CHAPTER 2

PHYSICAL ENVIRONMENT

2.1 Geographic setting

2.1.1 Topography and Geomorphology

The topography of Phuket island is mainly dominated by small mountains, part of the Tanaosri range that extended southwards within the Phuket island (Figure 2.1).

Geomorphologic features of the island are classified into six units (Sophonsakulrat, 1994), including hills, foothills, alluvial plains, mudflats, salt marshes, and beaches (Figure 2.2a). Hills are underlain by granite and sedimentary rocks of the Kaeng Krachan group. Foothills are occupied by colluvial deposits. Alluvial plains comprise floodplains and alluvial terraces. Mudflats have elevation ranges from 1-5 m above mean sea level and mangrove forests are present in the eastern part of the island. Salt marshes are composed of low-lying plains behind beach ridges. Beaches and beach ridges occupy the areas between the headlands and are composed of recent beaches.

Generally, the landforms can be subdivided into three main types; mountainous area, long-shore flat terrain, and flat plain (Figure 2.2b). Much of the island is occupied by low but rather steep mountains. The mountainous area occupies approximately 40 percent of the total area, and is restricted mainly to the western part and the high mountainous area with a maximum elevation of 529 m above mean sea level at Khao Mai Thao Sip Song in Kathu district. The long-shore flat terrain occupies approximately 20 percent of the total area of Phuket island, particularly between the mountainous area and flat plain surrounding the island, except in the parts that form headlands and sea cliffs. The flat plains of both coastal plain and floodplain occupy approximately 40 percent of the total area and mainly occupy the eastern part. Coastal plains along the east side, including a swampy zone, are covered by mangrove forest. Most of the coasts facing the Andaman Sea in the west are covered by beach sand and have extensively been developed as prosperous resort zones, such as Nai Yang, Surin, Kammala, Patong, Kata, and Karon beaches. Lying along the transition zones between the mountains and the plains are the terraces that are occupied by rubber tree plantation. Recently, the rubber plantation zones are extensively developed into large-scale resort facilities such as golf courses or expensive housing areas.

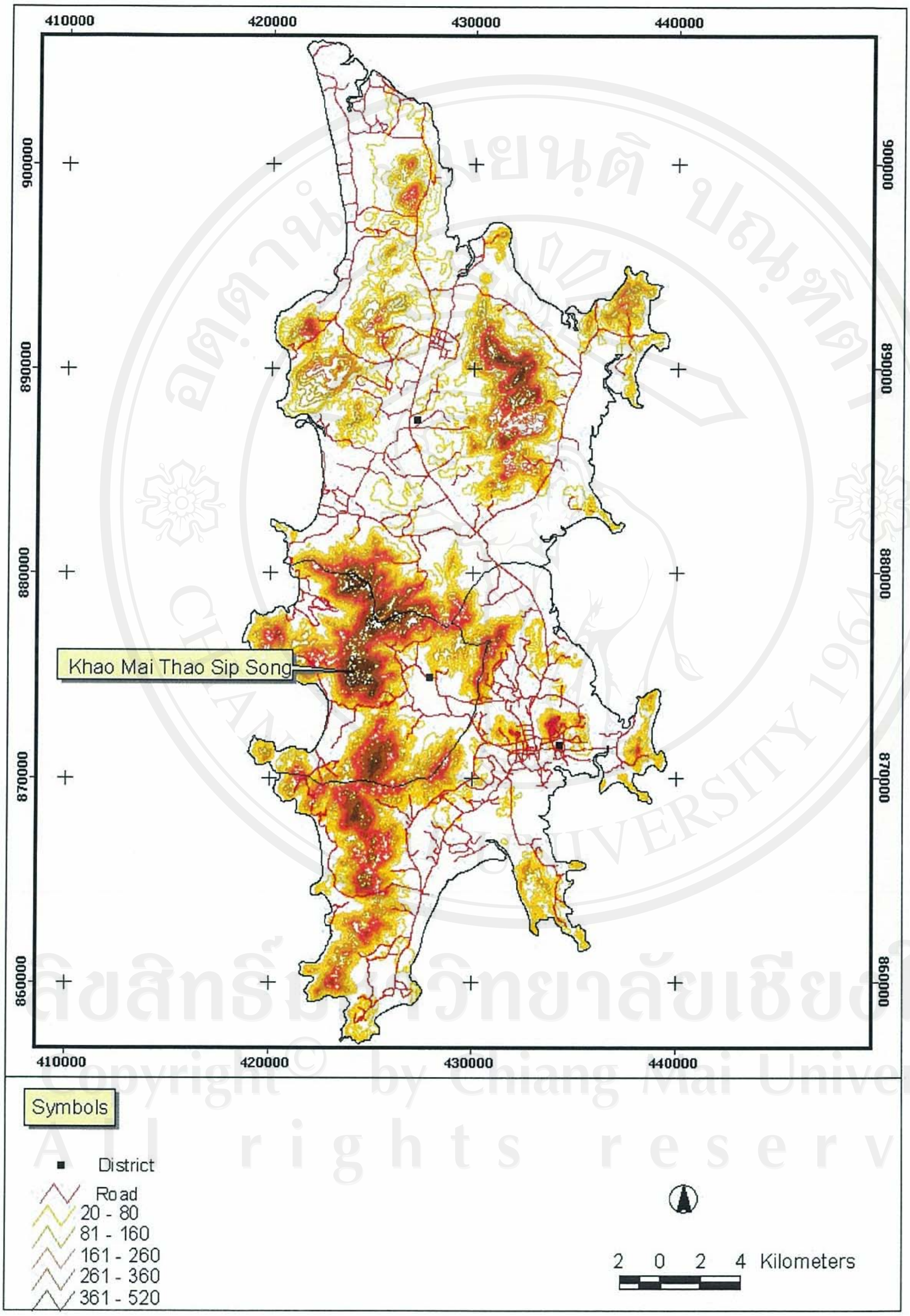

Figure 2.1 Topographic map of Phuket island (modified after Department of Mineral Resources, 2001).

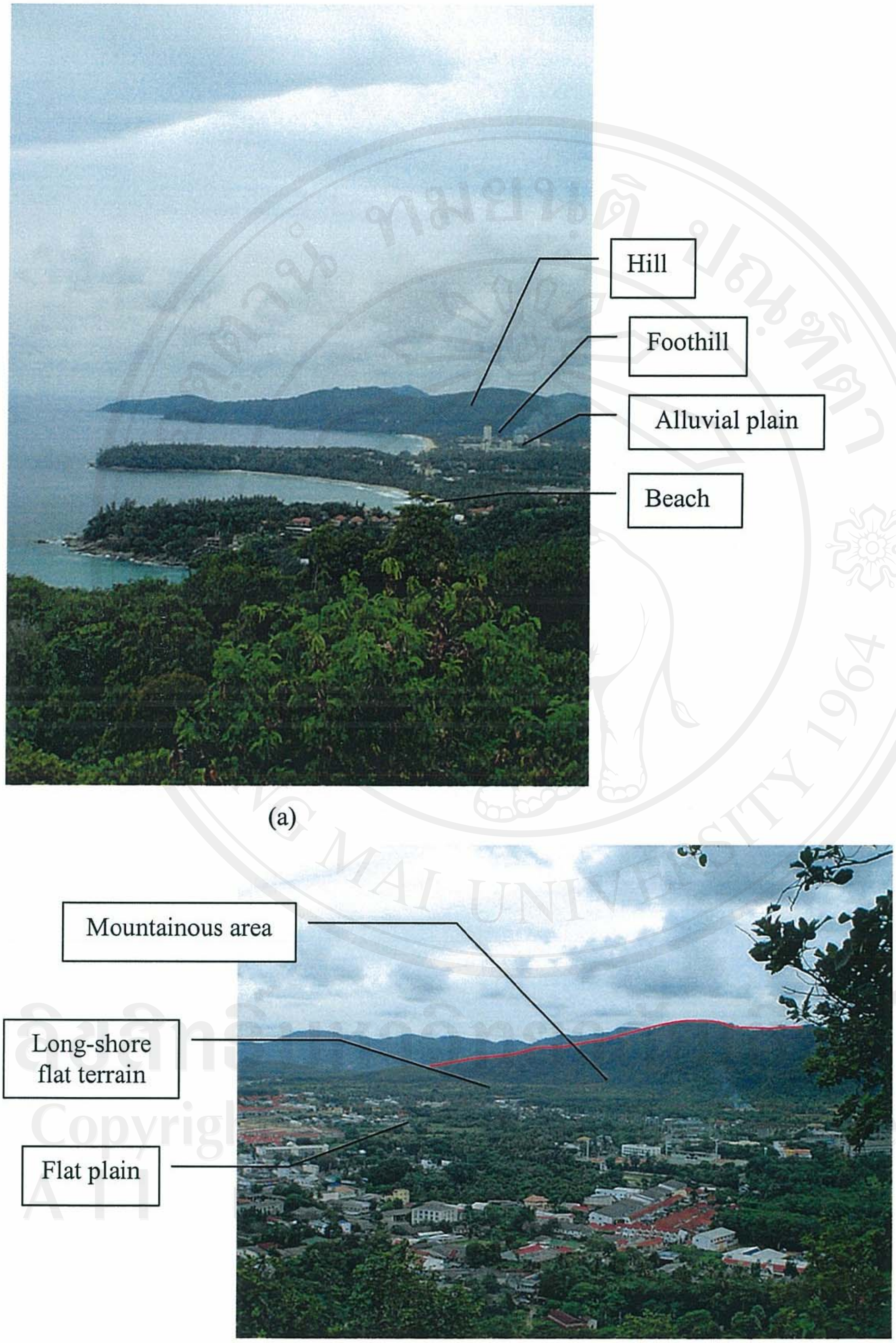

Figure 2.2 Photographs of (a) landform, and (b) geomorphologic units of Phuket island.

2.1.2 Meteorology

On the island, there are four meteorological stations located at Phuket Airport, Muang Phuket, Thalang and Bang War Dam. Most of the meteorological stations have a daily rainfall, air temperature, humidity and wind velocity (Table 2.1).

Table 2.1 Summary of meteorological data of Phuket island (Royal Irrigation Department, 1996).

Station	Type of Station	Observatory Item collected	Duration collected
Phuket Air port	Meteorological station	Daily rainfall, temperature, humidity, and wind	April 1964 to December 2003
Phuket	Meteorological station	Daily rainfall, temperature, humidity, and wind	April 1964 to December 2003
Thalang	Rain gauge station	Daily rainfall	April 1964 to December 1995
Bang War Dam	Meteorological station and hydrological station	Daily rainfall, pan evaporation, temperature, humidity, dam storage, and water level	April 1964 to December 1996

The annual average rainfalls at the four stations are presented in Table 2.2 and appear to range between 2,237 mm/y and 2,627 mm/y. It should be noted that the data from two stations at Thalang and Bang War Dam are not complete. The best correlation of the rainfall data is found between those of Phuket Airport and Phuket town.

Table 2.2 Average annual rainfall (in mm) at four meteorological stations during 1964 to 2003 (Royal Irrigation Department, 1996; Meteorological Department, 2004).

Year	Station			
	Phuket Airport	Phuket	Thalang	Bang War Dam
1964	2,916	2,443		
1965	2,461	2,270		
1966	3,114	2,543		
1967	2,097	2,279		
1968	2,431	2,531		
1969	2,578	2,490		
1970	2,696	2,378		
1971	3,159	3,171		
1972	2,041	1,819		
1973	3,310	2,629		
1974	3,091	2,787		
1975	3,005	2,648		
1976	2,148	2,260		
1977	2,082	1,994	1,343	
1978	2,916	1,774	1,481	
1979	2,461	1,637		
1980	3,114	2,606		
1981	2,097	1,709	4,501	
1982	2,431	2,076		
1983	2,578	2,492	1,876	
1984	2,696	2,581	2,114	2,885
1985	3,159	2,508	1,375	2,405
1986	2,041	3,164	3,059	3,365
1987	3,310	2,620	2,706	2,723
1988	3,091	2,353	2,216	2,632
1989	3,005	1,910	1,842	2,089
1990	2,148	1,994	2,154	
1991	2,082	1,976	1,792	
1992	3,091	1,372	1,710	
1993	3,005	2,553	2,789	
1994	2,148	2,477	2,601	2,750
1995	2,082	2,131		2,694
1996	2,421	1,644		
1997	1,935	1,867		
1998	3,090	2,437		
1999	2,594	2,550		
2000	2,618	2,371		
2001	2,975	2,202		
2002	2,199	1,967		
2003	2,664	2,431		
Average	2,627	2,291	2,237	2,394

In this area have only 2 seasons, dry season and wet season. Dry season begins from December to March, and wet season begins from April to November (Figure 2.3). The climate is tropical monsoon climate. The area is under the influence of the Southwest Monsoon between May to September. This monsoon brings the rain from the Indian Ocean. During October to April, the area is under the influence of the Northeast Monsoon, which brings the cold climate from China. Rainfall is usually concentrated within eighth months of the year starting from April to November while the rainy season extends from May to November; dry season occupies the rest of the year.

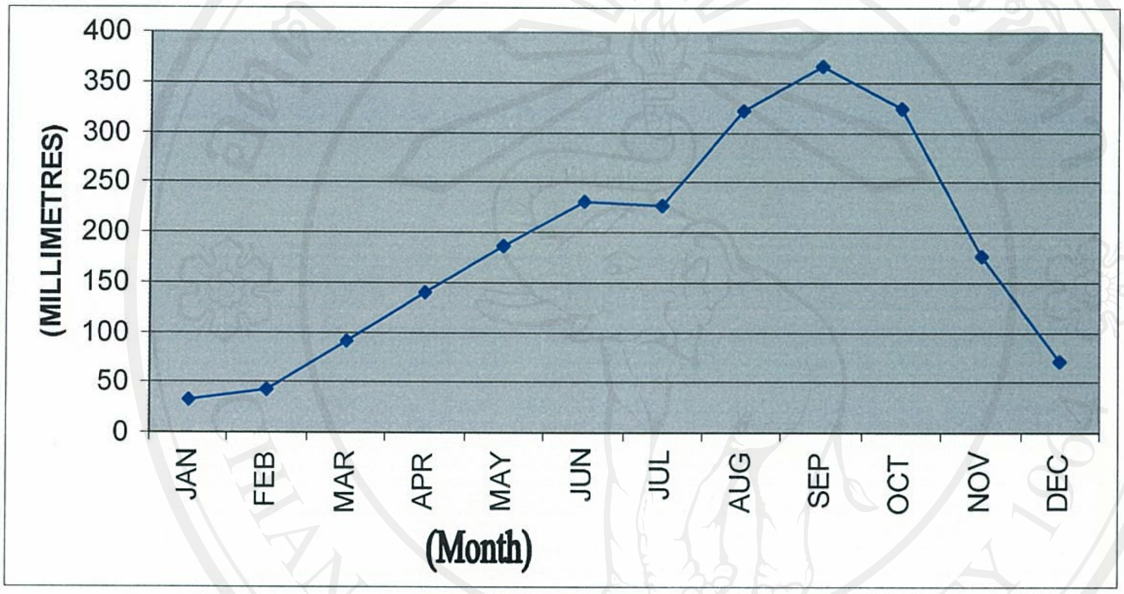

Figure 2.3 Average rainfall over the past 10-year (1994-2003) at Phuket town station (modified after Meteorological Department, 2004).

2.1.3 Soil and land use

The types of soil and landforms are usually closely related (Department of Land Development, 1992). The various mapped units of soils are grouped according to the general physiographic characteristics and their patterns as follows: gravel, sand, sandy loam, loam, clay loam, and muck. Table 2.5 shows the average permeability data and Table 2.6 presents the soil groups that are classified by their permeability. The soil map is shown in Figure 2.4.

Table 2.3 Average permeability data (Department of Land Development, 1992).

No.	Permeability class (O'Neal 1952)	Hydraulic conductivity (cm/hr)	Permeability (m/day)
1	Very slow	< 0.125	< 0.03
2	Slow	0.125-0.5	0.03-0.12
3	Moderately Slow	0.5-2.0	0.12-0.48
4	Moderate	2.0-6.25	0.48-1.50
5	Moderately Rapid	6.25-12.5	1.50-3
6	Rapid	12.5-25.0	3-6
7	Very rapid	> 25.0	> 6

Table 2.4 Soil groups based on permeability of soil types (modified after Department of Land Development, 1992).

No.	Units	Soil name	Group	USDA	Permeability class		Conductivity (m/day)
					Class	Group	
1	Ac-p	Stream sediment	59	Clay loam	Slow	2	0.03-0.12
2	EC	Estuary sediment	13	Muck			
3	Ba	Bangnara	6	Clay loam	Slow to moderately slow	2-3	0.03-0.12 to 0.12-0.48
4	Stu	Satun	6	Clay loam			
5	Kat	Kantang	25	Sandy loam	Moderately slow	3	0.12-0.48
6	Ko	Kokian	17	Sandy loam			
7	Pi	Suhipadi	17	Sandy loam			
8	Bh	Ban Thon	42	Sand	Moderate	4	0.48-1.50
9	Ak	Aoliek	26	Loam	Rapid	6	3-6
10	CL	Chalinglab	15	Loam			
11	Chl	Chalong	34	Loam			
12	Lh	Laharn	34	Loam			
13	Hp	Haipong	26	Loam			
14	Kbi	Krabi	26	Loam			
15	Kc	Khongchak	45	Gravel			
16	Kh	Khohong	39	Sandy loam			
17	Koi	Kokoi	26	Loam			
18	Ll	Lamphura	26	Loam			
19	Ntn	Naton	53	Loam			
20	Pac	Pakjan	26	Loam			
21	Pga	Phangnga	26	Loam			
22	Pk	Phuket	26	Loam			
23	Rg	Ranong	51	Sandy loam			
24	SC	Foot hill sediment	62	Sandy loam			
25	Tim	Timiang	26	Loam			
26	T.M.L	Tin Mine Lake	26	Loam			
27	Bc	Bacho	43	Sand	Very rapid	7	>6
28	Hh	Hunhin	43	Sand			
29	Mik	Maikhao	43	Sand			
30	R.B.	New beach sand	43	Sand			
31	Ry	Rayong	43	Sand			

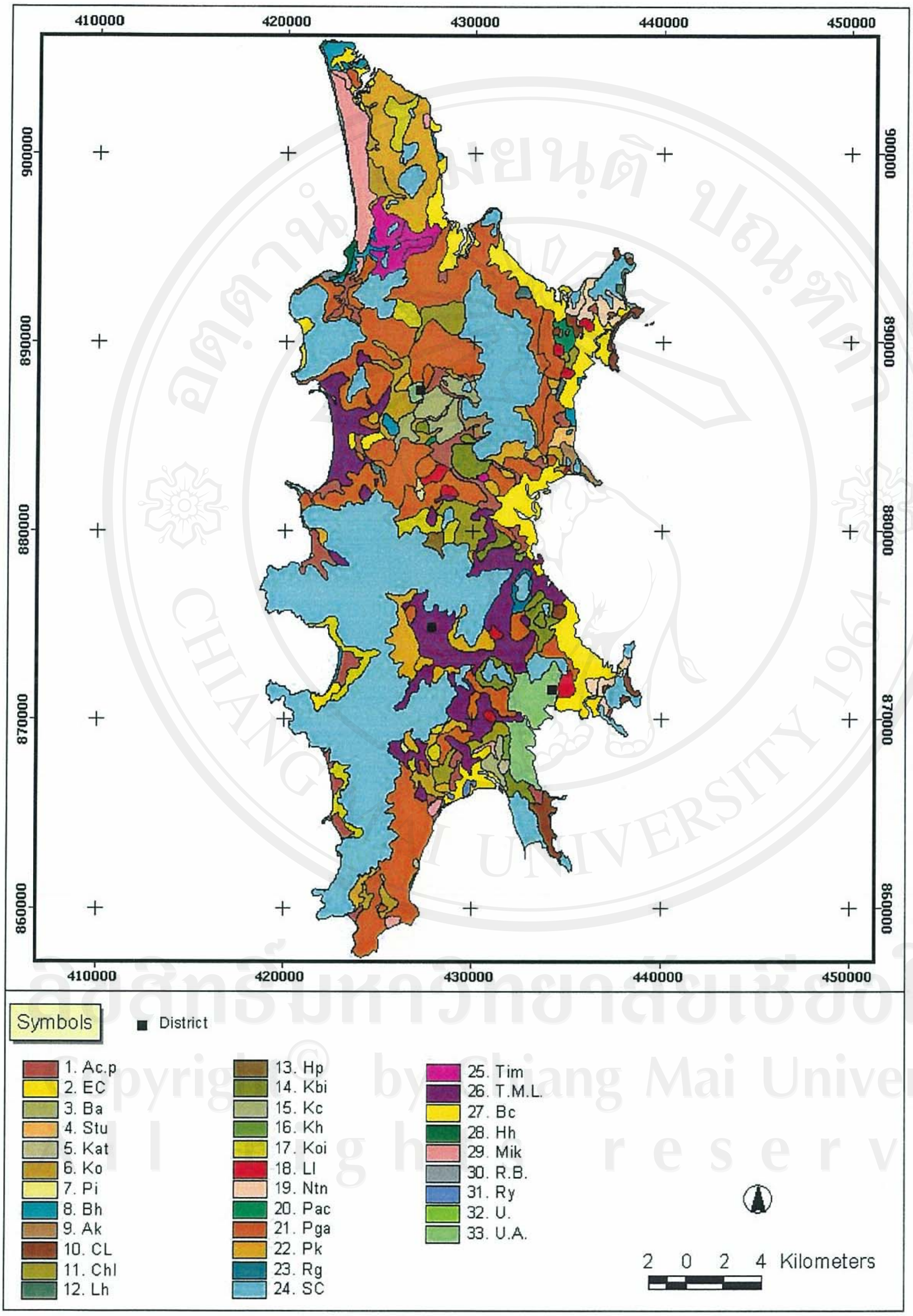

Figure 2.4 Soil types map of Phuket island (modified after Department of Land Development, 1992).

The land use pattern can be classified into four groups (Department of Land Development, 1987) as follow: urban and build-up, agricultural, forest, and miscellaneous areas (Table 2.7). The urban and build-up area is further subdivided into residential, commercial and services, industrial, transportation and communication, and institutional land. This category of land use covers approximately 6.22 percent of the total area. The agricultural area includes the paddy field, rubber plantations, coconut and pineapple plantations, and mixed orchards. This group of land use covers approximately 49.75 percent of the total area. The forest area is subdivided into beach forest, mangrove forest and topical forest and occupies approximately 29.89 percent of the total area. The Miscellaneous area is subdivided into range land, wet land, water body, old tin mines pit and beaches. This group covers approximately 14.14 percent of the total area. The land use and land cover is presented in Figure 2.5.

Table 2.5 Existing land use in the year 1987 (Royal Irrigation Department, 1996).

Type of land use	Area		
	Rais	Acres	Percent
1. Urban and build-up lands	**21,095**	**8,438**	**6.22**
- City, town, commercial and service	5,272	2,109	1.55
- Village, institutional land, transportation, Communication and utility, industrial land	15,823	6,329	4.67
2. Agricultural lands	**168,885**	**67,554**	**49.75**
- Paddy field	18,864	7,546	5.56
- Rubber plantations	127,151	50,860	37.46
- Coconut plantations	21,538	8,615	6.35
- Orchard (mixed, rambutan)	646	258	0.19
- Cashew plantations	476	190	0.14
- Field crop (corn, pineapple)	90	36	0.02
- Aquaculture land	120	48	0.03
3. Forest lands	**101,423**	**40,569**	**29.89**
- Evergreen forest	80,417	32,167	23.70
- Disturbed evergreen forest	2,141	856	0.63
- Mangrove forest	17,902	7,161	5.28
- Disturbed mangrove forest	241	96	0.07
- Beach forest	541	216	0.16
- Forest plantation	181	72	0.05
4. Miscellaneous lands	**47,993**	**19,197**	**14.14**
- Rangeland	862	345	0.25
- Abandoned mine	42,740	17,096	12.59
- Natural water body	662	265	0.20
- wetland	361	144	0.11
- Beaches	3,368	1,347	0.99
Total	**339,396**	**135,758**	**100.00**

Note: 1 Acre = 2.5 Rai

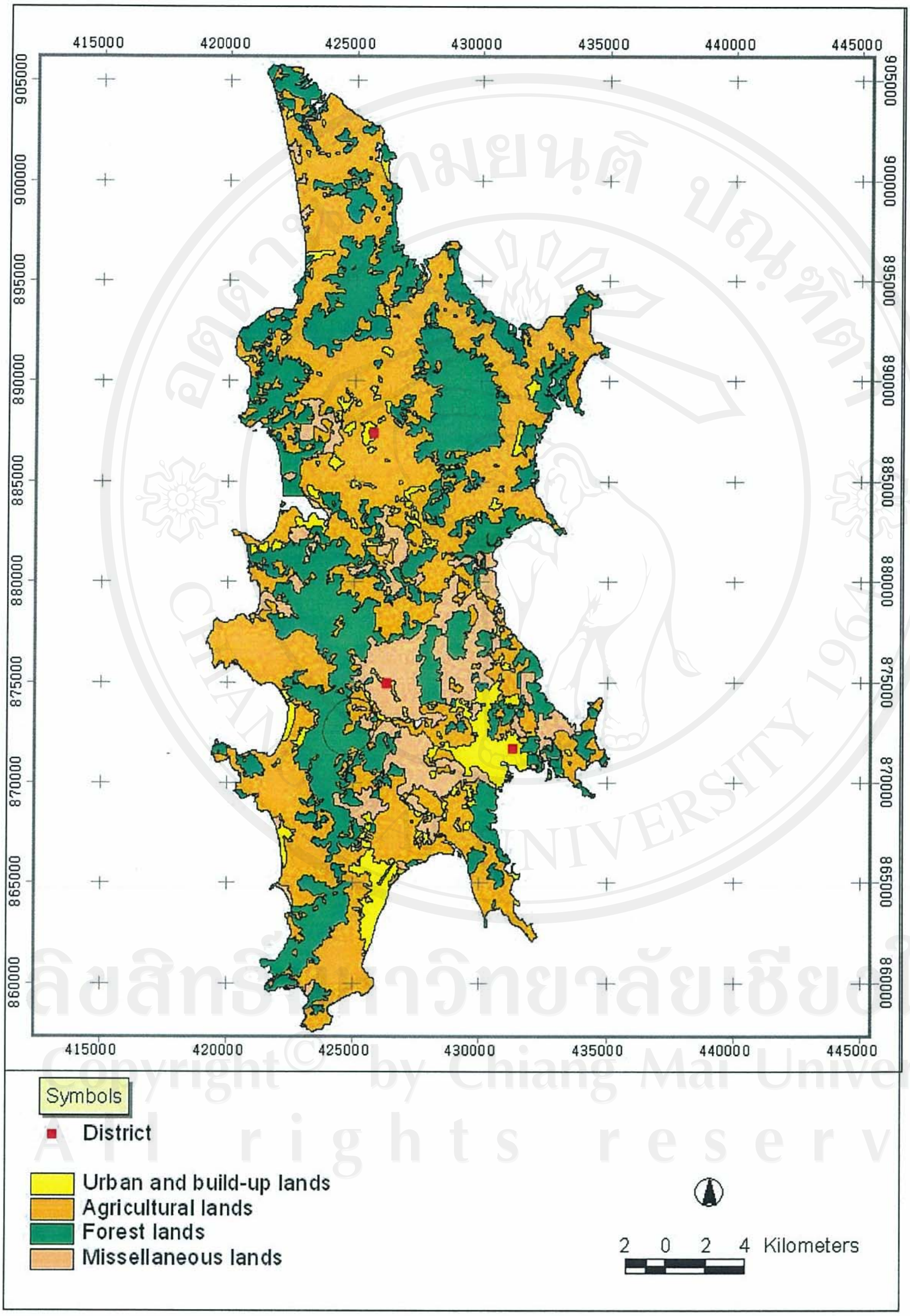

Figure 2.5 Land use and land cover map of Phuket island (modified after Department of Land Development, 1987).

2.2 Geological setting

The study area consists of various types of rock units including consolidated rocks and unconsolidated sediments. Consolidated rocks include sedimentary, meta-sedimentary, and igneous rocks, and much of the area is underlain by igneous rocks in the western part. The unconsolidated sediments occur in the north and east and are mainly the weathering products of rocks. The geological map of study area is presented in Figure 2.6.

The oldest rocks are the Carboniferous-Permian Kaeng Krachan Group or Phuket Group (Chaimanee and Teerarungsikul, 1990). The rocks are composed of pebbly mudstones, laminated mudstones, siltstones, shale and graywackes. They expose along the east coast, usually forming low and gentle mountains with elevations ranging between 100 and 200 m above mean sea level. They occur as north-south trending mountain range parallel to the coast and cover less than one third of the total area. A muddy coast covered by mangrove forest is formed wherever the area is underlain by this rock unit.

Parts of the Kaeng Krachan Group show evidence of low-grade metamorphism and are characterized by quartzitic sandstone, phyllitic shale, and slaty shale. In addition, extensive thermally metamorphosed sedimentary rocks occur around the granite plutons and as roof pendants (Putthapiban, 1984).

Major mountains are underlain by granitic rocks intruded in the Cretaceous age and cover more than two third of the island, mostly in the western, eastern, and central parts. Granites are classified into five groups from G1 to G5 granites based on the relative ages of intrusion (Putthapiban, 1984, Chaimanee and Teerarungsikul, 1993). These are Khao Prathiu suite-G1, Kata Beach suite-G2, Naithon Beach suite-G3, Khao Tosae suite-G4, and Khao Rang suite-G5. The granites form the elongate bodies aligned in a north-south direction. The intrusion of granites intensively affected the country rocks, especially along the contact zone. The country rocks were disturbed, degenerated, and extensively intruded by quartz veins or pegmatite veins. Granites usually have a very thick zone of weathering at the surface, ranging from 15 to 30 meters usually. Most sandy and rocky beaches, seen on the west coast of the island, are underlain by the granites.

The youngest rocks that overlie granites or sedimentary bedrock are unconsolidated sediments of the late Tertiary to Quaternary age (Chaimanee and Teerarungsikul, 1993). The sediments are classified into five units based on the sediment types and depositional environments. These are colluvial deposits-Qc (Pleistocene), residual deposits-Qr (Pleistocene), fluvial deposits-Qf (Holocene), near-shore deposits-Qn0 to Qn3 (Holocene), and beach ridge deposits-Qb (Holocene). The sediments are aggregates of gravel, sand, silt, and clay, which are the weathering products of the nearby rocks. Terrace deposits occupy the foothill and are characterized by sediments that are angular to subangular in shape and are poor in sorting. Fluvial deposits are restricted along the narrow river courses. Near-shore, mangrove deposits, and beach ridge deposits are developed along shorelines around the island.

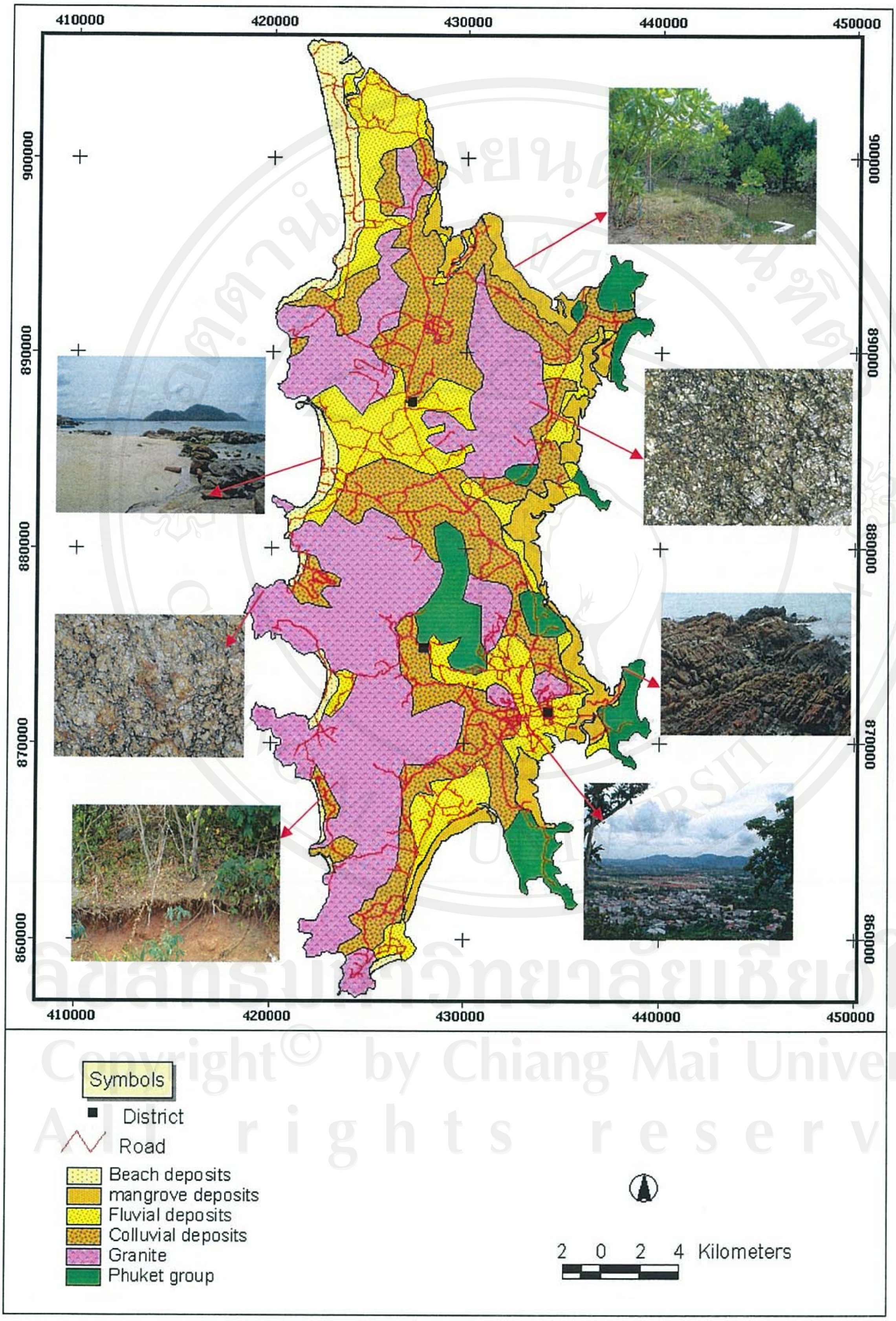

Figure 2.6 Geological map of Phuket island (modified after Department of Mineral Resources, 2001).

2.3 Hydrogeological setting

2.3.1 Hydrogeology

Groundwater resources of Phuket island can be classified into two types, based on degree of compaction and cementation (Department of Mineral Resources, 2001). There are unconsolidated and consolidated aquifers (Figure 2.7). The data used include lithologic logs of 43 groundwater wells (shown in Appendix A) provided by the Department of Mineral Resources (changed to Department of Groundwater Resources in 2002).

(1) Unconsolidated aquifers

The aquifers are characterized by aggregates of gravel, sand, silt and clay, which are the weathering products of rocks. These sediments were transported and deposited in any areas without being cemented. The unconsolidated aquifers can be classified into three types: colluvium aquifers (Qcl), floodplain aquifers (Qfd), and beach sand aquifers (Qbs). The colluvium aquifers are composed of poorly sorted strata with variable thickness. Depths to these aquifers vary from 15 m to 25 m depending on topographic conditions. A yield from this type of aquifers ranges between 2-10 m^3/hr on average. Groundwater quality is good. The floodplain aquifers are equivalent to alluvial deposits and channel deposits, which are found in the floodplains. The average depth to aquifer is in the range of 15 m to 30 m. The average yield ranges between 2-10 m^3/hr and groundwater quality is good. The static water level in this type of aquifers is in the range of 1-3 m. The beach sand aquifers consist of fine to coarse grained sands, which were deposited along the shorelines. It serves as a main shallow aquifer that provides fresh water for the local supply. The depth of aquifer is in the range of 2-5 m and yields range between 5-10 m^3/hr or higher in some areas. It yields good quality water, except in some areas that adjoins mangroves, where fair to poor water quality is commonly found. The static water level is in the range of 1-2 m.

(2) Consolidated aquifers

This type of aquifers can be classified to two categories: sedimentary or meta-sedimentary aquifers (PCms) and igneous rocks (Gr). The sedimentary or meta-sedimentary aquifers comprise pebbly mudstones, siltstones, shale, graywackes, quartzitic sandstone, phyllitic shale, and slaty shale. Groundwater is commonly found in fractures, joints, fault zones and weathered zones. Depth to aquifer is 25-35 m and yield is mostly less than 2 m^3/hr. Groundwater quality is in good condition. The igneous rocks aquifers consist of porphyritic biotite-hornblende granite, leuco-granite, pegmatite and quartz veins, which are dense and massive. Groundwater is found in the weathered zone and in secondary porosity such as in exfoliation fractures and cracks. The estimated yield is less than 2 m^3/hr. The average depth to the aquifer is 25-35 m and groundwater is in good quality, but is iron-rich in some areas. Table 2.8 summarizes aquifers characteristics in Phuket island.

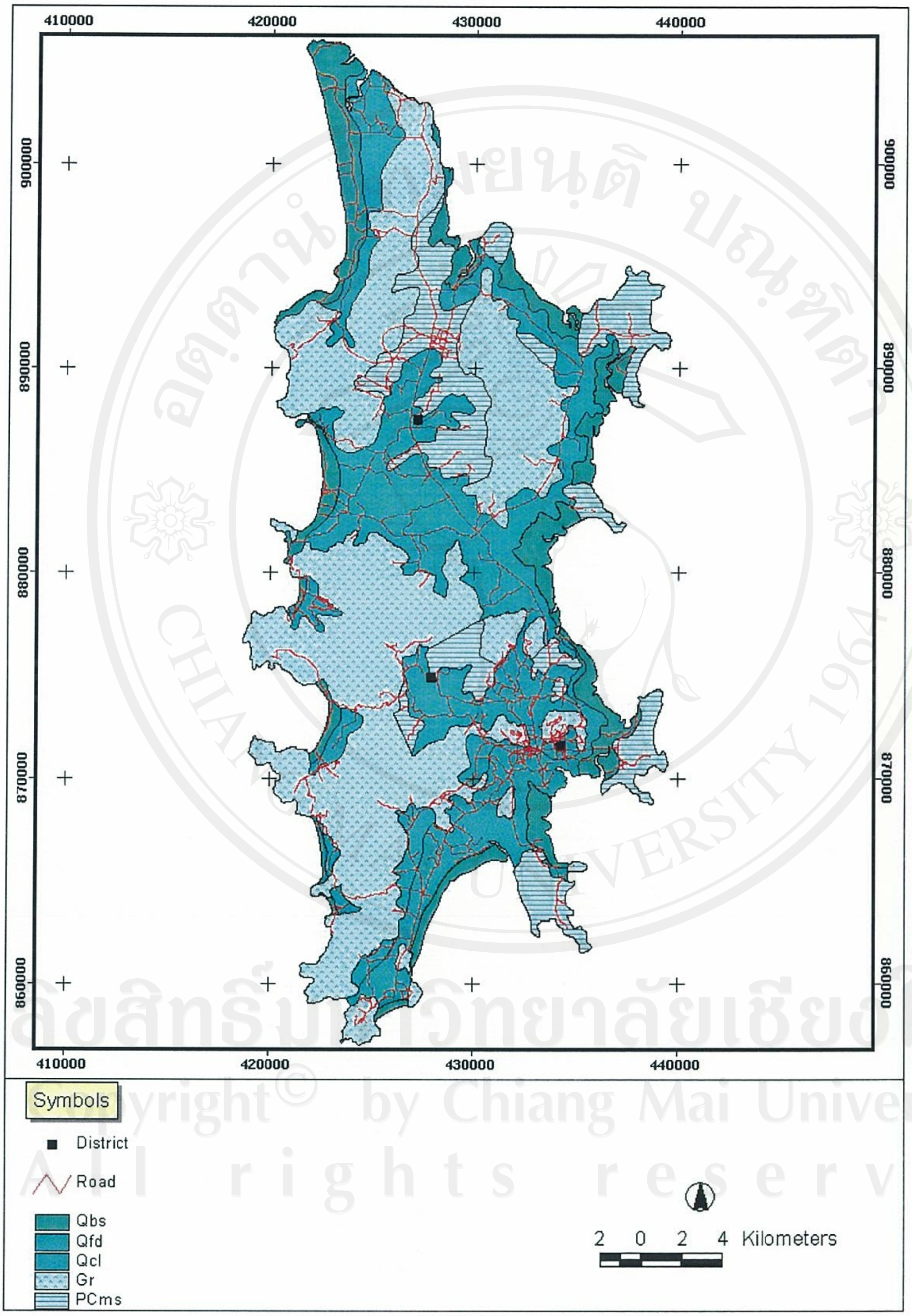

Figure 2.7 Hydrogeological map of Phuket island (modified after Department of Mineral Resources, 2001).

Table 2.6 Summary of aquifers characteristics of Phuket island (modified after Department of Mineral Resources, 2001).

Geologic Ages	Aquifer units	Lithology	Average Depth (m)	Yield (m^3/hr)	Groundwater quality
Quaternary	Qbs: Beach sand aquifers (Holocene)	Sand, coarse to fine grained, well sorted	2-5	5-10	Good quality except in some areas that adjoin mangroves
	Qfd: Floodplain aquifers (Holocene)	Gravel, sand, silt, clay and minute size of rock debris	15-30	2-10	Good
	Qcl: Colluvium aquifers (Pleistocene)	Gravel, sand, silt, and rock fragments, angular to subangular, poorly sorted	15-25	2-10	Good
Cretaceous	K: Granite aquifers	Porphyritic biotite-hornblende granite, leuco-granite, pegmatite and quartz	25-35	2	Good, but some areas are high in iron
Carboniferous to lower Permian	PCms: Sedimentary or meta-sedimentary aquifers	Pebbly mudstones, siltstones, shale, graywack, quartzitic sandstone, phyllitic shale, and slaty shale.	25-35	2	Good

2.3.2 Water Resources

In the former times, the island was a center of tin trading in the Andaman Sea, but now the island has become Thailand's most popular beach destination for domestic and overseas tourists. The number of both tourists and local people in the island has been increasing rapidly. As a consequence, demands for water resources have been increasing drastically while the increasing amounts of land are being reclaimed for industrial, agricultural, and domestic uses. The groundwater is originated from purified water such as rain and surface water. At present, the majority of local people still prefer to use shallow dug wells as the main source of water supply. This shallow groundwater is prone to contamination. Therefore, prior to develop for groundwater utilization such as: domestic, industrial, and agricultural uses. The user has to examine its physical, chemical, toxic and bacteriological characteristic. Water resources in Phuket island can be classified into two types: surface water and groundwater.

(1) Surface water

There are 24 watershed areas in Phuket island (Figure 2.8). Most of the surface drainage basins are originated at low but steep mountains in the northern, northeastern, and southwestern part. The island has no major river and no large surface drainage. However, there are a few small and short streams such as Bang Yai, Thalang, Kata, and Chalong. Bang Yai stream those originate from a mountainous area in the western part of Kathu district. These small steams flow through Kathu and Muang district, and eventually reach the sea at the upper part of Chalong Bay in the east coast. Thalang stream, originating from a mountainous area in the northeastern part of Thalang district, flows westwards through Thalang district and eventually merges with Kala stream and flows into the sea in the vicinity of Ko Tha. Kata and Chalong streams, originating from a mountainous area in the western part of Muang district, flow eastwards into the sea at the lower part of Chalong Bay. In addition to the natural streams, Bang War Dam and the old tin-mine pits widely distributed throughout the island are becoming reservoirs for surface water resources. A location map of the old tin-mine pits is shown in Figure 2.9.

(2) Groundwater

The groundwater basins in Phuket island almost occupy the same area as the surface water basins. However, they are rather small and mountainous. Therefore, a large scale groundwater basin has not been developed. Significant groundwater basins in their extents and depths are very few. There are several localities in the island where shallow groundwater is available in shallow dug-wells within the depths between 2 m to 4 m below the ground surface (Appendix B).

The sedimentary or meta-sedimentary aquifer yields are less than 2 m^3/hr, but the highest potential resource of subsurface water in the island is located around Thep Kasattri of Thalang district, at which fresh groundwater can be abstracted from sedimentary or meta-sedimentary aquifers from the depth of 20-40 m at a rate of 10-30 m^3/hr. Groundwater resource of lower potential is from the granitic aquifers, which contains both fresh and iron-rich water (Department of Mineral Resources, 2001). As mentioned earlier, both types of the rocks have rather thick weathering zones. In some places, the weathered granite forms a very excellent aquifer and shallow wells were dug in the weathered granite. The groundwater yield map is presented in Figure 2.10.

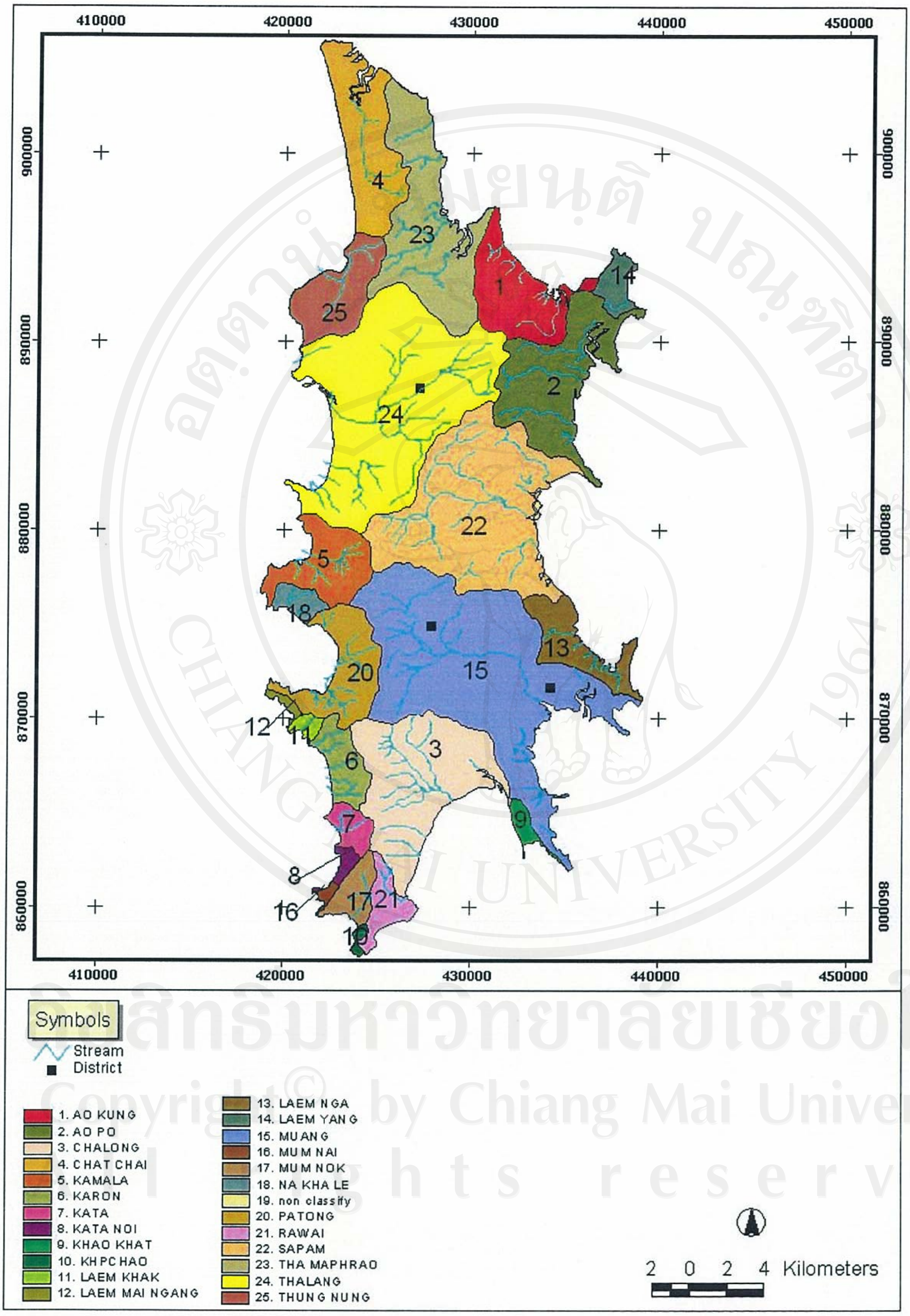

Figure 2.8 Watershed map of Phuket island (modified after Department of Mineral Resources, 2001).

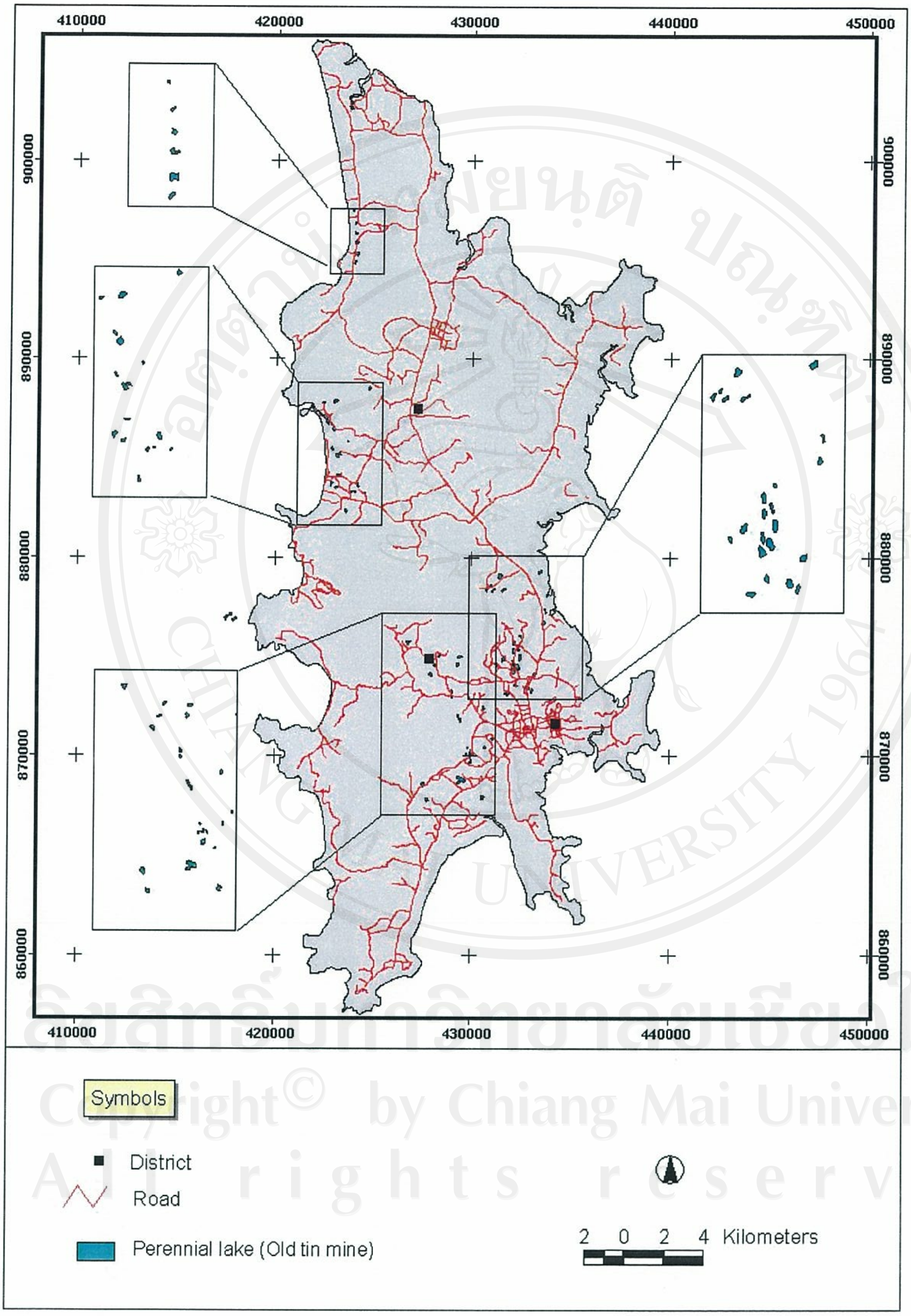

Figure 2.9 Map showing old tin mine pits of Phuket island (modified after Department of Mineral Resources, 2001).

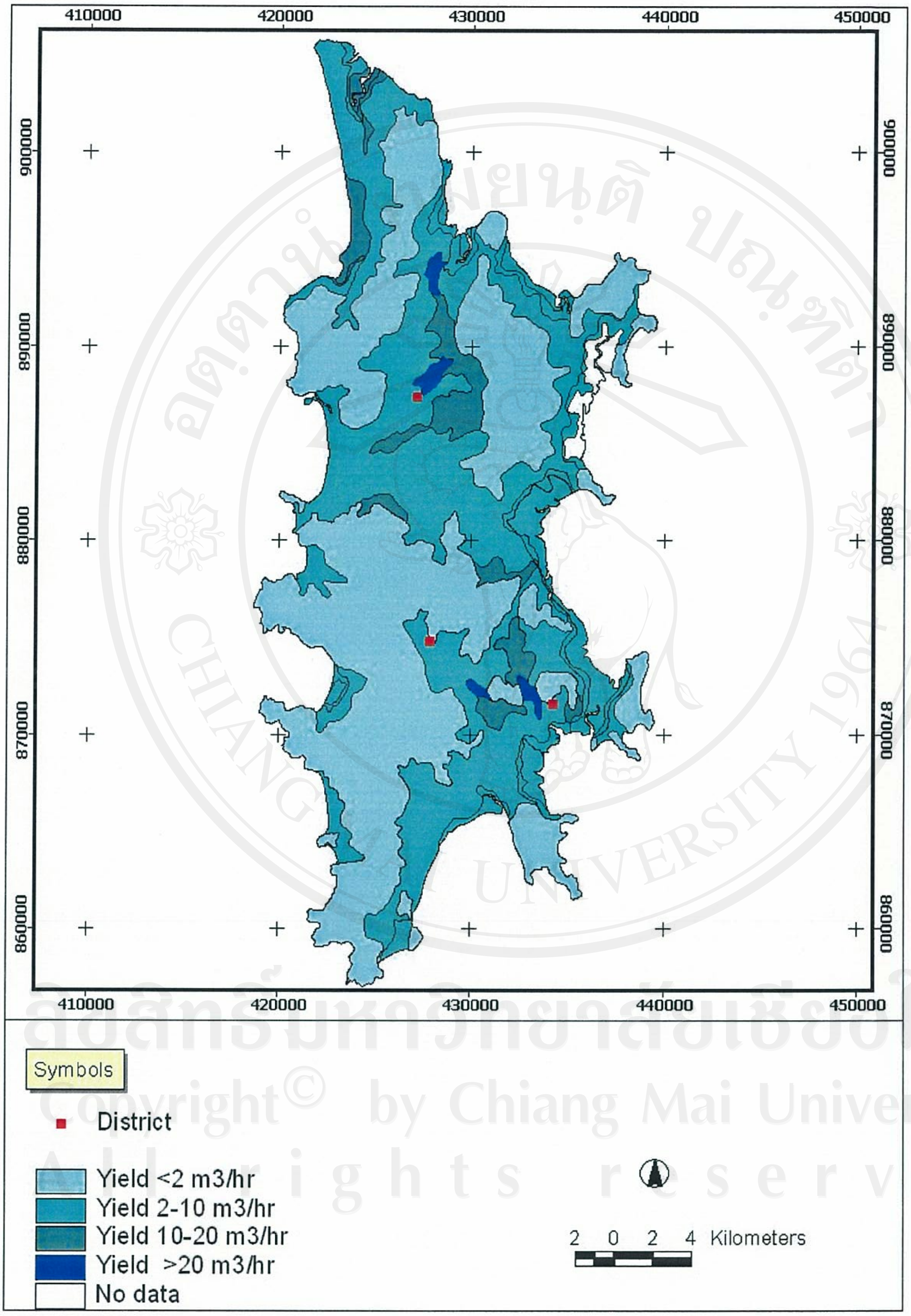

Figure 2.10 Groundwater yield map of Phuket island (modified after Department of Mineral Resources, 2001).

2.3.3 Pumping test

The hydrogeological investigation under an underground dam project of the Royal Irrigation Department in 1996 provided data that include test and observation well drilling, resistivity sounding, pumping tests, water quality analyses, and groundwater monitoring (Tables 2.9 and 2.10). Data of pumping tests are the important hydrogeologic factor in term hydraulic conductivity. Figure 2.11 shows the locations of pumping test sites in Phuket island.

Table 2.7 Hydrogeological investigations (Royal Irrigation Department, 1996).

Item	Quantity	Unit
Test well drilling	47	Wells
Observation well drilling	71	Wells
Resistivity sounding	50	Points
Pumping test	47	Sites
Water quality analysis	50	Samples
Groundwater monitoring (daily)	47	Wells

Table 2.8 Data of observation wells (Royal Irrigation Department, 1996).

Well No.	T (m^2/day)	S	Thickness (m)	K (cm/sec)	Pump rate (m^3/day)
BTO-01	71	3.10E-05	34.6	2.38E-03	76.9
BTO-02	731	2.40E-03	20.4	4.15E-02	491
BTO-03	62	2.60E-03	21.4	3.35E-03	251.1
BTO-04	144	1.70E-03	16.4	1.02E-02	106.3
BTO-05	45	3.203-04	14.5	3.59E-03	98.6
BTO-07	309	1.80E-15	21.5	1.66E-02	109.8
BTO-08	31	3.70E-03	22.9	1.57E-03	251.1
BTO-10	26	1.70E-03	15.8	1.90E-03	125.3
BTO-11	150	4.50E-03	19.8	8.77E-03	65.4
BTO-12	112.3	9.30E-03	14	9.28E-03	112.3
BTO-14	32	6.50E-05	23.2	1.60E-03	139.1
BTO-18	1,330	5.70E-07	21.3	7.23E-02	1,098.1
BTO-20	25	1.80E-06	5	5.79E-03	114.9
BTO-23	206	1.90E-02	11.7	2.04E-02	34.6
BTO-24	88	3.90E-03	11	9.26E-03	21.6
BTO-25	29	4.20E-03	13.9	2.41E-03	94.2
BTO-26	23	3.60E-03	11	2.42E-03	49.2
BTO-27	56	2.80E-03	2.8	2.31E-02	21.6
BTO-28	119	1.60E-02	10.2	1.35E-02	57
BTO-29	57	1.90E-06	9	7.33E-03	110.6

Table 2.8 (Continued).

Well No.	T (m^2/day)	S	Thickness (m.)	K (cm/sec)	Pump rate (m^3/day)
BTO-30	168	1.60E-03	8.3	2.34E-02	37.4
BTO-31	69	6.60E-04	18.11	4.41E-03	53.6
BTO-32	15	4.20E-04	21	8.27E-04	21.6
BTO-33	95	5.00E-03	6.9	1.59E-02	21.6
BTO-35	38	2.90E-04	18.9	2.33E-03	43.2
BTO-36	104	1.80E-03	12.7	9.48E-03	99.9
KTO-03	241	1.20E-04	12.3	2.28E-02	397.3
KTO-04	9	3.20E-04	39.8	2.62E-04	163.6
KTO-05	188	3.60E-03	15.5	1.40E-02	573.0
KTO-11	479	4.70E-04	15.8	3.51E-02	965.4
KTO-12	6	1.40E-03	16.1	4.31E-04	36.3
KTO-13	676	1.60E-04	8.0	9.83E-02	216.9
SKO-01	601	3.80E-06	16.0	4.36E-02	603.0
SKO-03	57	4.20E-03	20.0	3.30E-03	70.6
SKO-07	61	2.60E-01	24.7	2.86E-03	247.4
SKO-08	331	5.60E-05	13.8	2.78E-02	426.3
SKO-09	7	1.50E-05	23.3	3.48E-04	68.2
SKO-10	227	1.90E-09	22.8	1.15E-02	109.0
CLO-02	7	3.50E-05	26.0	3.12E-04	46.7
CLO-06	28	2.30E-09	2.8	1.17E-02	55.3
KAO-01	36	2.20E-04	18.5	2.25E-03	78.6
KAO-02	21	4.40E-04	12.1	2.01E-03	241.3

Note: T is transmissivity
S is storage coefficient
K is hydraulic conductivity

Theis Method

$$S = \frac{4Tut}{r^2}$$

u Dimensionless constant
t Time since pumping began
r is radial distance to the well

Cooper-Jacob Straight-Line Time-Drawdown Method

$$S = \frac{2.25Tt_0}{r^2}$$

t_0 is the time, where the straight line intersects the zero-drawdown axis

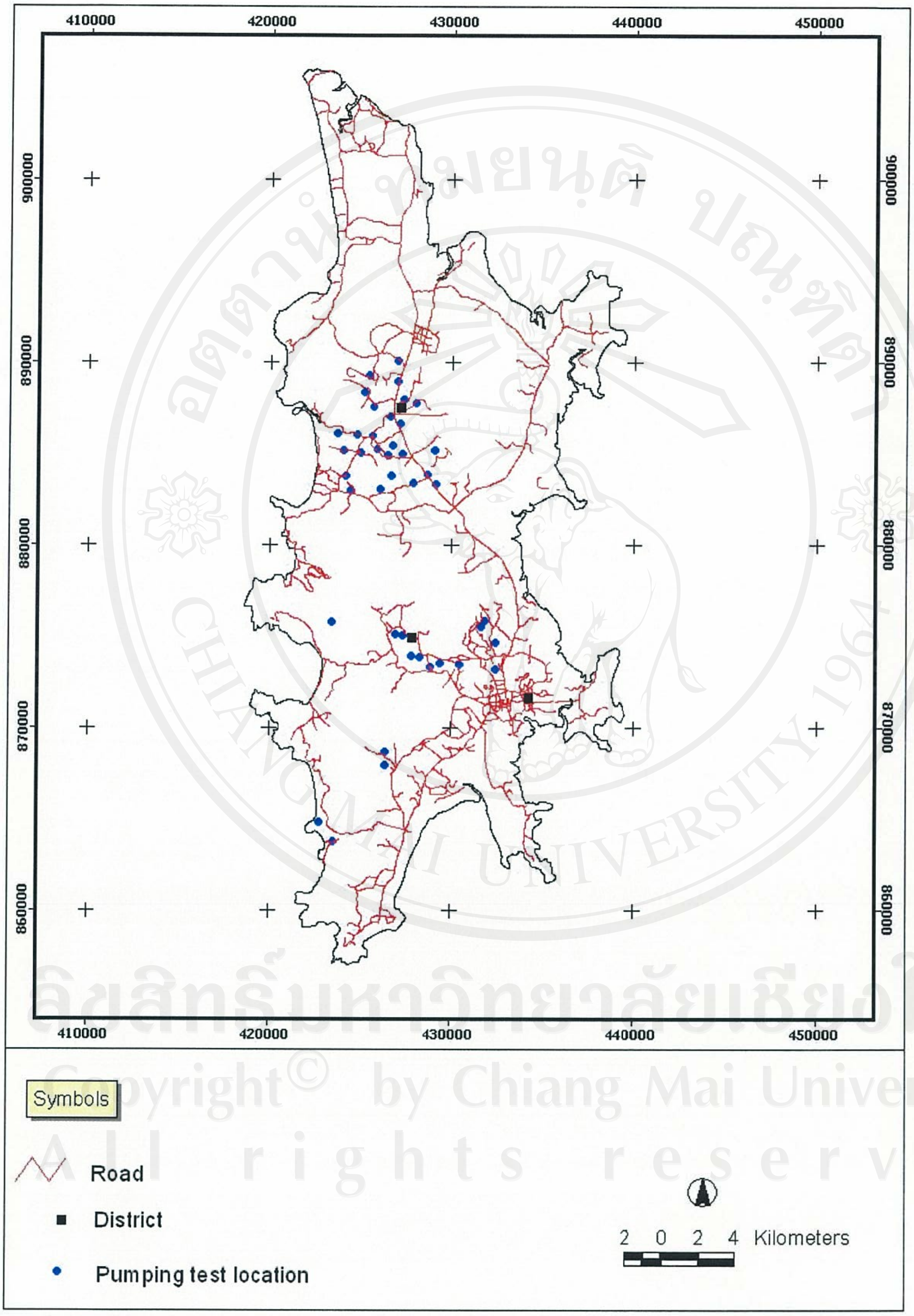

Figure 2.11 Location map of the pumping test sites (modified after Royal Irrigation Department, 1996: and Department of Mineral Resources, 2001).

2.4 Reconnaissance field observation

Over the period of this study, a hydrogeological survey was performed. The field observation includes measuring groundwater levels in 73 shallow groundwater wells, and taking 116 water samples in June and July, 2004 from both surface and subsurface (73 dug wells, 15 rivers, 10 old tin mine pits, and 18 rainwater samples) and from these isotopic analyses were carried out for about 31 samples (Table 2.11). Figures 2.12 to 2.16 present the locations of sampling sites, dug-wells, rivers, old tin mine pits, and Bang War Dam.

Through the field geological and hydrogeological reconnaissance, it was found that the bedrocks are Permo-Carboniferous sedimentary or weakly metamorphosed Phuket group and granite rocks. The Phuket group is found mainly in the east and usually forms low and gentle mountains while granitic rocks form major mountains and cover approximately 40 percent of the total area, especially in the west. The overburden consists of gravel, sand, clay, and locally lateritic soils or rock fragments. As previously mentioned, both types of bedrocks have rather thick weathering zones. In particular, the weathered granite locally provides a very excellent aquifer. At present, the resorts or big buildings in mountains areas favor to have their own drilled wells.

In the island, the water supplies rely on surface water and shallow groundwater that are sensitive to contamination by waste water, garbage, and other pollutants in urban areas (Figure 2.17). This requires a proper management of the available groundwater resources in order to avoid overexploitation and pollution.

For surface water resources, Bang War Dam, and the old tin-mine pits provides water supply in addition to the existing natural streams. People on the island prefer to dig shallow dug-wells rather than to drill groundwater wells. Based on the measurements in this study, the depth to water table of shallow dug-wells is in the range 1.14 m to 10.51 m with an average of 3.52 m below the ground surface and the contour map of these data is shown in Figure 2.18. Compared to the contour map of the Department of Mineral Resources (Figure 2.19), it is apparent that both have a similar pattern. The contours reflecting the greater depths to water table are limited to the eastern part.

Table 2.9 Depth to water table in 73 shallow groundwater wells (data taken from June to July, 2004).

No.	Sample	Location		Depth to Water level (m)
		X	Y	
1	021W	0431620	0871211	6.55
2	022W	0429960	0869147	4.80
3	023W	0431727	1868256	4.40
4	024W	0432072	0867186	1.34
5	025W	0434367	0862964	2.06
6	026W	0433873	0863888	1.78
7	027W	0434058	0965402	1.14
8	028W	0433236	0866129	3.86
9	029W	0431616	0866970	2.58
10	030W	0431081	0867982	2.22
11	031W	0425448	0876736	3.77
12	032W	0426084	0875930	4.69
13	033W	0427458	0875385	5.54
14	034W	0426329	0875135	1.42
15	035W	0428625	0873572	2.47
16	036W	0427847	0874645	1.90
17	037W	0427964	0875140	1.50
18	038W	0426801	0874473	1.46
19	039W	0431111	0874925	4.02
20	040W	0433143	0876113	4.46
21	041W	0433409	0874733	8.76
22	042W	0434371	0074293	1.17
23	043W	0427793	0884677	1.93
24	044W	0426780	0887713	1.91
25	045W	0428856	0887424	9.35
26	046W	0426413	0888141	2.01
27	047W	0425993	0889156	3.97
28	048W	0425285	0889376	2.79
29	049W	0423364	0891309	3.10
30	050W	0423374	0893927	1.35
31	051W	0426844	0897538	10.51
32	052W	0424050	0897984	5.50
33	053W	0422684	0903729	4.05
34	054W	0422559	0906080	1.66
35	055W	0423621	0901848	1.18
36	056W	0424393	0904040	5.34
37	057W	0424999	0901827	4.50
38	058W	0427136	0901339	2.86
39	059W	0427431	0899331	9.58
40	060W	0427353	0894295	4.50

Table 2.9 (Continued).

No.	Sample	Location		Depth to Water level (m)
		X	Y	
41	061W	0428852	0894700	3.65
42	062W	0430360	0897429	4.74
43	063W	0430786	0894559	3.07
44	064W	0431797	0893071	10.20
45	065W	0432314	0892753	4.10
46	066W	0434924	0890401	1.77
47	067W	0436006	0892051	3.00
48	068W	0433622	0888961	3.50
49	069W	0434076	0887821	4.80
50	070W	0433763	0885697	3.08
51	071W	0432569	0883832	5.34
52	072W	0433774	0872783	3.20
53	073W	0434123	0871371	1.50
54	074W	0432006	0870106	1.10
55	075W	0433025	0878051	0.40
56	076W	0430179	0881834	1.96
57	077W	0426190	0882032	3.90
58	078W	0424144	0884536	1.20
59	079W	0423026	0882693	3.91
60	080W	0421122	0879580	2.48
61	081W	0420890	0878333	2.10
62	082W	0422354	0874731	3.12
63	083W	0423932	0873506	2.35
64	084W	0422423	0871190	2.95
65	085W	0422284	0868161	0.61
66	086W	0423077	0864751	1.92
67	087W	0424706	0861153	5.90
68	088W	0423681	0858704	2.93
69	089W	0426670	0862491	6.96
70	090W	0426082	0860788	1.87
71	091W	0427110	0864623	2.90
72	092W	0425381	0868898	6.65
73	093W	0429074	0868022	1.70
	Average depth to water level			3.52

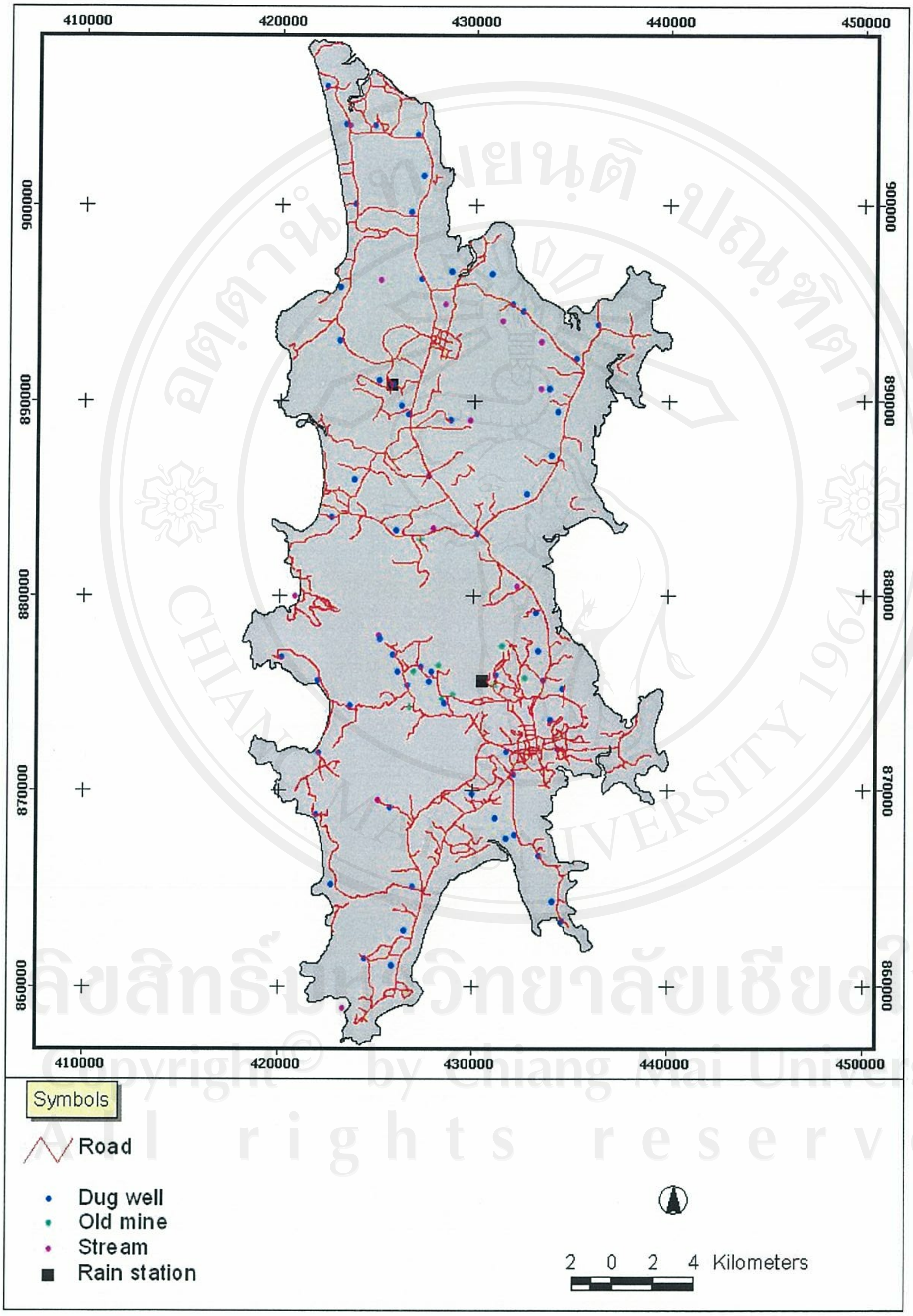

Figure 2.12 Map showing the locations of water sampling sites.

Figure 2.13 Photographs of shallow dug-well.

Figure 2.14 Photographs of small natural streams.

Figure 2.15 Photographs of old tin mine pits.

Figure 2.16 Photographs of the Bang War Dam.

Figure 2.17 Photographs showing water contaminations.

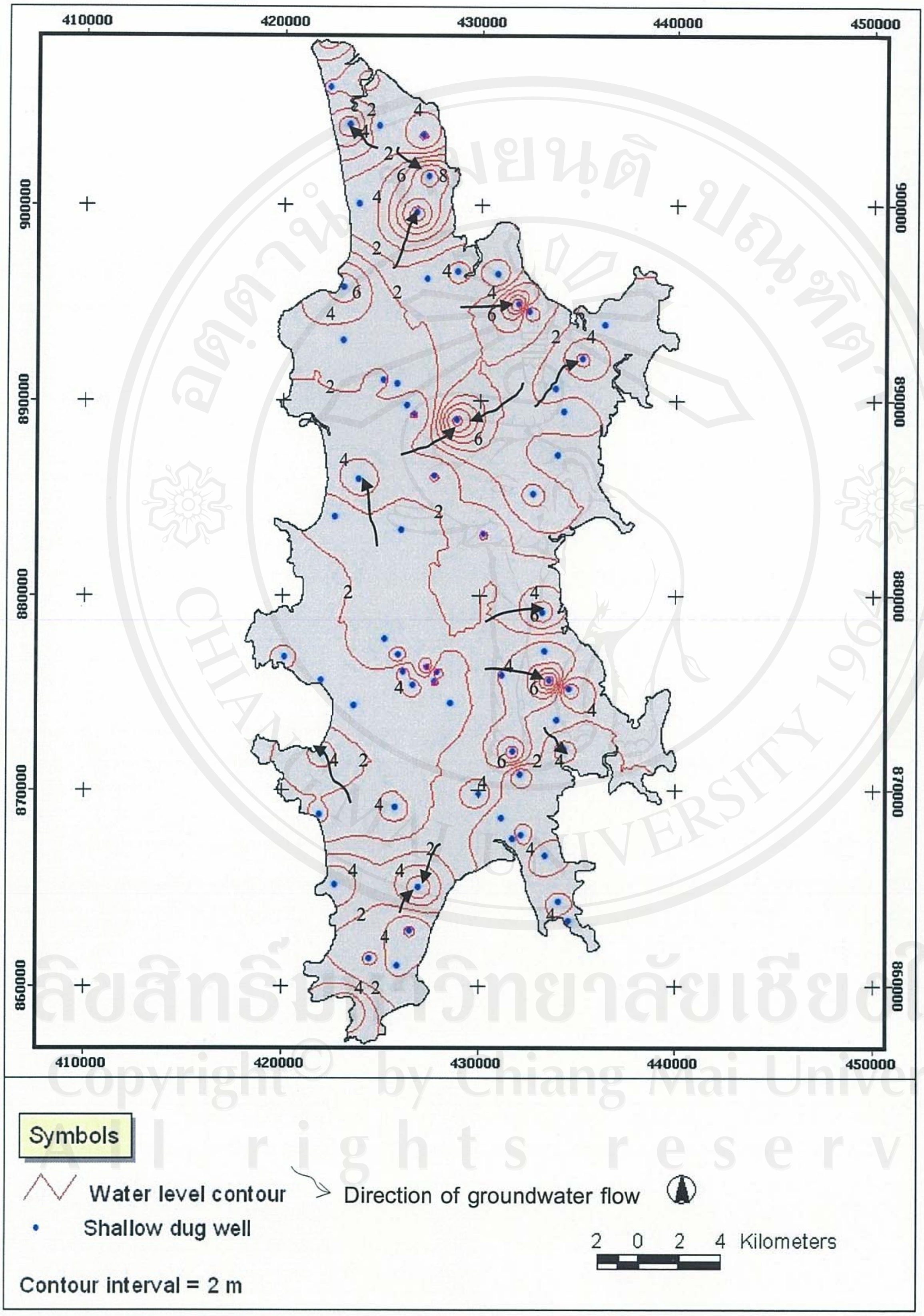

Figure 2.18 Contour map of the depth to water table from June to July, 2004.

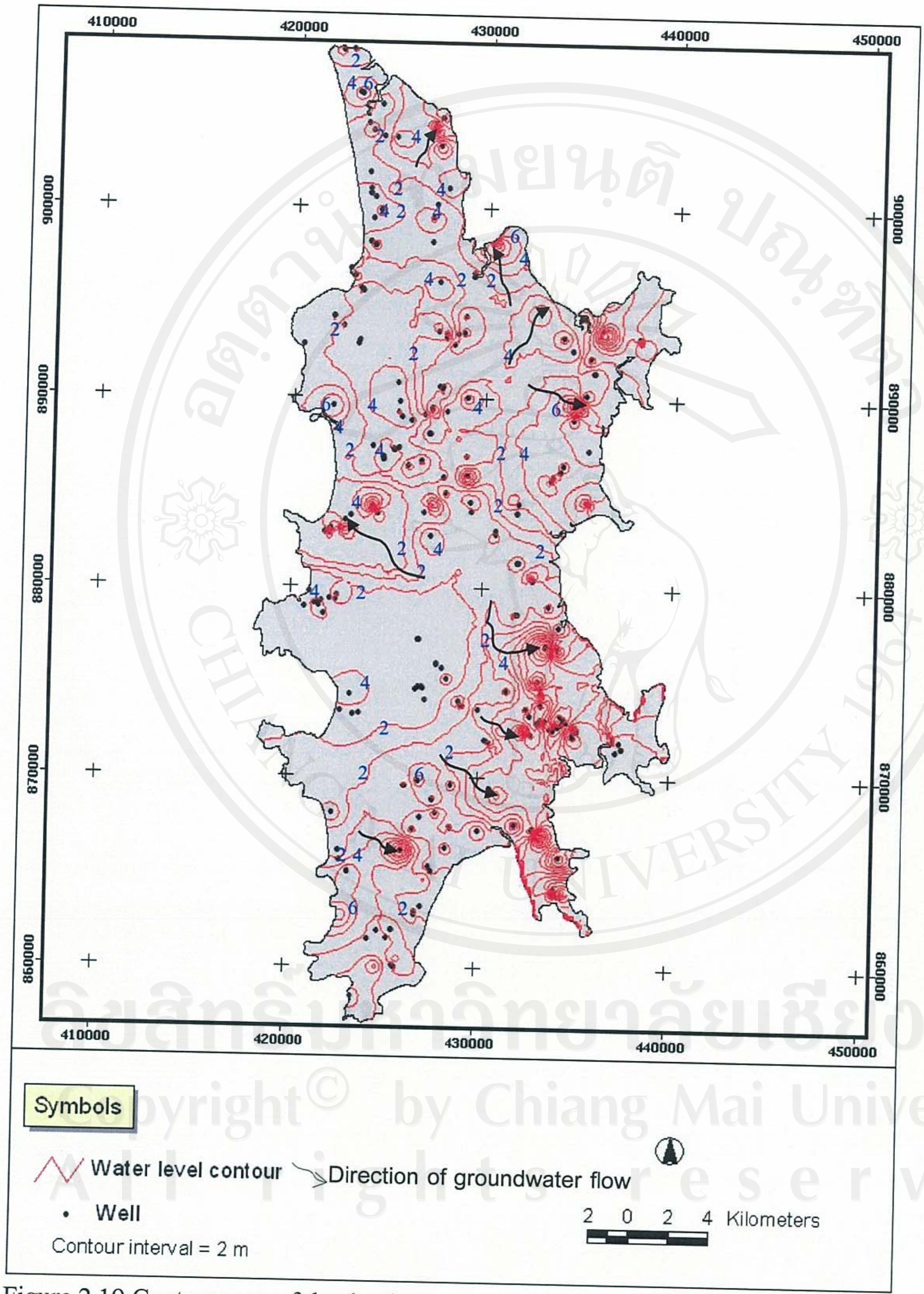

Figure 2.19 Contour map of the depth to water table (modified after Department of Mineral Resources, 2001).

2.5 Origin of groundwater

The knowledge of the origin and recharge process of groundwater is very important for preventing deterioration of water quality by pollution. All waters have "fingerprints" of naturally occurring isotopes that provide information about their origin. The fingerprinting tools are the ratios of stable isotopes of hydrogen from deuterium to hydrogen (D/H) and of oxygen-18 to oxygen-16 ($^{18}O/^{16}O$). The D/H and $^{18}O/^{16}O$ isotope ratios are highly conservative tracers for monitoring the origins and recharge process of water within the hydrogeology cycle. Because oxygen and hydrogen are the major constituents of water, it is practically impossible for their isotope ratios in water to change, except where there are substantial amounts of evaporation and/or mixing with significant proportions of water of different isotope ratio.

The ratios of stable isotopes may change in nature; this is known as isotope fractionation or separate into light and heavy fractions. For example, the stable isotopes of oxygen in rainfall "fractionate" across continents as a result of well-known meteorological processes such as temperature, and factors such as elevation and distance from the sea. If R is the ratio of the heavy isotope to the light one, then the relative fractionation is expressed in denotation as (Fetter, 1988):

$$\delta = \frac{R_{sample} - R_{standard}}{R_{standard}} \times 1000 \qquad (1)$$

If the value of δ is positive, the sample is enriched in the heavy isotope relative to the standard, a negative sample is isotopically light.

On the Earth, the oceans are the largest reservoir of stable isotopes. Therefore, the measured values of stable isotopes in seawater are used as standard values. In 1961, Craig found the ratios of D/H and $^{18}O/^{16}O$ are relative to the standard mean ocean water, SMOW. Isotopic ratios for hydrogen and oxygen isotopes are expressed in terms per mil deviation (‰) differences relative to the standard mean ocean water.

$$\delta^{18}O = \frac{(^{18}O/^{16}O)sample - (^{18}O/^{16}O)SMOW}{(^{18}O/^{16}O)SMOW} \times 10^3 \qquad (2)$$

and

$$\delta D = \frac{(D/H)sample - (D/H)SMOW}{(D/H)SMOW} \times 10^3 \qquad (3)$$

The relationship between δD and $\delta^{18}O$ concentrations in natural meteoric waters is plotted on a δD-$\delta^{18}O$ diagram. The general correlation of D and ^{18}O values of natural water follows the equation:

$$\delta D = a\delta^{18}O + d \qquad (4)$$

For water which have not been subject to evaporation the value of a is 8 and d is represents deuterium excess.

Based on the results of global investigation of the International Atomic Energy Agency/World Meteorological Organization (IAEA/WMO) can be determined a linear relationship between δD and $\delta^{18}O$ in rainwater. "Craig's meteoric relationship" (or line) is a linear correlation between δD and $\delta^{18}O$ of meteoric water defined by Craig (1961). This relationship can be expressed by the following formula:

$$\delta D = 8\delta^{18}O + 10 \qquad (5)$$

This linear function is known as the Global Meteoric Water Line (GMWL). Continental precipitation samples tend to group near to this line. Precipitation falling in areas of lower temperatures or at higher latitudes will have lower δD and $\delta^{18}O$ values. Naturally, oceanic water falls below the meteoric water line as it is isotopically enriched. Deviations from the meteoric water line can be interpreted as being caused by precipitation that occurs during a warmer or colder climate.

At the Research Institute of Materials and Resources, Mining College, Akita University, Japan; analyses of stable hydrogen and oxygen isotopes, deuterium and oxygen-18 were conducted on 31 water samples collected during June to July, 2004. The samples included of four rainwater samples, five river water samples, three old tin mine samples, and nineteen groundwater samples.

The process for determining hydrogen isotopes by the Zn closed tube reduction method (Coleman and others, 1982) was done such that water samples were converted to hydrogen gas through the reaction with zinc metal at the temperature of about 700 °C. Approximately 2 mg of water contained in a microcapilliary tube was dropped into a pyrex tube containing a few grains of Zn. The tube was attached to the vacuum line and was frozen in liquid N_2. Once a large enough batch of samples had been prepared, they were placed in a furnace at 700°C to reduce the water to H_2. The oxygen isotope was determined by the CO_2 equifibration method of Socki and others (1992) employing disposable pre-evacuated 5 ml. About 0.5 atmosphere of medical grade CO_2 was equilibrated with about 5 ml water for 6 hours at 25 °C. The sample with CO_2 was attached to the vacuum line, frozen in liquid N_2 and to reduce the water to O_2. After that, the D/H ratio of the hydrogen gas and $^{18}O/^{16}O$ ratio of the oxygen gas were measured with a mass spectrometer. The data of stable hydrogen and oxygen isotopes analysis are presented in Table 2.12.

Table 2.10 The stable hydrogen and oxygen isotopic data of 31 collected water samples.

No	Sample	Location	X	Y	Aquifer	δD	$\delta^{18}O$	d
Groundwater								
1	026W	Ban Laem Phanwa, Muang	0433873	0863888	PCms	-15.2	-2.5	4.8
2	060W	Ban Muang Mai, Thalang	0427353	0894295	PCms	-35.8	-5.7	9.8
3	030W	Ban Bo Rae, Muang	0431081	0867982	Qfd	-30.1	-5.2	11.5
4	087W	Ban Saiyuan, Muang	0424706	0861153	Qfd	-33.9	-5.9	13.3
5	052W	Ban Mai Khao, Thalang	0424050	0897984	Qbs	-33.0	-5.2	8.6
6	073W	Ban Ko Sire, Muang	0434123	0871371	Qbs	-22.7	-3.9	8.5
7	036W	Ban Kathu, Kathu	0427847	0874645	Qcl	-23.6	-3.6	5.2
8	041W	Ban Kuku, Muang	0433409	0874733	Qcl	-31.1	-5.2	10.5
9	043W	Ban Liphon, Thalang	0427793	0884677	Qcl	-28.3	-5.1	12.5
10	048W	Ban Phru Champa, Thalang	0425285	0889376	Qcl	-33.0	-5.4	10.2
11	049W	Ban Sakhu, Thalang	0423364	0891309	Qcl	-33.9	-5.6	10.9
12	055W	Ban Yit, Thalang	0423621	0901848	Qcl	-26.4	-4.9	12.8
13	065W	Ban Phara, Thalang	0432314	0892753	Qcl	-31.1	-5.4	12.1
14	070W	Ban Phak Chit, Thalang	0433763	0885697	Qcl	-33.0	-5.6	11.8
15	076W	Ban Tha Rua, Thalang	0430179	0881834	Qcl	-29.2	-5.1	11.6
16	079W	Ban Bang Thao, Thalang	0423026	0882693	Qcl	-27.3	-5.2	14.3
17	081W	Ban Kammala, Thalang	0420890	0878333	Qcl	-33.0	-5.2	8.6
18	083W	Ban Patong, Kathu	0423932	0873506	Qcl	-32.0	-5.3	10.4
19	086W	Ban Kata, Muang	0423077	0864751	Qcl	-33.0	-5.3	9.4
Surface water (S = Stream, M = Old tin mine)								
20	081S	Nam Tok Kathu, Kathu	0425375	0876900		-32.0	-5.6	12.8
21	082S	Nam Tok Ton Sai, Thalang	0429819	0887432		-26.4	-4.7	11.2
22	084S	Khlong Muang Mai, Thalang	0425382	0894275		-27.3	-4.2	6.3
23	087S	Khlong Bang Nao, Thalang	0431359	0892273		-25.5	-4.7	12.1
24	095S	Khlong Katha, Muang	0425381	0868898		-32.0	-5.4	11.2
25	072M	Ban Ket Ho, Kathu	0428488	0873805		-21.7	-3.6	7.1
26	078M	Ban Kak Kongsi, Muang	0432512	0874807		-7.7	-0.6	-2.9
27	080M	Ban Chalong, Muang	0425949	0868507		-31.1	-5.1	9.7
Rainwater								
28	001R	Ban Phru Champa, Thalang	0425993	0889156		-46.0	-7.2	11.6
29	010R	Ban Phru Champa, Thalang	0425993	0889156		-4.0	-0.7	1.6
30	011R	Ban Thungka, Muang	0430429	0874717		-23.6	-4.1	9.2
31	018R	Ban Thungka, Muang	0430429	0874717		-51.7	-7.2	5.9
Average deuterium Excess = 9.44								

Note: d (Deuterium Excess) = $8\delta^{18}O-\delta D$

Interpretation of the isotopic composition of precipitation in the study area can be made by comparing data with the Thailand meteoric water line. These data are available on the Internet in the framework of the global network of isotopes for precipitation, GNIP (International Atomic Energy Agency/World Health Organization, 2001). The δ-values of precipitation available for Thailand are from January 1968 to December 2000. The δD and $\delta^{18}O$ values are given in the form of mean monthly values. This study used the global network for isotopes in precipitation data for the Bangkok station in order to derive δD-$\delta^{18}O$ relationships and to u nderstand t he i sotopic c haracteristics o f t he T hailand p recipitation. U sing d ata Thailand precipitation data, this study defined the Thailand meteoric water line as follows (Kwansirikul, 2005):

$$\delta D = 7.53\delta^{18}O + 6.11, \text{ with } R^2 = 0.972$$

Figure 2.20 presents a plot of δD-$\delta^{18}O$ for Thailand meteoric water baseline and global meteoric water baseline. The Thailand meteoric water line deviates from the global meteoric water line of Craig (1961). This deviation probably reflects the partial evaporation of water as its fall through the atmosphere. Thailand's lower slope indicates evaporation under conditions of lower relative humidity. Figure 2.21 is shown plot of δD-$\delta^{18}O$ of groundwater from aquifer and surface water in the island.

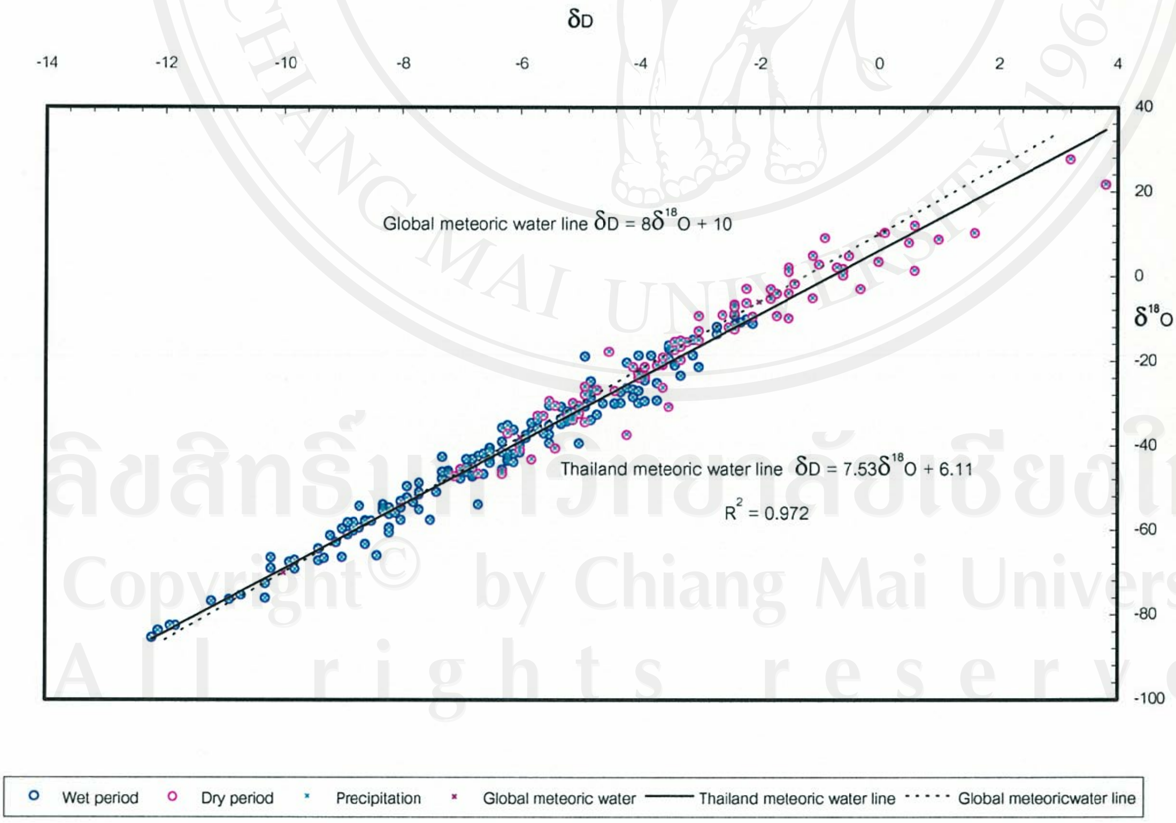

Figure 2.20 Plot of δD-$\delta^{18}O$ for Thailand meteoric water baseline and Global meteoric water baseline (Kwansirikul, 2005).

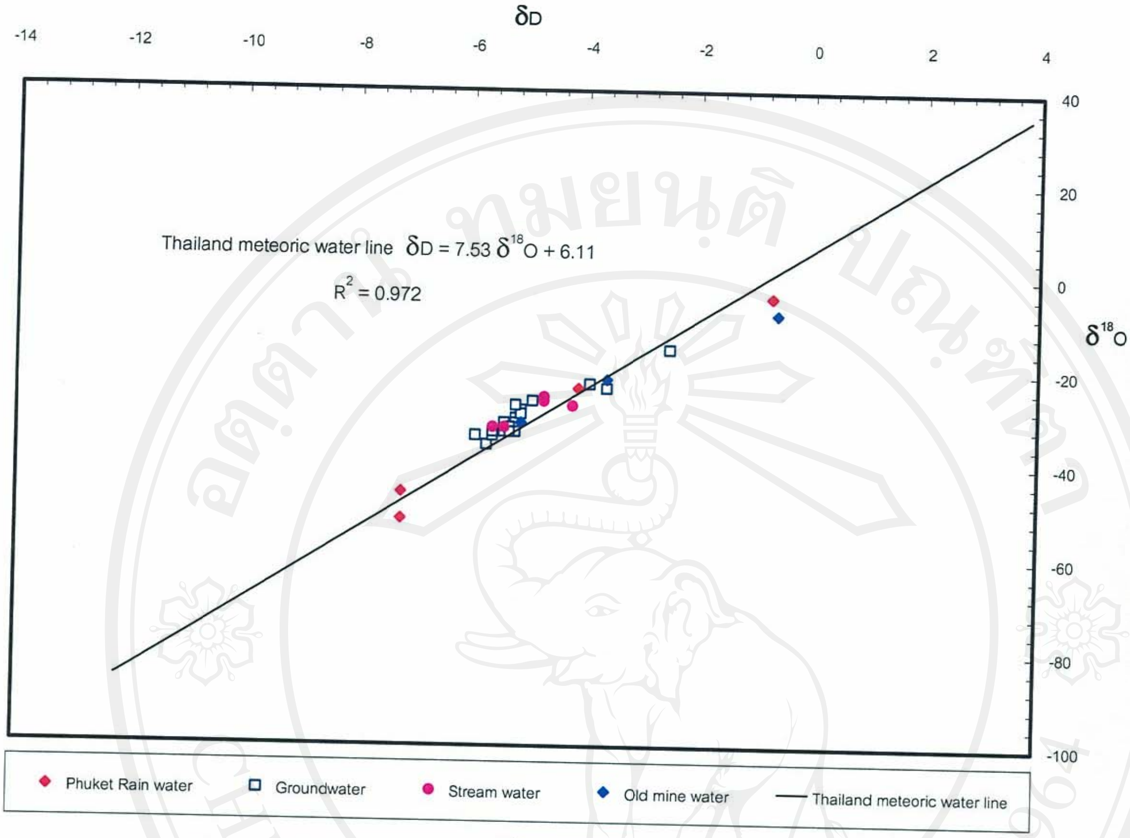

Figure 2.21 Plot of δD-$\delta^{18}O$ of groundwater, rain water, and surface water.

The trend and distribution of δD and $\delta^{18}O$ data points of Phuket rainwater, groundwater, stream water and old tin mine pits water follow the Thailand meteoric water line and the plot of the range of values of the isotopic composition in the wet season. The δD values of rainwater are -51.7 to -4.0 per mil and $\delta^{18}O$ values are -7.2 to -0.7 per mil. The groundwater δD values are -35.8 to -15.2 per mil and $\delta^{18}O$ values are -5.9 to -2.5 per mil. The stream water δD values are -32.0 to -25.5 per mil and $\delta^{18}O$ values are -5.6 to -4.2 per mil, while the δD values of old tin mine pits are -32.4 to -7.7 per mil and $\delta^{18}O$ values are -5.1 to -0.6 per mil.

This study suggests that Phuket island and Thailand's meteoric water have the same vapor source for rainfall. Therefore, this study did not define Phuket island meteoric water line. Instead, the Thailand meteoric water line was used as Phuket island meteoric water line.

From the isotopic determinations of groundwater samples, it can be seen that the isotopic composition of groundwater is close to that of precipitation in the wet season. The trend and distribution of groundwater δD and $\delta^{18}O$ deviates significantly from the Thailand meteoric water line, this deviation may reflect the evaporation of recharging water as it moves through the unsaturated zone.

The similarity between the isotopic composition of groundwater and the isotopic composition of the precipitation show that the groundwater recharges from local precipitation and infiltration into the groundwater system.

Surface water from streams and old tin mine pits are often in hydrologic connection with the groundwater system. The trend and distribution of surface water is enriched in heavy isotopes comparing to the groundwater. The old tin mine pits water have more heavy isotopes than the stream water that were collected at the same time. This suggests that the isotopic composition of surface water samples from the old tin mine pits water changes as a result of evaporation in the pervasive subtropical climate of Thailand. It is obvious that the old tin mine pits water is subject to strong evaporation.