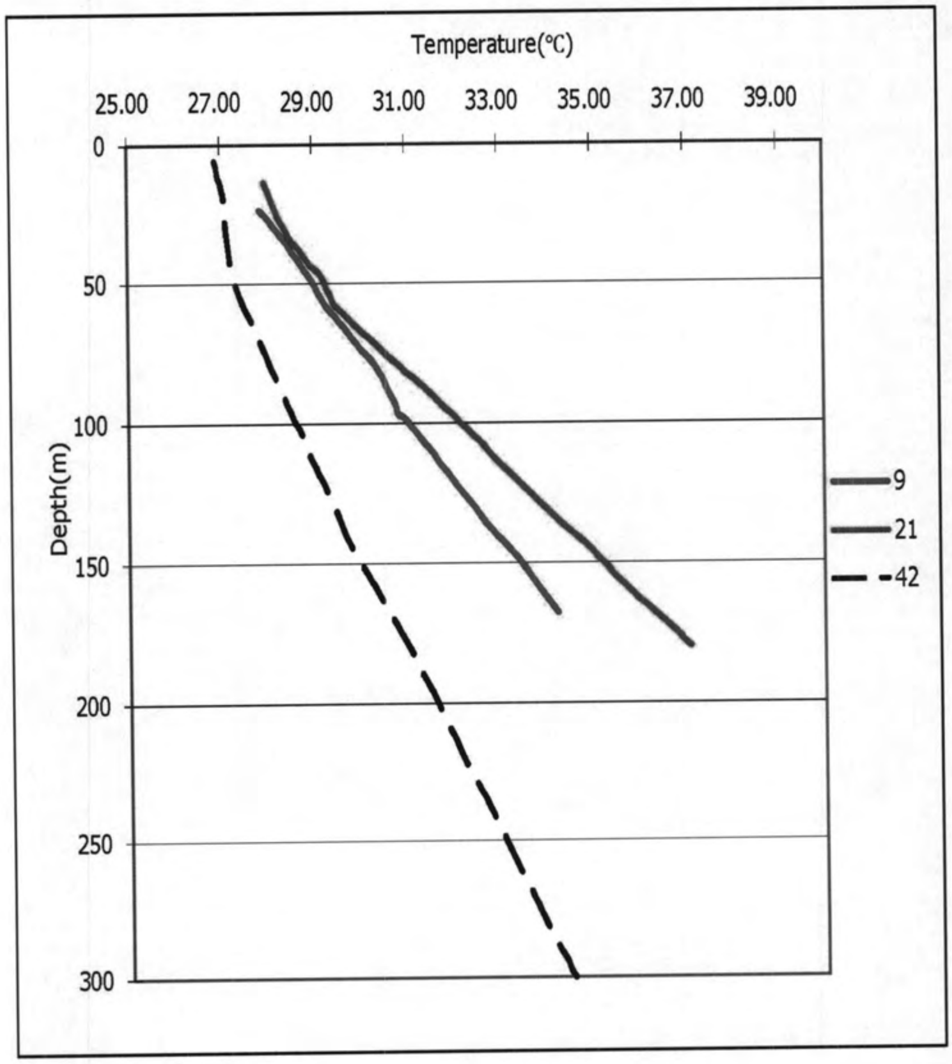

Figure 5.11 Temperature depth-profile of Group 6 (Qcr) at the rim of basin in active depositional environment. The No. 42 is shown as the reference profile.

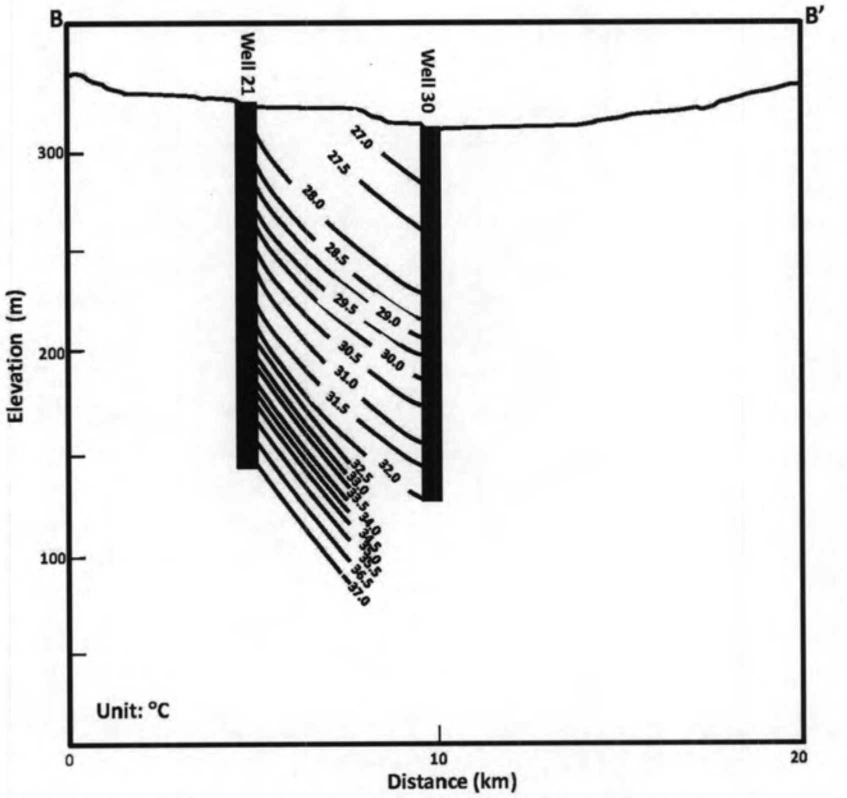

Figure 5.12 Cross-section line B-B' showing steep isotherm at well 21.

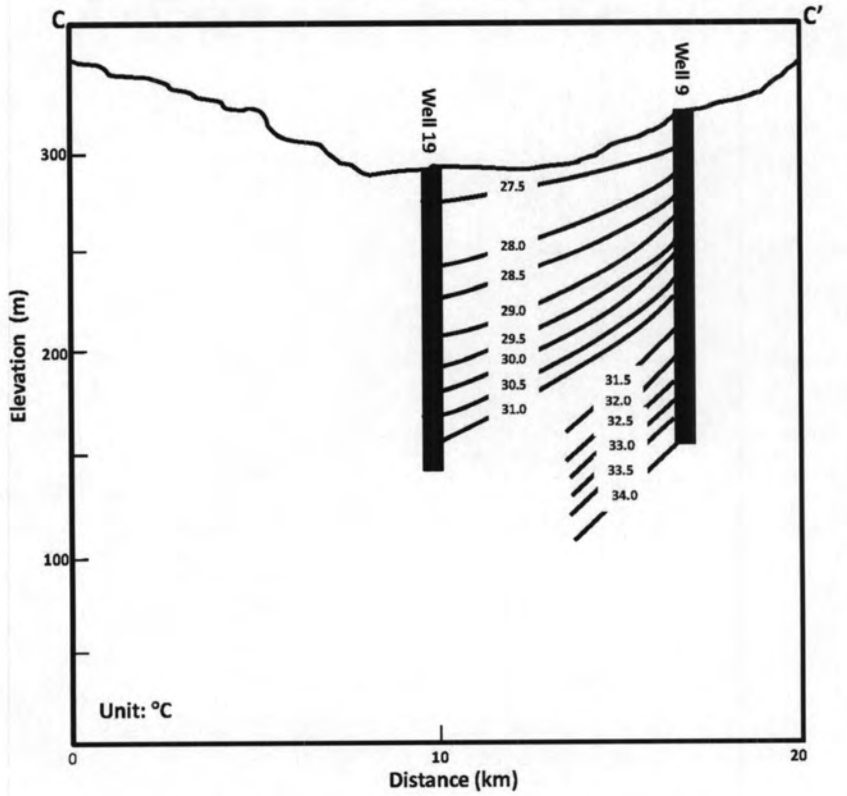

Figure 5.13 Cross-section line C-C' showing steep isotherm at well 9

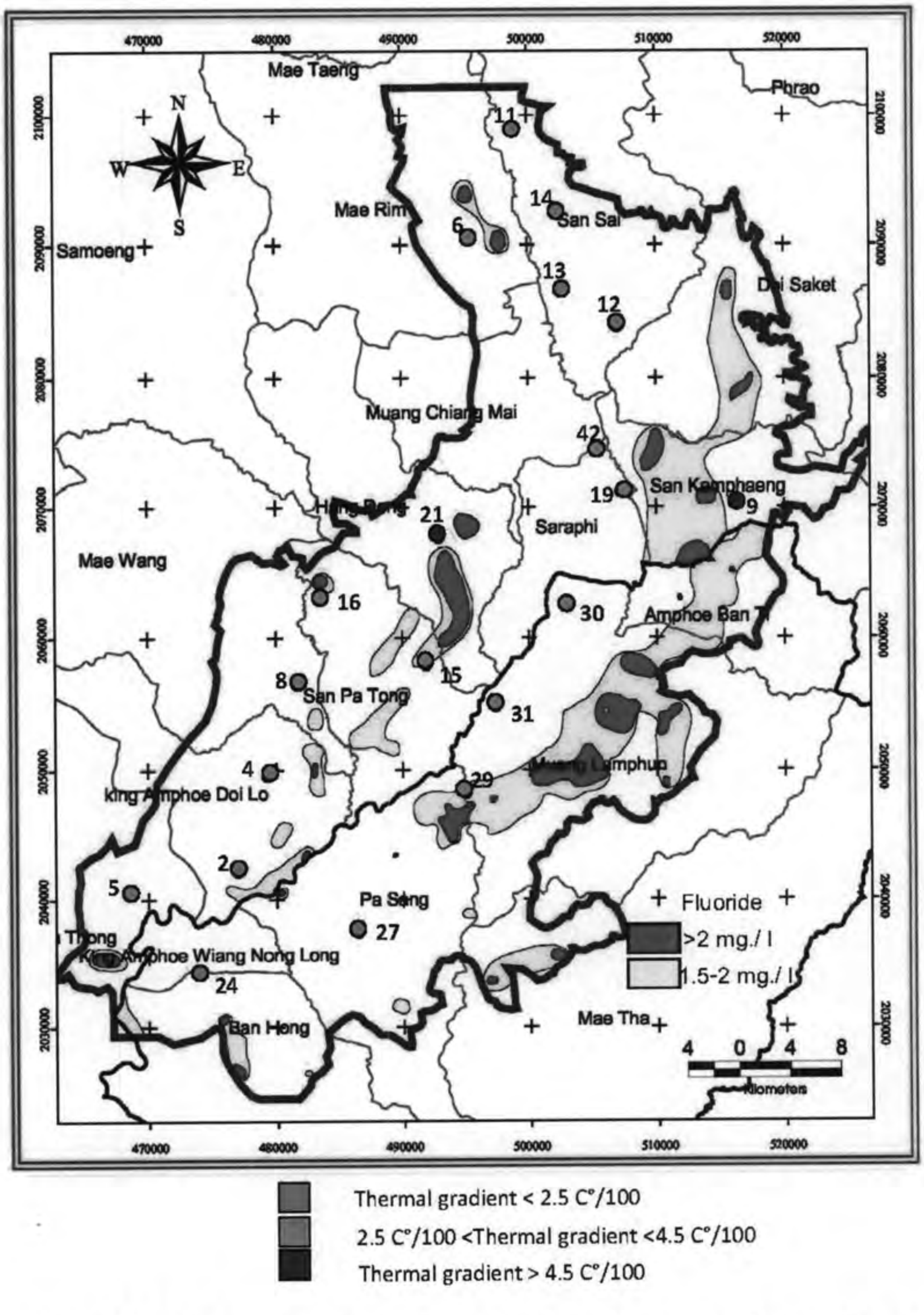

Figure 5.14 Map showing the distribution of fluoride contents of groundwater and rates of geothermal gradients observed in the observation wells in the Chiang Mai Basin (modified after Benjavun Ratanasthien and Tavisakdi Ramingwong, 1982).

5.4 Recharge versus discharge areas

The last aspect needs to be discussed here is recharge versus discharge areas of Chiang Mai Basin based on the calculated vertical groundwater flow direction of all the observation wells shown in Table 5.1 and plotted in Figure 5.15.

As generally expected, almost all observation wells in Chiang Mai Basin give downward flow direction or recharge zone except only four wells show upward flow direction or discharge zone. The reason why almost all Chiang Mai Basin areas are recharge zone is explained by the fact that any surface runoff will try to seep into subsurface by gravity or by the law of water flow. Because the Cenozoic Chiang Mai Basin is filled with unconsolidated Quaternary sediments of gravels, sands, silts and clays, it is therefore, easy for surface water to replenish into underground aquifers particularly in the areas filled mainly with well sorting and large grain unconsolidated sediments and high vertical hydraulic gradient. However in those four wells (5, 9, 29 and 31) that show discharge zone, they may be due to some unusual conditions which have been discussed individually earlier in section 5.1. In brief, because the Well 5, Well 29 and Well 31 are located near the river and/or in the populated or agricultural areas, the groundwater may discharge into the river (gaining stream) and/or there may be excessive exploitation of groundwater in the municipal or agricultural areas. As for the Well 9, it could be effected by heat source underneath in relation to NE-SW active basement faults parallel to the eastern basin edge (see Figure 2.3) and to NE-SW Mae Tha active fault zone about 10 kilometers toward the eastern side of the basin basement. This is because there is a good evidence of well known hot spring near its location (San Kamphang hot spring).

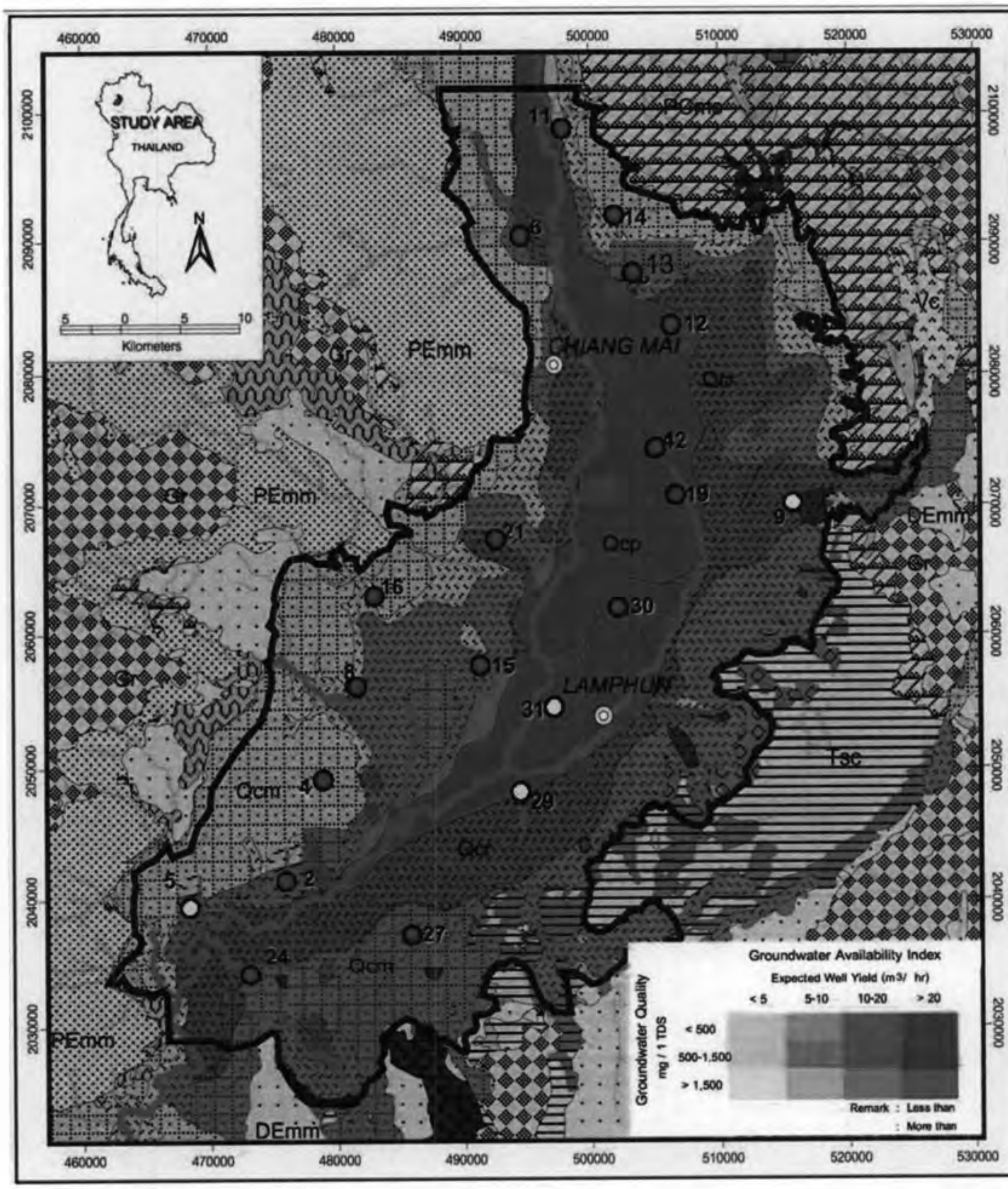

Figure 5.15 Map showing two cases of vertical flow direction, recharge and discharge. Pink circle represents groundwater moving downward or recharge, and yellow circle represents groundwater moving upward or discharge.