CHARTER 2

HYDROGEOLOGY OF THE BANG PAKONG RIVER BASIN

2.1 Physical Settings

2.1.1 Topography

The Bang Pakong river basin is one of the 25 main river basins in Thailand and it is an important basin in the eastern region of Thailand. The area comprises two major physiographic features, highland and lowland. Tidal river with brackish water can reach up to 120 km upstream during the dry season when freshwater runoff is minimal. The western boundary of this basin is located at the distance about 60 km to the east of Bangkok, whilst the basin extent about more than 200 km connects to the nation border of Cambodia. The geography of the study area and its adjacent is characterised by generally flat to slightly undulating terrain of moderate relief, rolling landforms, and mountainous terrain of high relief, which the variation of elevation range from 0 to 1,351 meters above mean sea level (MSL), as shown in Figure 2-1. The majority of the basin area is a low plain with landslope of 2% or less covering approximately 33% of the total area, and is frequently subject to flooding. A relatively high water table is affected by seawater intrusion in the dry season resulting in brackish water during the months of January to April. In the northern part is composed of high mountains and highlands that lie in the direction of northwestern

and southeastern with gradually decreasing elevation from north to south. The plains cover extensively the central and western part of the basin which is ideal for rice cultivation and other farming activities. In contrast, the eastern and southern part of this basin is covered by rolling hills and lower-lying areas which is dominantly formed by colluvial and alluvial deposits whose slope is between 2 to 5%. The Bang Pakong river flows through this region from the northern highlands and discharge into the Gulf of Thailand in west.

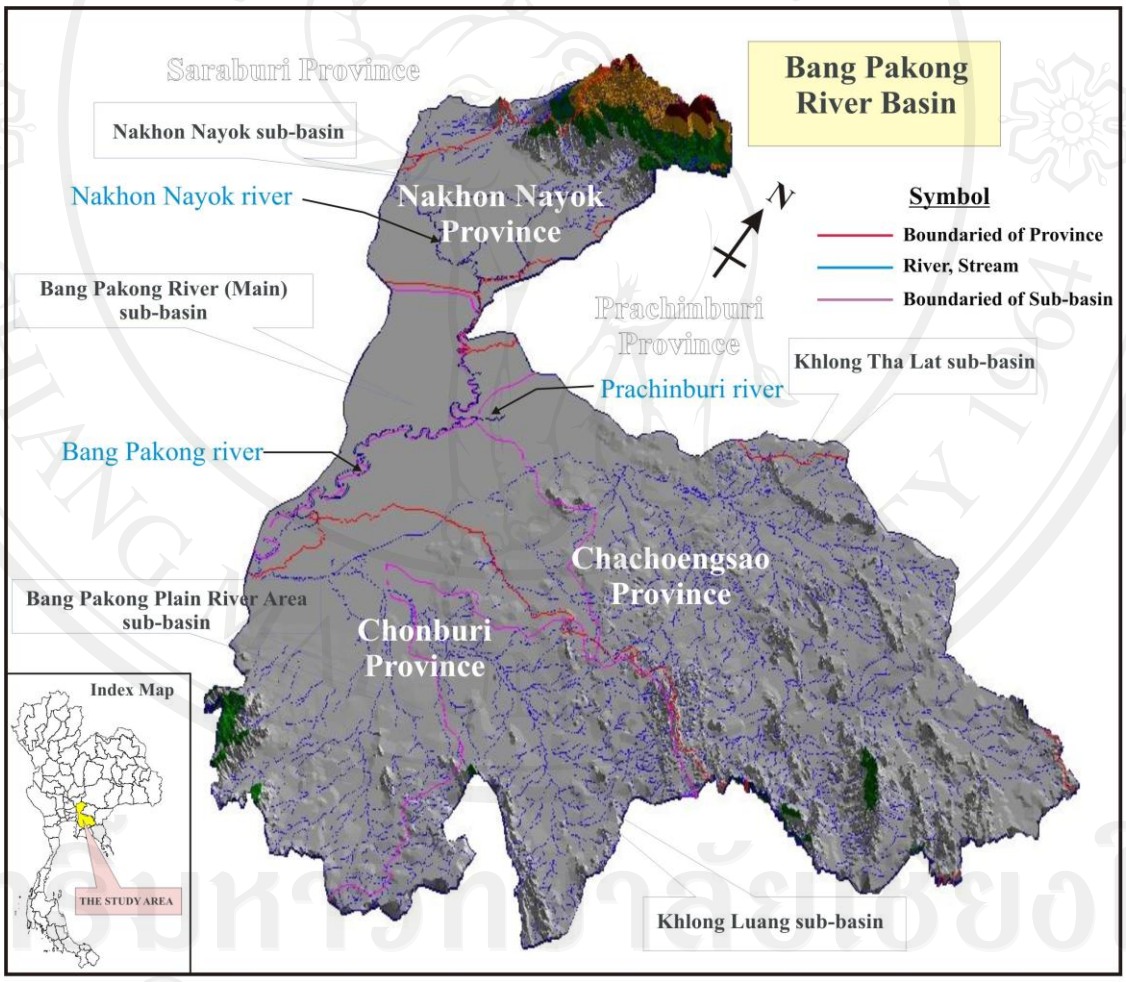

Figure 2-1 Geographic features and boundaries of the Bang Pakong river basin.

2.1.2 Hydrology

The basin has a drainage area of 18,500 square kilometers and has storage capacity approximately 131 million cubic meters. It consists of 5 sub-basin: Nakhon Nayok river sub-basin, Bang Pakong river Plain Area sub-basin, Bang Pakong river (main) sub-basin , Tha Lat canal sub-basin, and Luang canal sub-basin. Total catchment area is about 8,641 square meters (Figure 2-1). The drainage system in the area is dendritic. There are two primary tributaries of the Bang Pakong river; Nakhon Nayok and Prachin Buri rivers. Both of join at Ban Sang sub-district, southeast-west of the basin before it empties into the Gulf of Thailand. The other tributaries flow from the mountains in northern and eastern highlands to the plains in south and west. The main rivers run through the agricultural and urban areas of the basin into the Gulf of Thailand. Although it provides freshwater supplied along its length, brackish (salty) water reaches all the way upstream during the dry season due to tide causing chronic local seasonal shortage of freshwater.

Hydrological data of main rivers and tributaries were monitored and collected at 19 gage stations. Table 2-1 shows hydrological data of the Bang Pakong river basin. The mean annual runoff is 1,481.3 millimeters, mean annual effective storage volume is 8,653 million cubic meters, and mean annual yield is 17 liters per second. The major infrastructure of the basin is the Bang Pakong Diversion Dam which is designed to regulate the flow and reduce salinity intrusion during the dry season. The other minor infrastructures consist of Si Yat dam, Rabom reservoir, Lung reservoir, and Huai Pra reservoir.

2.1.3 Climate

The study area is influenced by a tropical monsoon climate where temperatures normally ranges from an average annual high of 38 °C to a low of 19 °C (annual mean 28 °C). There are three seasons: dry season, rainy season, and winter season. The dry season extends from February to May. During the dry season temperature rises

Table 2-1A Characteristic of the river and main tributaries in sub-basin. (from http://flood.dpri.kyotou.ac.jp/ihp_rsc/riverCatalogue/Vol_04/09_Thailand-7.pdf; *Last accessed: 10 October 2010*)

No	**Sub-basin name**	**Length, (km) Catchment area,(km^2)**	**Highest peak Elevation (m)**	**Major cities / district**
1	Nakhon Nayok river	114 2,543	Kead Mt. 1,351	Pakphli, Mueang district of Nakhon Nayok Province
2	Tha Lat canal	113 2,965	Yai Mt. 777	Sanamchikhet district of Chachoengsao Province
3	Luang canal	53 796	Chao Mt. 525	Bothong district of Chonburi Province
4	Bang Pakong river (plain)	134 2,400	Chompoo Mt. 732	Banbueng district of Chonburi Province and Mueang district of Chachoengsao Province
5	Bang Pakong river (main)	241 806	Kead Mt. 1,351	Chonburi, Nakhon Nayok, and Chachoengsao Provinces

Table 2-1B Characteristics of the sub-basin (DGR, 2006).

Sub-basin name	**Drainage Area (km^2)**	**Sub-basin**	**Range of recharge area (km^2)**	**Range of annual yield (cu.m./s-km^2)**
Nakhon Nayok river	2,086	13	12.00-627.20	21.56-48.81
Bang Pakong river (main)	1,366	3	4.00-1,242.00	6.00-7.48
Tha Lat canal	2,970	13	21.00-976.00	7.02-9.28
Total	**6,422**	**29**	**4.00-1,242.00**	**6.00-48.81**

Table 2-1C Hydrological data in the Bang Pakong river basin (DGR, 2006).

River Name/Station Name	**Station Code**	**Drainage Area (km^2)**	**Year**	**Annual runoff (cu.m./s)**		
				Averg.	**Max.**	**Min.**
1. Si Yat canal at Ban Tha Kloi	KGT 18	951	1969-1999	190.8	500.0	54.6
2. Rabom canal at Ban Cham Pa Ngam	KGT 25	243	1978-1989	44.1	123.9	19.1
3. Nakhon Nayok river at Khao Nang Buat	NY 1B	519	1978-1980, 1991-1999	314.9	535.0	172.0
4. Ban Na canal at Ban Pa Kha	NY 3	203	1978-1999	71.0	114.8	22.1
5. Samo Pun canal at Ban Haew Narok	NY 4	128	1986-1999	232.8	389.5	74.0
6. Tha Dan canal at Ban Si Suk	NY 5	186	1986-1990	296.8	615.8	159.3
Average				**191.7**	**379.8**	**83.5**

dramatically in the second half of March, spiking to well over 40 °C. The rainy season takes over from June to October when the south-west monsoon sweeps across the Indian Ocean to drench the study area. Finally, during November to January when the northeast monsoon brings cooler and weather from China resulting in winter with the coldest months are in December and January.

The average annual rainfall is about 1,334.2 millimeters, with the mean monthly rainfall ranges from 4.4 millimeters in December to 264.5 millimeters in September. Most of the rain is caused by the regular south-west monsoon winds but smaller portion falls in the form of very intense torrential from tropical storms. The monthly mean evaporation is 101.83 millimeters, with the mean evaporation varies from a minimum 79.67 millimeters in February to a maximum 130.16 mm in April (Figure 2-2). The mean relative humidity is 71 %, with a minimum average humidity is 63 % in January to a maximum 79 % in September.

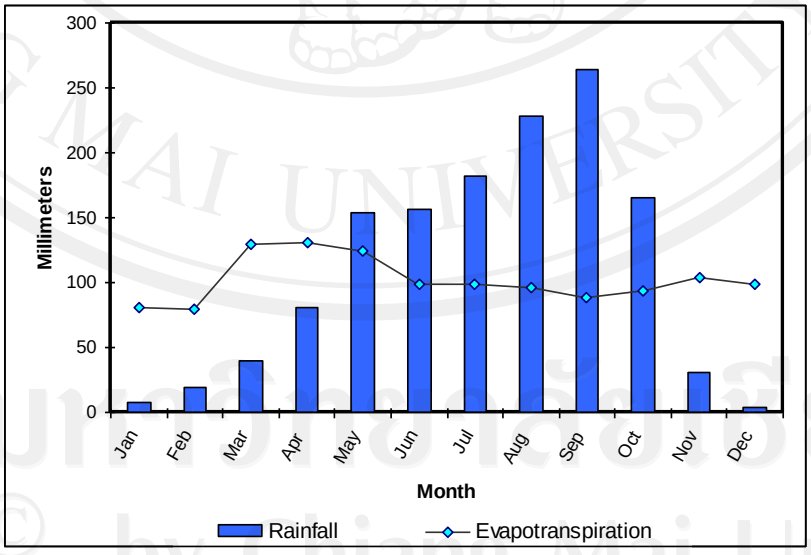

Figure 2-2 Distribution of average rainfall and average evaporation for the period 30 years (1977-2006) from 35 stations in the Bang Pakong river basin.

2.1.4 Landuse

This basin comprises of the most important productive agricultural area including paddy field, farmlands, orchards, aquacultures, and industrial area. The previous studied of DGR (2006) classified the Bang Pakong river basin into five groups based on landuse and soil maps which it consists of forest, agricultural, grassland, urban area, and water resources as shown in Figure 2-3, Table 2-2 summarizes the basin's landuse in the study area.

2.2 Geologic Setting

The study area is partly underlain by the rocks of inferred Precambrian, Ordovician, Premo-Carboniferous, and Quaternary superficial deposits. The igneous rocks represented by the Triassic-Jurassic granitic batholith distributing in the central part of the study area, and some scatted outcrops along the coast line. Generalized geological map of the area is shown in Figure 2-4A and geologic cross-section is illustrated in Figure 2-4B. The inferred Precambrian rocks are restricted to the eastern part, and comprise mainly of gneisses, amphibolites, calc-silicate rocks, and schists. The western part composed of the Ordovician sedimentary, metasedimentary rocks, and their metamorphic equivalents. These are characterized by the interbeded sequence of sandstones, siltstones, shales, mudstones, cherts, quartzite, schists, phyllite, phyllitic shales, slate, slaty shales intercalated by argillaceous and dolomitic flaser limestones, marbles, cala-silicate rocks, spotted slates, and hornfelses. Only a limited portion of Permo-Carboniferous rocks comprising of sandstones, pebbly sandstones, conglomerates, tuffaceous shales, and cherts are confined to the most eastern part of the study area. The rest of the area is occupied by the Quaternary

Table 2-2 Landuse category of the Bang Pakong river basin (DGR, 2006).

Group Name	Land use code	Description	Area (km^2-%)
Agricultural Land	A	- Rice paddy field, Corn, Farm, Sugar cane, Irrigation areas, Plantation, Rubber tree, Horticultural land, Orchard, Agricultural land - Alluvial, Colluvium, Flood plains - Discharge area - Low hydraulic conductivity	6,085.1-70.70
Forest Land	F	- Forest, Rangeland, Deciduous forest , Evergreen forest - Mountain ranges, hills, highlands - Recharge area - High to moderate hydraulic conductivity - Deep slope	1,797.8-20.89
Grassland or Barren Land	M	- Grassland, Shrub rangeland, Barren land, mining waste, mining pit, fallow area, rock quarries, old quarries - Colluvium/Alluvial rims, hills, low to high terrain - Local recharge area - High to moderate hydraulic conductivity - Gentle slope	59.1- 0.69
Urban Land or Built-up Land	U	- Urban or build up land, Industrial, Commercial and services, Transportation and communication - Alluvial plains, Flood plains - High Evapotranspiration - Barrier of recharge and discharge area - flat to rather flat land area	572.6-6.65
Water resources	W	- Dam, Lake, River, Canal, stream, Reservoir, Wetland - Alluvial plains, flood plains - Discharge area - Low hydraulic conductivity - Gentle slope	92.2-1.07

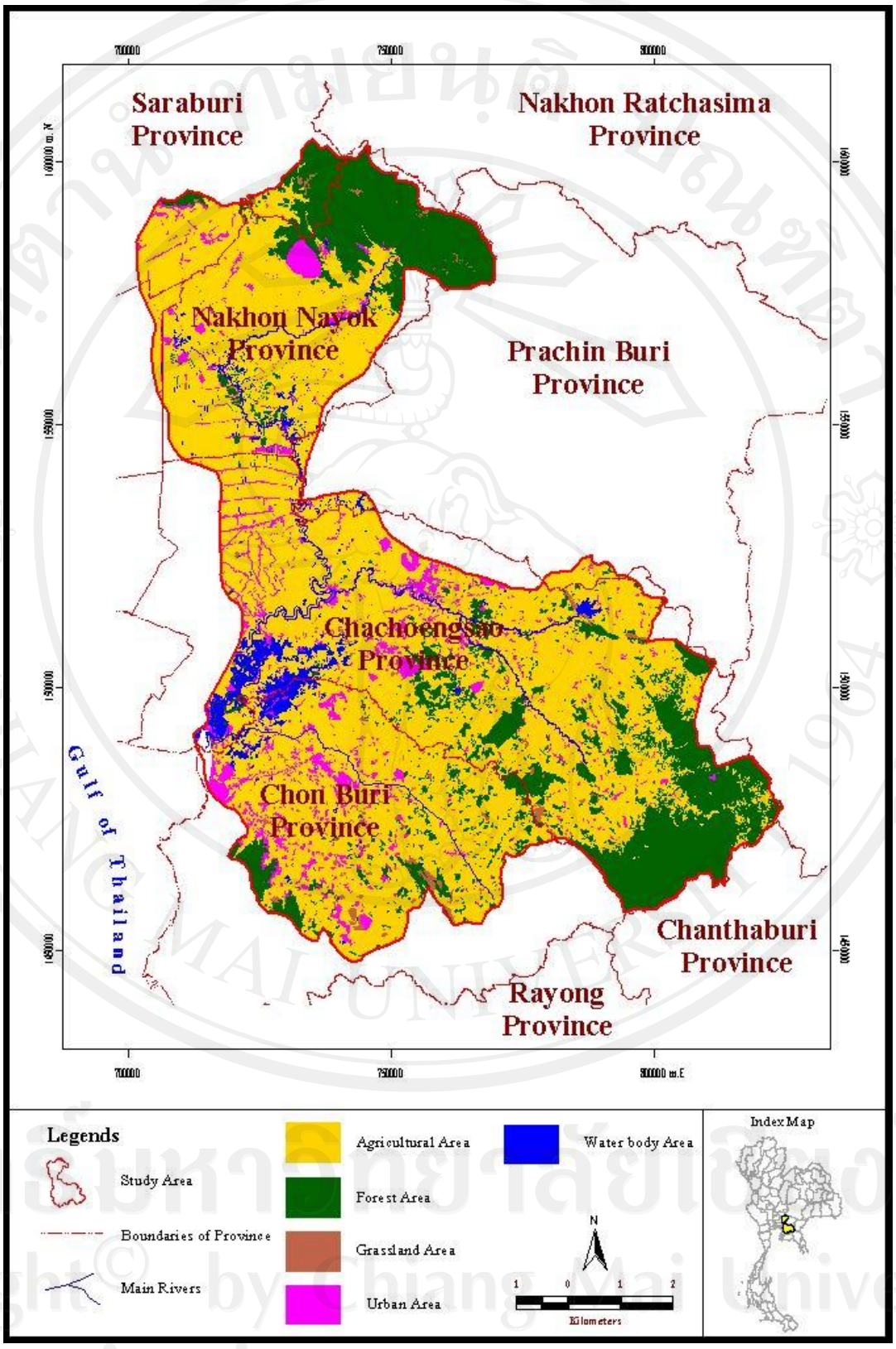

Figure 2-3 Landuse map of the Bang Pakong river basin.

deposits which consist pre-dominantly of unconsolidated clastic sediments of fluvial and marine origins. Most of the sediments are deposited in the intermountane and coastal plains. The lower part of the sequence is characterized by high and low terrace deposits, laterites, fluviatile and marine gravels, sands, silts, and clays, whereas the upper part comprises mainly of alluvium and beach sands. Structurally, the fold N-S and NE-SW regional trend of the Ordovician rocks appear as roof pendant of the granitic rocks (Sarapiome et al., 1983).

The geology of the study area and its surroundings can be separated into two groups with has a cover of unconsolidated sediments and is underlain by consolidated rocks which have been divided into ten units. Brief descriptions of the units from young to old are described below:

(1) Precambrian rocks: Pε; It underlies in the central and occurs along the southern rim of the study area, which are forming great relief and steep slopes. They comprises mainly of the medium to high grade metamorphic rocks including orthogneiss, paragneiss, schist, quartz mica schist, calc-silicate and marble of amphibolite facies, and micaceous pegmatite. Generally it forms in disseminated aggregate or in large and small lenses is commonly observed and can been seen foliations also parallel to the NW-SE Three Pagoda fault zone.

(2) Silurian-Devonian rocks: SD; It consists mainly of phyllite, carbonaceous phyllite, and siliceous phyllite which is commonly exposed contact to Precambrian rocks along southern rim of the basin.

(3) Devonian-Carboniferous rocks: DC; It consists mainly of chert, tuff, limestone, and volcanic rocks, that was most subject to metamorphism. This unit

located along the edge of eastern part boundary of the basin i.e. lower part of Srimahaphol district and Mueang district in Prachin Buri Province.

(4) Carboniferous rocks: C; This unit can be divided into two formations ranging in age from Lower to Middle Carboniferous (C1 formation) and the other one formation ranging in age Upper Carboniferous (C2 formation). The C1 formation consists mainly of siliceous sandstone, silty shale, limestone, and chert with exposed contact to granite rock in Triassic age and volcanic rock in Permian age. The rocks of the C1 formation are localized and only detected around in Thatakeab district in Chachoengsao Province. The C2 formation were metamorphosed sedimentary rocks, consists mainly of phyllitic conglomerate, phyllite, recrystalline tuffaceous sandstone, shale with it is partly intercalated by Precambrian rocks at the southern part of the study area.

(5) Permian: P; This unit exposed in this area namely Saraburi Group (P_S-2) which contains clastic and non-clastic rocks. The group consists of 6 formations (Hinthong et al., 1985) in ascending order as Phu Phe, Khao Khwang, Nong Pong, Pang Asok, Khao Khad, and Sab Bon Formations. It consists mainly tuffaceous sandstone, sandstone, siltstone, limestone, and chert including rhyolite dike. Parts of limestone were locally metamorphosed to be marble and calc-silicate hornfels due to igneous intrusions. It occurred at rim eastern of the basin with contacted with Devonian-Carboniferous rocks and volcanic rocks in Permian-Triassic age.

(6) Triassic rocks: Tr; Triassic sequence in the study area consist of two formation, in ascending as Pong Nam Rong Formation (T_{RPN}) and Noen Phuyai Yua Formation (T_{RN}). Chaodumrong (1994) interpreted these rocks as having been deposited in submarine fan environments consisting of 4 lithofacies. The Pong Nam

Ron Formation, more than 200 meters thick, consists mainly of thick to massive bedded, dark gray feldsparthic greywacke, conglomerate and mudstone. Most of clasts are rounded and of vocalnics and Permian limestone origin. Graded bed can be seen in both sandstone and conglomerate. In general, grain size decreases westward. It expanded at the eastern part of the study area. The Noen Phuyai Yua Formation, 300 meter thick, contains mostly interbedding of thin to medium bedded, gray to dark gray sandstone and mudstone. Beds are even and parallel type with very good lateral continuity. Sandstone overlies mudstone with shape and planar contact. Mudstone increases in proportion up sequence and in general, grain size decreases westward.

(7) Jurassic rocks: J; They were named as Khorat Group consisting of 9 formations, in ascending order as Huai Hin Lat, Nam Phong, Phu Kadung, Phra Wihan, Sao Khua, Phu Phan, Khok Kruat, Mahasarakham, Phu Tok Formations . The study area only has Phu Kadung Formation (Jpk), mainly of maroon micaceous siltstone, mudstone, sandstone, and conglomerate. Sandstone shows less calcareous and less micaceous than siltstone. Lenses of fine-clast conglomerate with calcareous cement are often associated with sandstone throughout the unit. Clasts can be limestone, siltstone, granite, volcanics and caliche. The unit is conformable to the underlying Nam Pong Formation and partly floored as the base of the Khorat Group. The Jurassic rock occurred along the rim eastern of the basin at Pakpli district in Nakhon Nayok Province.

(8) Jurassic-Cretaceous rocks: JK; Jurassic to Cretaceous continental red beds crop out extensively in southern part of basin. This unit exposed along the mountain ranges in southern part of Khlong Rabom Reservoir at Sanamchaiket district in Chachoengsao Province and Pakpli district in Nakhon Nayok Province.

Phra Wihan formation (JKpw) conformably overlies the Phu Kradung formation. This unit is characterized by pale-gray and white sandstone, and subordinate intercalated maroon and reddish brown siltstone, mudstone and conglomerate. Rocks show thin to thick beds with cross lamination and fine-pebble orientation particularly in sandstone beds. Small amount of calcareous cement and mica content exist in sandstone and less mica in siltstone. In general, depositional environments of the competent beds of Phra Wihan and Phu Phan formations were interpreted as having been deposited in briaded stream of fluvial environment, while the incompetent beds of. Phu Kadung, Sao Khua and Khok Kruat formations were deposited in meandering river and flood plain environments (Heggemann et al., 1994; Meesook, 2000; Sattayarak et al., 1997).

(9) Quaternary: Q; The unconsolidated deposits within this area are catergorized into four major types namely; coastal plain deposits, residual/landslide and colluvial deposits, terrace deposits, and alluvial plain deposits. All have been deposited with high accumulation rates during the Quaternary age between 1.6 million to present. Brief descriptions of the units are as follows:

- ***The coastal plain deposits: Qmc*;** It includes beach, dune, estuarine, and tidal flat deposits. The deposits having thickness of 5 and 20 centimeters is loamy sand to loamy coarse sand, while the deeper subsoil is medium to very coarse sand, sandy loam to loamy sand in the depression. Those textures of the surface soil of the estuarine and tidal flat deposits are characterized by clay and silty clay, respectively.

- ***The residual/landslide and colluvial deposits: Qc*;** This unit is subdivided on the basis of parent materials, mostly of sediments and metasediments,

schist and quartzite, granitic and gneissic rocks. Generally, the texture of the deposits vary form gravelly to sandy clay.

- ***The terrace deposits: Qt;*** These units consist of sand, clay, laterite, and rounded gravel, ranging in size from granule (2-4 millimeters) up to boulder (1 meter). These units are found in the hilly area. High terrace deposits consist of quartz, sandstone, and volcanic rock e.g. andesite, rhyolite, agglomerate and tuff. Pyroclastic fragments are highly weathered and decomposed to clay and combine high resistant grains together.

- ***The alluvial plain deposits: Qa;*** This unit comprises of floodplain and channel, alluvial fan, terrace, and valley-filled deposits. Sediments of the alluvial deposits are essentially derived from granitic and gneissic rocks. The prominent grain texture of the sediments is represented by free silica silt and fine sand. Except in floodplain deposits can generally found silt and clay. However, the floodplain and channel deposits show surface soil texture at the depth of 10-30 centimeters as clay loam, sandy clay loam.

(10) Igneous rocks: Trgr or **PTrv;** This unit occurs as major batholiths and large complex plutons of restricted compositional range and commonly associated with gneissic granite and migmatites. They are S-Type granites, mainly of Triassic age and tin-tungsten mineralization. These rocks can be separated using their rock type into two groups. These are porphyritic biotite granite and equigranular porphyritic granite (Trgr) of Triassic age, and volcanic rocks (PTrv) in Permian age. The granite units are white to light gray in color, medium to coarse grained, equigranular to porphyritic texture, consists of porphyritic biotite-muscovite granites, granodiorite, muscovite-tourmaline granite, tourmaline granite, and muscovite

granite. It formed high mountains in the southern at Bothong district, Banbung district, Panusnikhon district, and Thatakeab district in Chon Buri Province, and Plangyao district and Sanamchaiket district in Chachaengsao Province. Volcanic rocks found in the north also formed high mountains and in small area in the south. There are two lithological facies of volcanic rocks: pyroclastic rocks and lava flow. Pyroclastic rocks are tuff, pyroclastic flow tuff, ignimbrite, block and ash flow. Lava flow is andesite, reachitic-andesite, rhyolite, and rhyodacite.

2.3 Hydrogeologic Setting

2.3.1 Hydrogeology of the Study Area

(1) Hydrogeological Conditions

The study area consists of unconsolidated aquifers and consolidated aquifers. The unconsolidated aquifers appear in the central area whereas the consolidated aquifers appear in the north, south, and in the north-east (Figures 2-5A and B). Unconsolidated formations and hard rocks in the basin are classified based on the water-bearing properties which resulted in different hydrolgeological units or aquifers. The description of water-bearing properties of aquifers are described below (DGR, 2006):

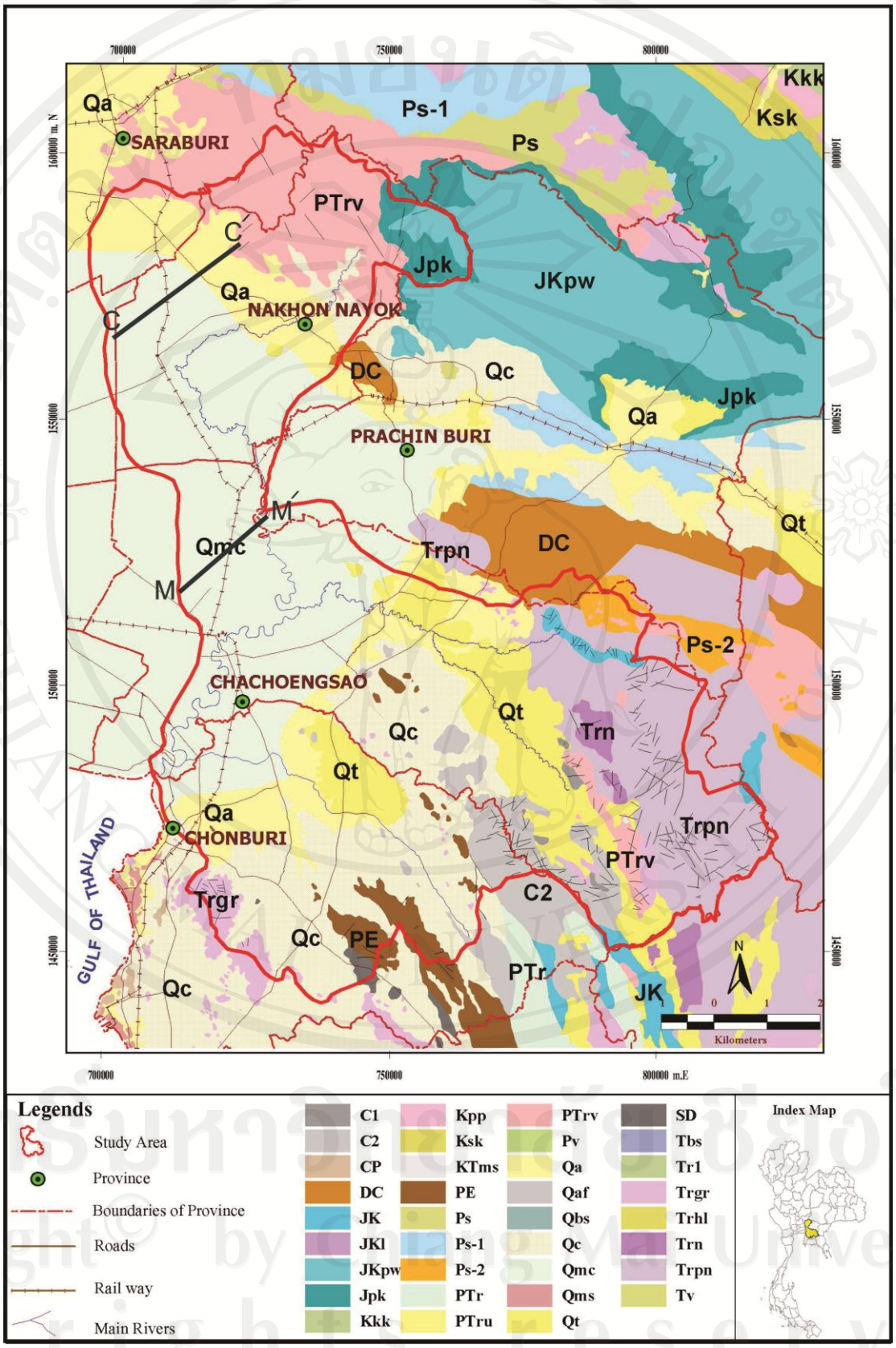

Figure 2-4A Geological map of the study area**.**

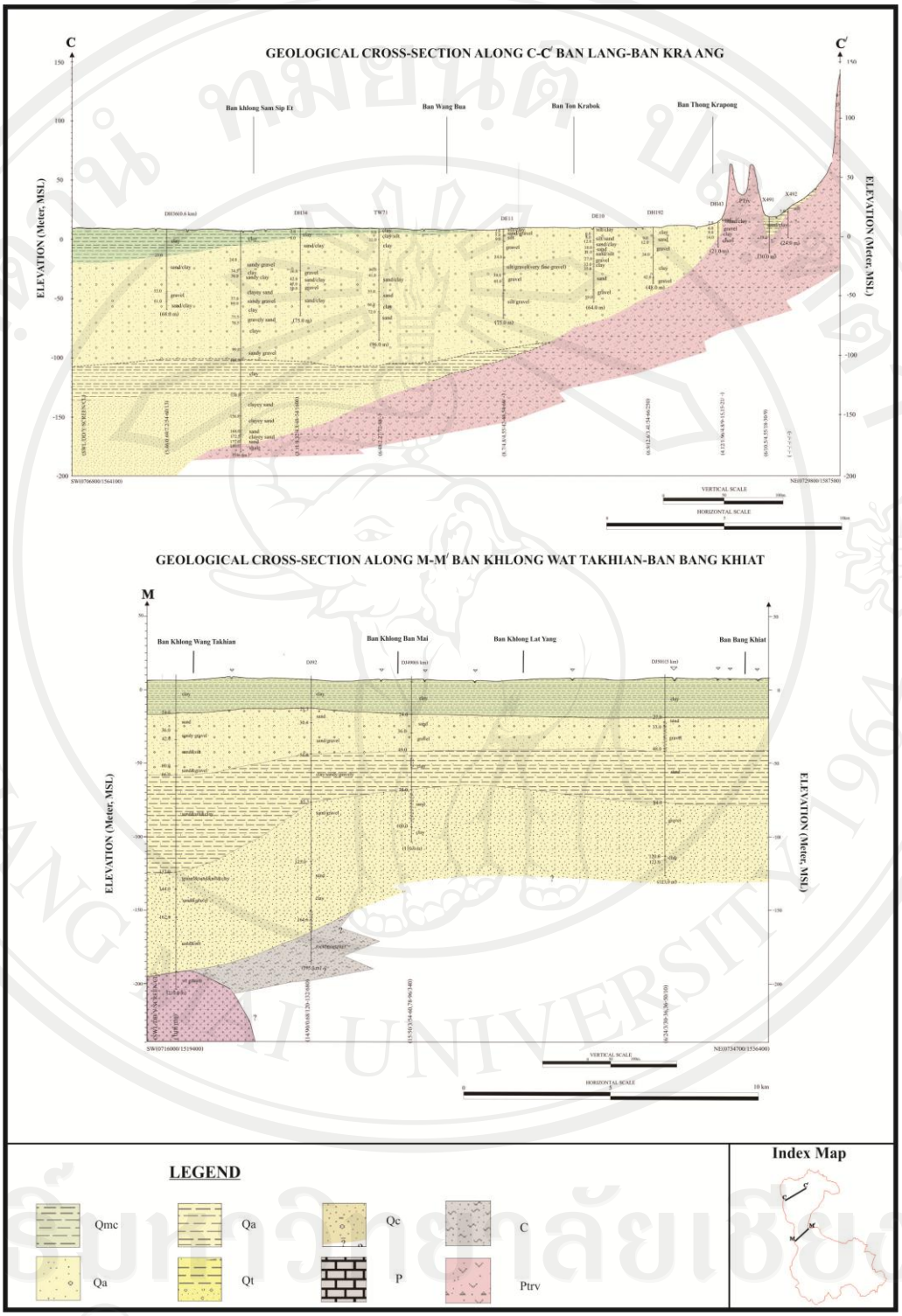

Figure 2-4B Illustration of two-dimensional of stratigraphical section of the study area, cross-section number C-C′ and M-M′ (Adapted from DGR, 2006).

(I) Unconsolidated Aquifers

Groundwater accumulates between pore spaces of gravel, sand, silt, rock fragments, and clays which are loosely cemented. These sediments have been transported and deposited by wind, river or the sea. In general, groundwater is occurred in intergranular pores of material but the capacity of groundwater being stored in the sediments depends on thickness of aquifer, assortment of material, shape or roundness of grains. There are three unconsolidated aquifer in the study area as follows:

- ***Floodplain Aquifer: Qfd*;** This water bearing rock is composed of gravel and sand interbedded with silt and clay. It is predominated by the deposition of clayey sand and clayey gravel transported under medium to low energy conditions by the Nakorn Nayok River and Bang Pa Kong River. The groundwater is trapped within the pore spaces of gravel and sand, which is deposited on the floodplains, meandering belts, old channel fills, delta and marine sediments. The average thickness of this unit is between 30-100 meters whereas the thickness is in the central of the basin more than 200 meters. Depth to aquifer is commonly in the range of 50-100 meters. This type of aquifer is present in some parts the areas of Ongkkharak district, Ban Na district, and Muang district in Nakhon Nayok Province, Khlongkuan district, Sanamchaiket district, Thalat district, Plangyao district, Ratchasan distric, Bangnampraw district, and Banpol district in Chacheangsao Province. This aquifer covers both sides of the main rivers including their tributaries. The well yield is 2-10 cubic meters per hour, but in some places this may be up to more than 20 cubic meters per hour.

- ***Terrace Aquifer: Qt;*** The terrace aquifer is fluvial deposits comprising of the majority of clay, silt, sand, and gravel in lowlands and terrian of the basin. The average depth of aquifer is 20-80 meters and average yield about 5-10 cubic meters per hour. It can be divided into two units as follows:

(a) *Young Terrace Aquifer: Qyt*; This aquifer is composed of coarse gravel, sand, silt and clay, overlain by young floodplain deposits and marine sediments. Groundwater accumulates between pore spaces of sand and gravel. Depth to aquifer is commonly in the range of 20-70 meters and the average thickness of this unit is between 30-70 meters. The well yield is 2-5 cubic meters per hour, but in some places this may be more than 10 cubic meters per hour. This unit is found in some part the area of Panomsarakham district, Thatakeb district, and Plangyao district in Chacheangsao Province.

(b) *Old Terrace Aquifer: Qot*; This aquifer is composed of coarse gravel, sand, silt, clay, and laterite which occurred in the foothill terraces. Groundwater is stored between pore spaces of gravel and sand, overlain by young floodplain deposits and marine sediments. Depth to aquifer is commonly in the range of 30-50 meters and the average thickness of this unit is between 10-30 meters. The well yield is 5-10 cubic meters per hour, but in some places this may be less than 5 cubic meters per hour. It is found in some parts the area of Ban Na district , Muang district, and Pakpli district in Nakhon Nayok Province.

- ***Colluvium Aquifer: Qcl***; This water bearing sediment consists of pebble, cobble, gravel, sand, rock fragments, and clay. It is poorly sorted with angular to sub-angular fragments. Groundwater is stored between pore spaces of sand, gravel and rock fragments at the foothill and the high terrain closed to mountainous area,

which is not widely extend. Depth to aquifer is commonly in the range of 10-30 meters and aquifer thickness ranges from 10-30 meters, yielding fresh water of 2-5 cubic meters per hour. This aquifer is occurred in some parts of Panus Nikhon district in Chon Buri Province.

(II) Consolidated Aquifers

Groundwater can be generally stored in the consolidated rocks in both primary pore space and secondary opening, including joints, fractured, faults, and bedding plains. The water-yielding properties vary widely depending on size and continuity of these opening. These aquifers can be divided into sedimentary, meta-sedimentary and igneous aquifers, with details as follows:

(a) Sedimentary Aquifers

The sedimentary aquifer in this area is classified as follow:

- ***Middle Khorat Aquifer:*** **Jmk;** comprises maroon micaceous siltstone, mudstone, sandstone, and conglomerate. Lenses of fine-clast conglomerate with calcareous cement are often associated with sandstone throughout the unit. It is equivalent to Phra Wihan Formation and Phu Kadung Formation that were deposited in meandering river and flood plain environments . In Nakhon Nayok Province these units are mostly found in the highly areas. Generally,depth of aquifer is commonly in the range of 10-100 meters, the well yield is 2-10 cubic meters per hour.

(b) Meta-sedimentary Aquifers

The meta-sedimentary aquifer in this area is classified as follow:

- ***Carboniferous meta-sediment aquifer:*** ***Cms;*** The aquifer is consisted of tuffaceous sandstone, graywake sandstone, shale, limestone**,**

conglomerate, and bedded chert. Depth of aquifer is commonly in the range of 10-50 meters, the well yield is 2-5 cubic meters per hour. This unit is occurred in western part of Sanamchaiket district and Thatakeb district in Chachaengsao Province.

(c) Metamorphic Aquifer

The metamorphic aquifers in this area found into two units, it is classified as follow:

- **Silurian-Devonian Metamorphic aquifer: SDmm;** This unit is consisted of silty shale, limestone, phylitic conglomerate, and phyllite which is contacted with Granite rocks in Triassic age. Generally, depth of this unit is in the range 40-60 meters, the well yield is 2-5 cubic meters per hour. It found in Sanamchaiket district and Thatakeb district in Chachaengsao Province.

- **Precambrian Metamorphic aquifer: PEmm;** This unit is consisted of paragneiss, orthogneiss, schist, quarts mica schist, calc-silicate and marble of amphibolite facies, and mica pegmatite. Generally, depth of this unit is in the range 20-60 meters, the well yield is 2-5 cubic meters per hour. It found in Bothong district, Banbung district, and Nongyai district inChon Buri Province.

(d) Igneous Aquifers

Igneous aquifer in this area can be divided into two units it comprises of volcanic aquifer and granitic aquifer as follow:

- ***Granitic aquifer: Gr;*** This unit is consists of medium to coarse grained, equigranular to porphyritic texture, consists of porphyritic biotite-muscovite granites, granodiorite, muscovite-tourmaline granite, tourmaline granite, and muscovite granite. Generally, depth of this unit is in the range 20-90 meters that

occurs in faults, factures, and weather zone, the well yield is 2-5 cubic meters per hour. It found in some part of Panusnikhom district in Chon Buri Province.

- ***Volcanic aquifer: Vc***; This unit is consists of rhyolite, andesite, tuff, and agglomerate, which is exposed in relatively small hill and mountain range. The depth to the aquifer is in the range of 20-60 meters. The well yield is usually 2-10 cubic meters per hour. It is found at Ban Na district, Muang district and Pak Phli district in Nakhon Nayok Province.

(2) Hydraulic properties of aquifers

All of hydraulic properties values of aquifers can be determined by a pumping test which was evaluated from pumping test 249 groundwater wells (DGR, 2006). Pumping tests gave most transmissivity values of 0.30 to 50.0 m^2/day, hydraulic conductivity values from 0.03 to 10.0 m/day and storage coefficient values between 0.003 and 0.01 for unconfined aquifers. The confined aquifers have most of ranging of transmissivity values between 0.50 to 50.0 m^2/day, hydraulic conductivity values from 0.07 to 10.0 m/day and storage coefficient values were between 0.001 and 0.007. In Table 2-3 are given the values of the hydraulic properties for each hydrogeologic material in Bang Pakong river basin.

Table 2-3 Summarizes the hydraulic properties for each hydrogeologic material (Source; DGR, 2006).

No	Hydrogeologic unit	Range of hydraulic properties values from pumping test		
		Hydraulic conductivity, K (m/day)	Transmissivity, T (m^2/day)	Storativity/Specific yield, S
1	Floodplain aquifer (Qfd)	0.22-11.67	0.67-76.90	0.0000953-0.132
2	Young terrace aquifer (Qyt)	0.037-10.89	0.23-65.33	0.000359-0.129
3	Old terrace aquifer (Qot)	0.037-10.89	0.23-65.33	0.000359-0.129
4	Colluvium aquifer (Qcl)	0.0243-4.49	0.75-61.13	0.00035-0.47
5*	Middle Korat aquifer (Jmk)	0.216-14.7	1.30-88.80	0.0233-0.137
6	Pong Nam Rong aquifer (Trpn)	0.0756-7.15	0.45-59.50	0.00844-0.246
7	Carboniferous meta-Sediment aquifer (Cms)	0.0694-0.450	0.42-2.70	0.000624-0.0759
8*	Silurian-Devonian Metamorphic aquifer (SDmm)	0.0756-7.15	0.45-59.50	0.00844-0.246
9*	Granitic aquifer (Gr)	0.078-1.26	0.47-7.55	0.0166-0.0632
10*	Volcanic aquifer (Vc)	0.0829-11.97	1.58-36.0	0.0233-0.137
11	Precambrian metamorphic aquifer (PEmm)	0.0861-11.67	0.52-69.93	0.000195-0.857

***Note**: * However, values are quite different one point to others because of lack of data from pumping tests and little data is available on hydraulic conductivities from pumping tests evaluations.*

(3) Groundwater Potential

The groundwater aquifers with highest potential in the study area are floodplain and terrace aquifers. They are located at the central of the area. Groundwater can be developed from a depth of 50-120 and 20-60 meters, respectively. The well yield is in the range of 5-10 cubic meters per hour. However, yields of 10-20 cubic meters per hour, and more than 20 cubic meters per hour have been found in some areas of the northern part of this basin. The moderate potential aquifer is a colluvial aquifer of 10-30 meters in depth. The well yield is in the range of 2-10 m^3/hr with good to moderate quality water. Well yield 10-20 cubic meters per hour is presented in Ban Na district, Sanamchaiket district, and Plangyao district in Chachaengsao Province. Low potential aquifer is the volcanic aquifer, which yield about 2-5 cubic meters per hour at a depth of 20-40 meters. Higher yields are found in proper structure conditions. Expected groundwater yield from different water bearing rocks is shown in Figure 2-5A.

Groundwater quality in the context of total dissolved solids content, chloride content, hardness content and iron content. Groundwater quality in general is good (TDS less than 500 mg/L) to moderate (TDS between 500-1,500 mg/L) except for some areas, where water quality is brackish to salty (TDS more than 1,500 mg/L).

(4) Groundwater Flow Systems

From the previous study, the sets of value of the groundwater level were measured from 716 wells during the months of May (dry season) and September (rainy season) on 2006. An average values were calculate for each observation well and kriging was used for interpolating these values to obtain and estimated map of the

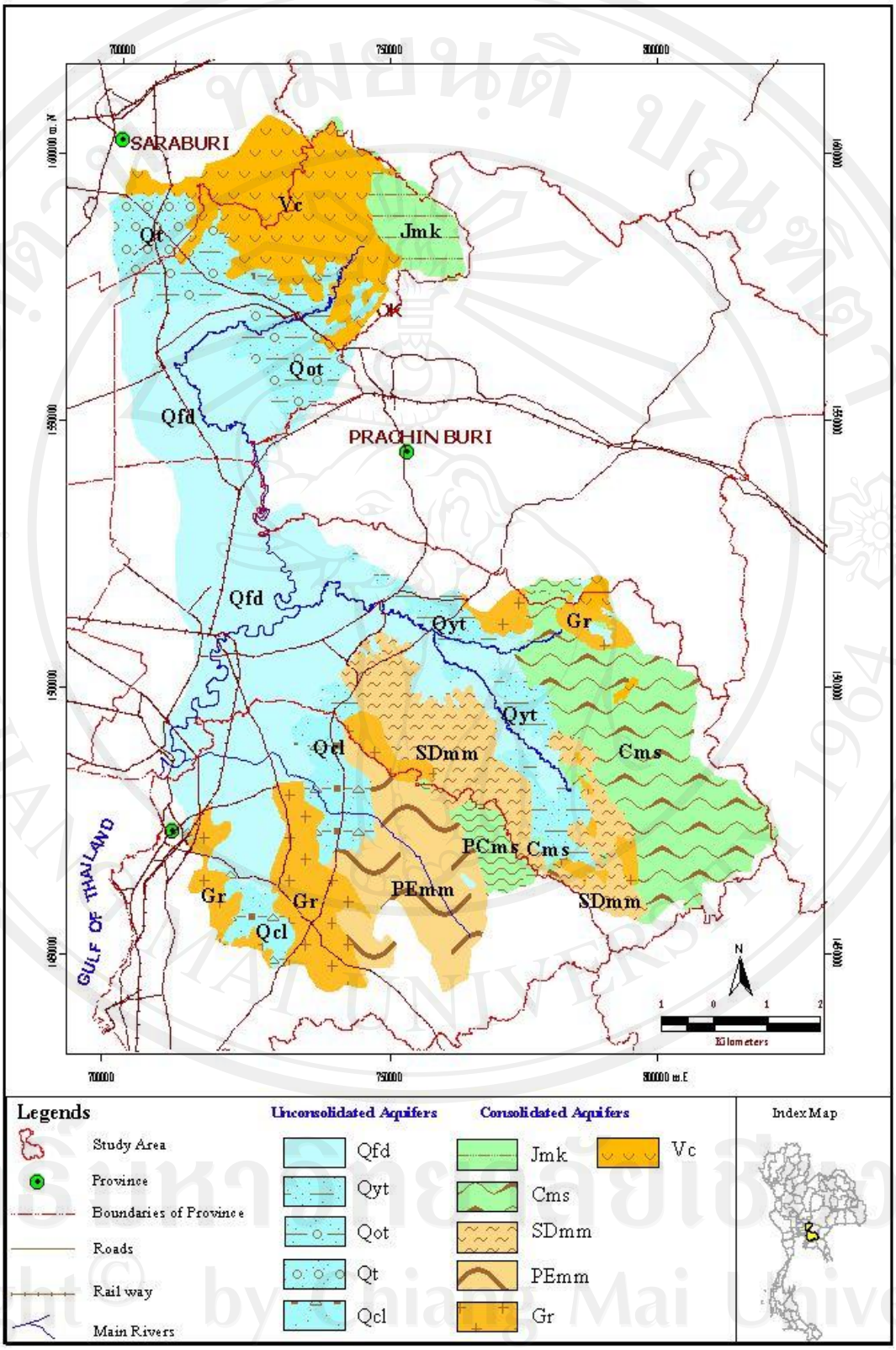

Figure 2-5A Distribution of the sedimentary and hydrogeological units in the study area.

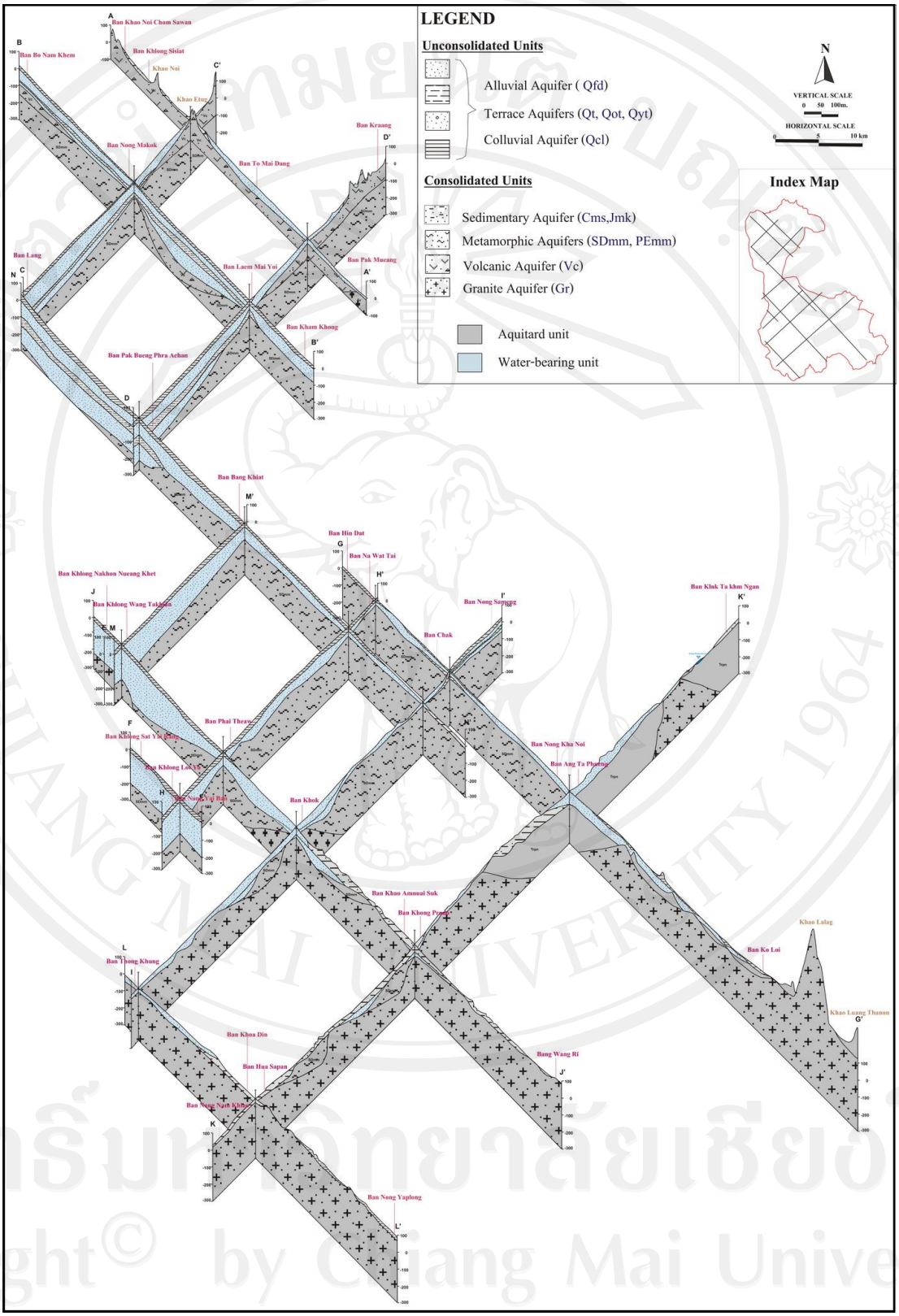

Figure 2-5B Schematic cross-section of the aquifer system of the study area.

(Modified from DGR, 2006).

groundwater heads as shown in Figure 2-6. From this map, one can deduce the direction of the groundwater flow, as shown in this figure. It appears that in the north and south, groundwater emerges from the mountain ranges and highland flow to the central part of the basin, where the most of the pumping wells are situated and flatten area. Here, the groundwater flows to slow down and gradually change direction to the west, where it drains to the Bang Pakong river and the estuary of a river.

2.3.2 Groundwater Usage

The study area has developed groundwater resources for alternative water resources and has used in conjunction with surface water. Most of groundwater abstractions in the study area are for domestic use, agriculture, and small-scale industry. Figure 2-7 shows the approximately total number of wells drilled by the government and suppliers in the study area. Table 2-4A and B describe the total amount of groundwater withdrawn that it can be estimated amount of pumping rate in 2006.

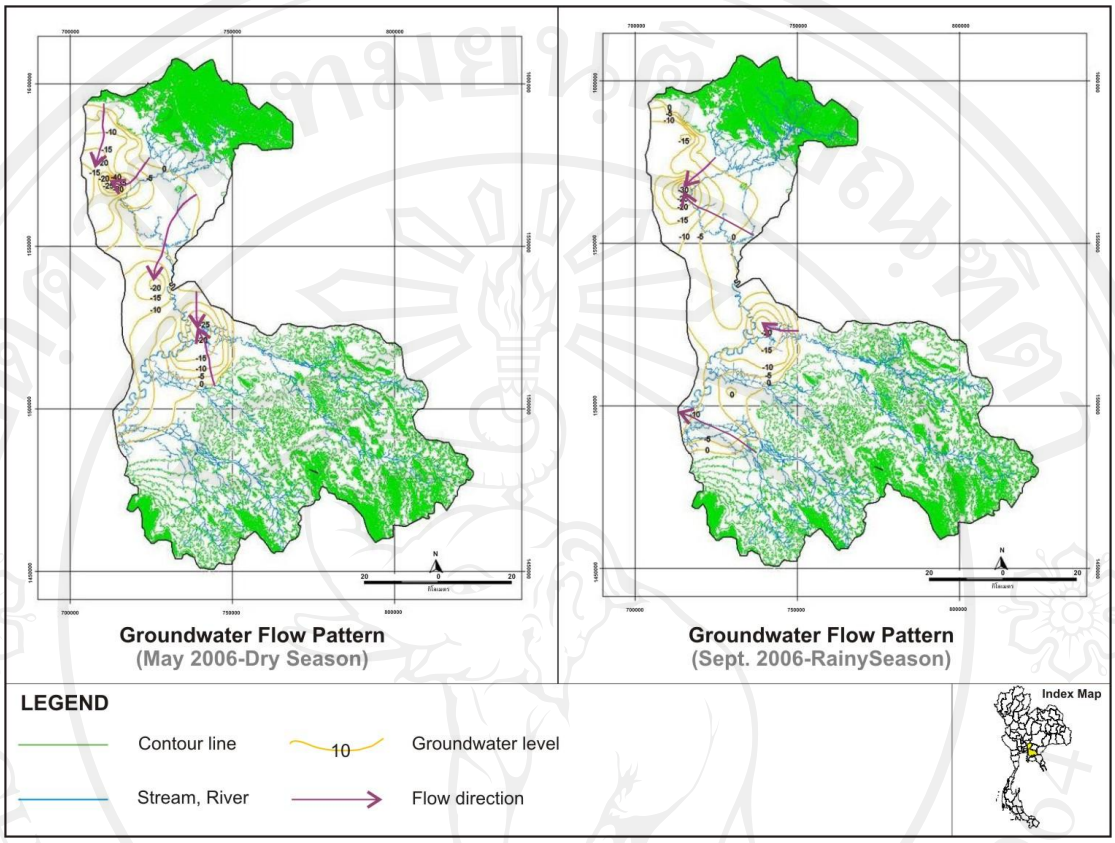

Figure 2-6 Piezometric head maps, regional groundwater flow direction during the months of May (dry season) and September (rainy season) 2006 (Modified from DGR, 2006).

Table 2-4A Estimation of total amount of groundwater abstraction.

Type of groundwater used	**Number of well**	**Amount of groundwater pumping, (cu.m/day)**
Domestic used	777	32,166.6
Industrials & Commercials used	294	21,309.0
Agricultural used	123	9,562.0
Total	**1,194**	**63,037.6**

Table 2-4B Number of drilled wells and estimation of pumping discharged in each province on 2006 (Modified from DGR, 2006).

No.	Province Name	Number of well	Amount of groundwater pumping, (cu.m/day)	Owner
1	Nakhon Nayok	1,120	estimated	Government
		199	20,266	Private
2	Saraburi	425	estimated	Government
		(None)		Private
3	Chon Buri	620	estimated	Government
		318		Private
4	Chacheangsao	1,739	estimated	Government
		208	14,784	Private
5	Prachin Buri	10	estimated	Government
		(None)	19,219	Private
Total		2,900	64,207.10	Government & Private suppliers

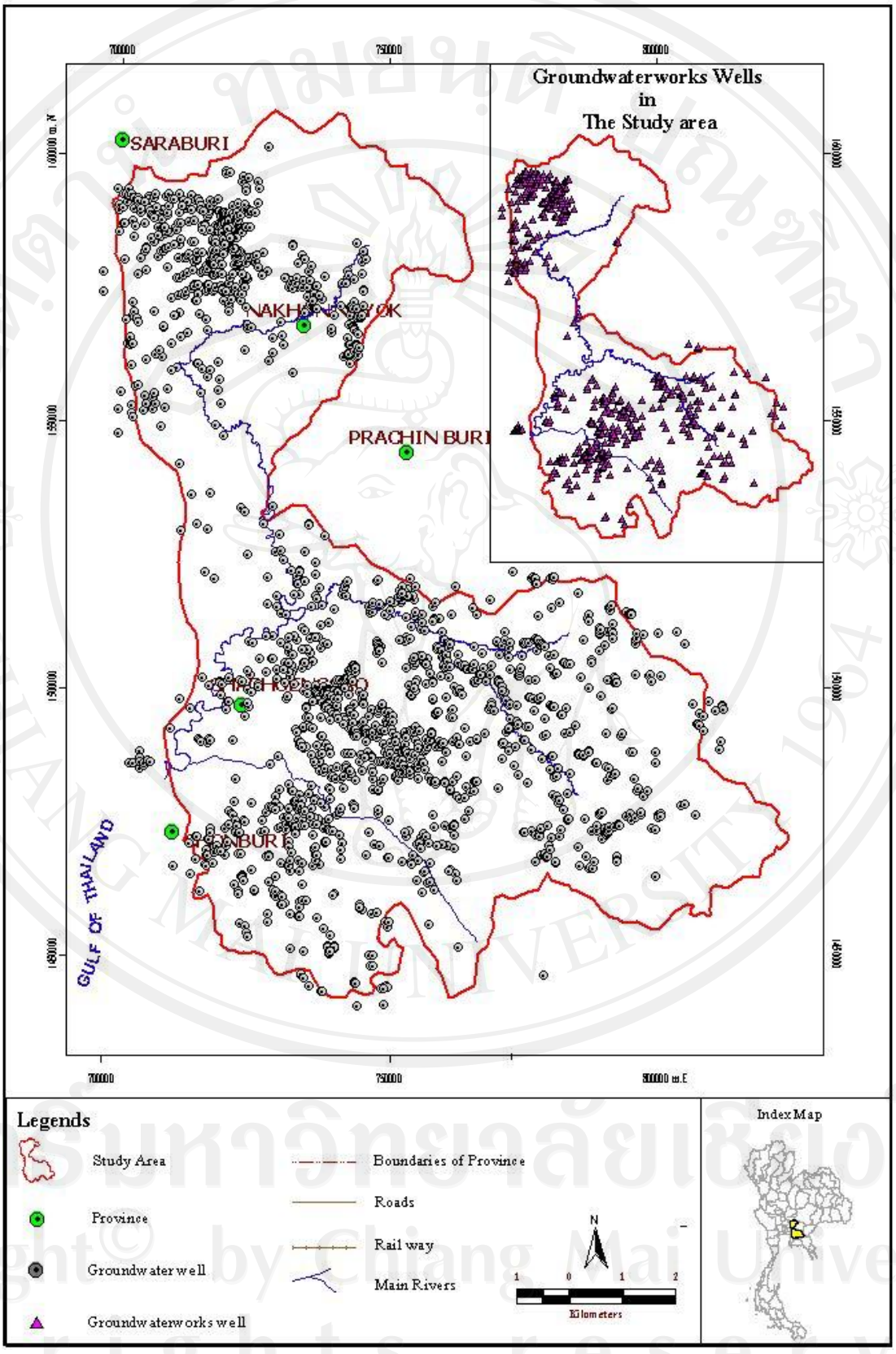

Figure 2-7 Distribution of groundwater wells drilled on the study area.