Current Situation of Water Resources and Proposal for the Construction of a Subsurface Dam in Northeast Thailand

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Abstract

The northeastern part of Thailand is considered to be the least developed region compared with the other regions of the country. Due to erratic rainfall, shortage of agricultural rainwater, and low soil fertility, income in this region is the lowest in the country. The shortage of irrigation water is the main cause of poverty in Northeast Thailand. Further large-scale dams cannot be constructed in Northeast Thailand due to topographical constraints. The development of water resources through the construction of small-scale ponds is the only feasible method of irrigation in the region. However, small-scale ponds are seldom used for irrigation in spite of their large number. In this report, the situation of water resources in Northeast Thailand is reviewed. Then, some issues concerning the current utilization of small-scale ponds will be discussed. Subsurface dams will be proposed as a new method of effectively using excess rain water in the rainy season.

Additional key words: rainfed paddy field, small-scale pond, saline groundwater, excess rain water

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Introduction

The northeastern part of Thailand, also known as the Khorat Plateau, is considered to be the least developed region compared with the other regions of the country. The population (19 million) and the area (170,000 km^2) account for one-third of the country. However, the GDP is only about one-fifth of the whole country[1]. Agriculture is the dominant industry in this region.

After World War II, widespread deforestation and development of agricultural land experienced a rapid progression to support the increase of the population. As a result, the vast plain and forest area have been changed into rainfed paddy fields and upland crop fields. There is no longer any space to expand fields. Yields have been decreasing year by year since development started, in some areas in Northeast Thailand[2,3].

The shortage of irrigation water is the main cause of poverty in Northeast Thailand. Since the topography of most areas consists of a gentle plain and the mountainous area is relatively small compared with the area of rainfed paddy fields, it is difficult to develop new water resources by constructing large dams. Development of water resources through the construction of small-scale ponds is the only feasible method of irrigation in the region[2,4]. However, small-scale ponds are seldom used for irrigation in spite of their large number.

In this report, the situation of the water resources in Northeast Thailand is reviewed. Then, some issues concerning the current utilization of small-scale ponds will be discussed. Subsurface dams will be proposed as a new method of effectively using excess rain water in the rainy season.

Natural conditions of Northeast Thailand

1) Physiography

Northeast Thailand consists of a plateau with a square shape of about 170,000 km^2 which is often called the Khorat Plateau. The Khorat Plateau is relatively flat with a low elevation (Fig. 1). Approximately 63% of the plateau has an elevation

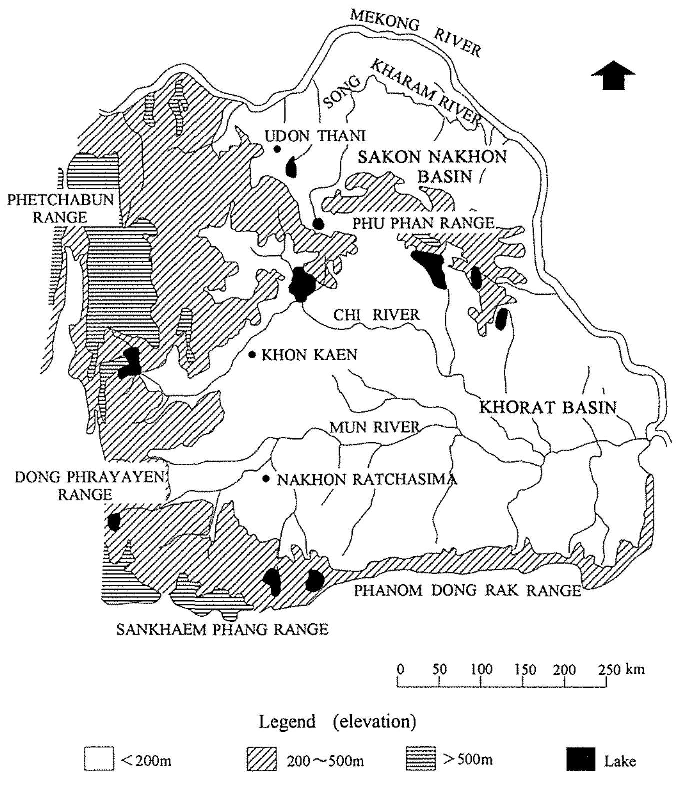


Fig. 1. Physiography of Northeast Thailand[28]

of 100-200 m, 28.4%, 200-500 m, 6.8%, 500-1000 m and 1.8% has an elevation of above 1000 m[5]. The terrain forms a basin structure which is surrounded by mountain ranges to the west (Phetchabun Range, 1500 m) and to the south (Phanom Dong Rak Rang, 600 m) and bounded by the Mekong River to the north and east[6]. The terrain is separated by Phe Phan Range (600 m) into two sub-basins: Sakon Nakhon Basin (33,000 km^2) to the north and Khorat basin (10,000 km^2) to the south[6]. The Khorat Basin is slightly inclined to the southeast and is drained by two big rivers: the Chi and Mun Rivers. These rivers flow into the Mekong River. Sakon Nakhon Basin is drained by the Songkharam River and the Kham River. The general physiography inside of the Khorat Basin can be divided into three main types of terrain: elongated hills, rolling hills, and lowland alluvial plain[7].

2) Weather

Northeast Thailand has a tropical monsoon climate. The climate is characterized by a sharp alternation of rainy season (June - November) and dry season (December - May). It is classified as tropical savanna based on Koeppen's system. Fig. 2 shows the distribution of the average annual precipitation in Thailand from 1950 to 1992[8]. The

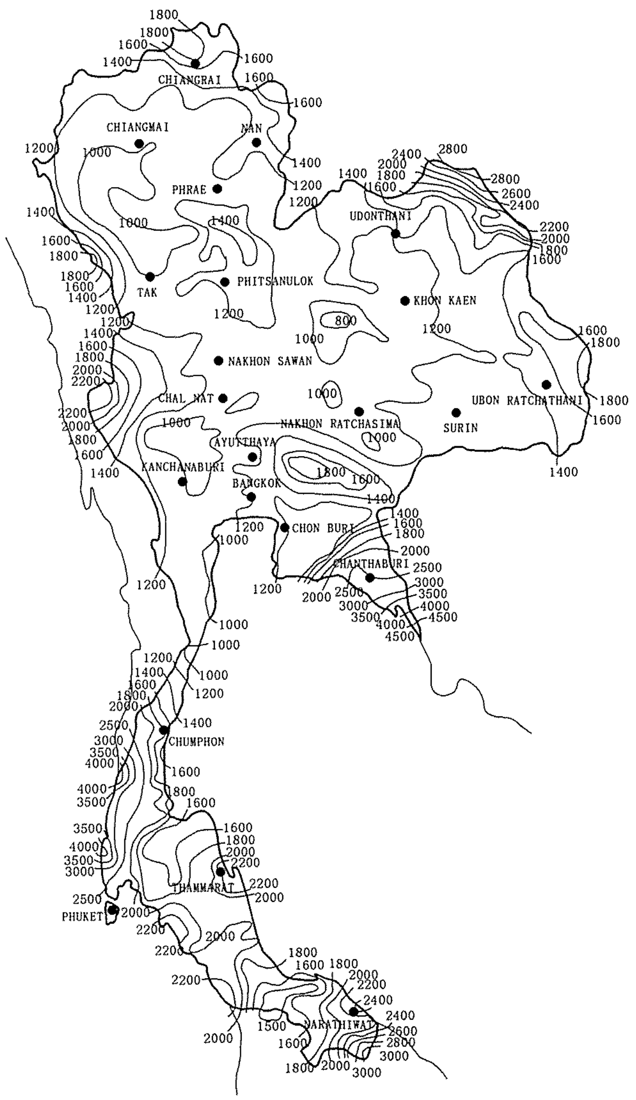


Fig. 2. Distribution of average annual precipitation in Thailand from 1950 to 1992[8]

average annual precipitation in the Khorat Basin ranges from 1,000 mm to 1,300 mm. However, the area along the border with Laos receives 2,000 mm of rain or more. Pan evaporation varies from about 600 to 2000 mm[7]. Fig. 3 shows the monthly precipitation in Khon Kaen in 1995-1997. It is characterized by little rainfall for the period from December to January. The onset of the rainy season is erratic, ranging from April to May and 80% or more of the rain falls in downpours from May to September. During this period, precipitation exceeds evaporation[9]. Sometimes there are no rainy days for about three weeks in August (with a return period of ten years), causing damage to the rice crop[4].

3) Geology

Northeast Thailand is mainly composed of Mesozoic sediments designated as the Khorat Group. The Khorat group in Khorat was deposited unconformably over the unexposed Ratburi Group as shown in Fig. 4. The Khorat Group consists of the Huai Hin Lat, Nam Pong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, Khok Kraut, Maha Sarakham and Phu Tok Formations (Fig. 5). The distribution area of the Phu Tok Formation is included in the Maha Sarakham Formation indicated in Fig. 5.

Shales, sandstones and siltstones of the Maha Sarakham Formation were deposited in a salt marsh or tidal flat environment[10]. Consequently, claystones and shales interbedded with two to three layers of evaporites (halite, gypsum, anhydrite, carnallite and sylvite) varying in thickness from 10 to 170 m[11] were deposited in the upper part of the Maha Sarakham Formation. These evaporite beds pinch out at the flanks of synclinal and anticlinal structures.

The Phu Tok Formation is overlain by unconsolidated clay, sand and gravel of the Quaternary age. The Quaternary deposits can be divided into four lithostratigraphic units composed of sand and gravel deposits, laterite deposits, loess deposits and alluvium.

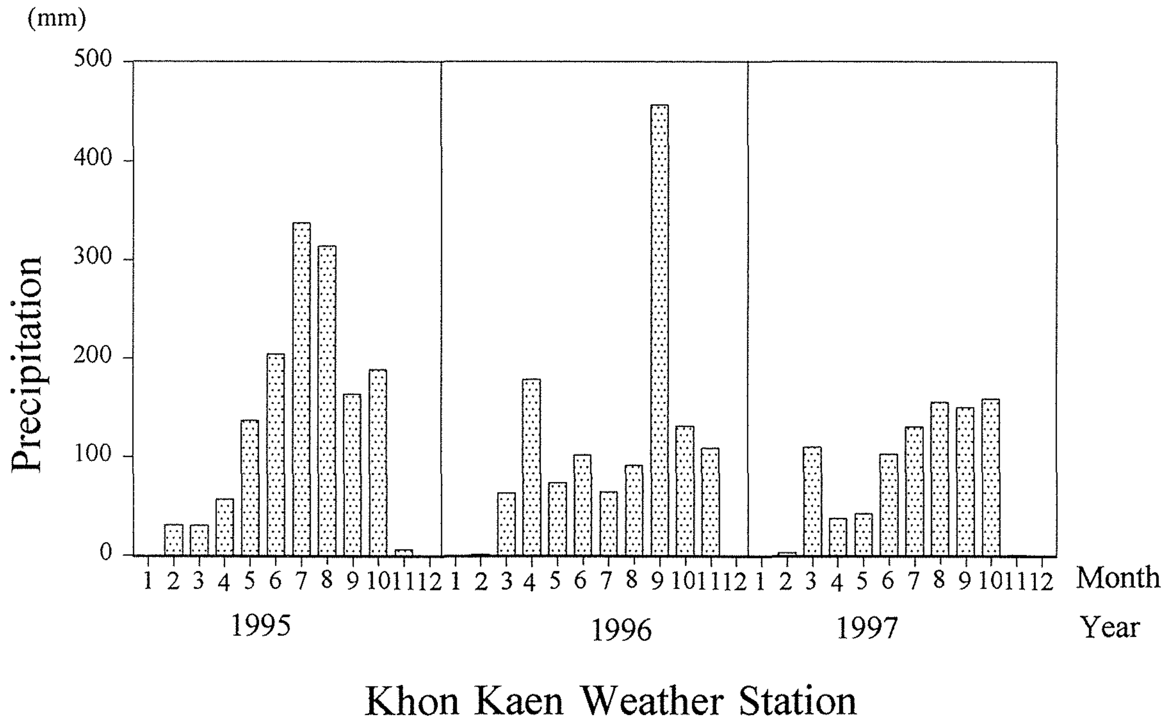


Fig. 3. Monthly precipitation in Khon Kaen from 1995 to 1997

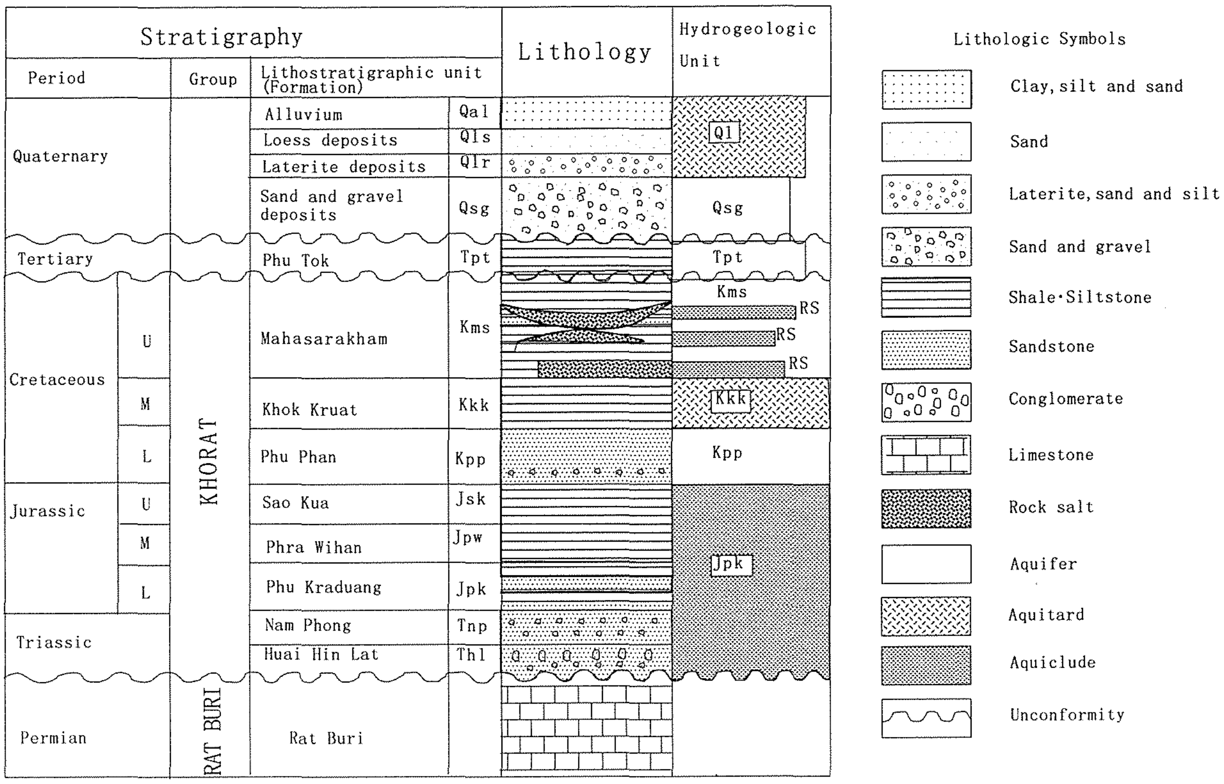


Fig. 4. Stratigraphy and lithology in the Khorat Basin (modified from Srisuk[7])

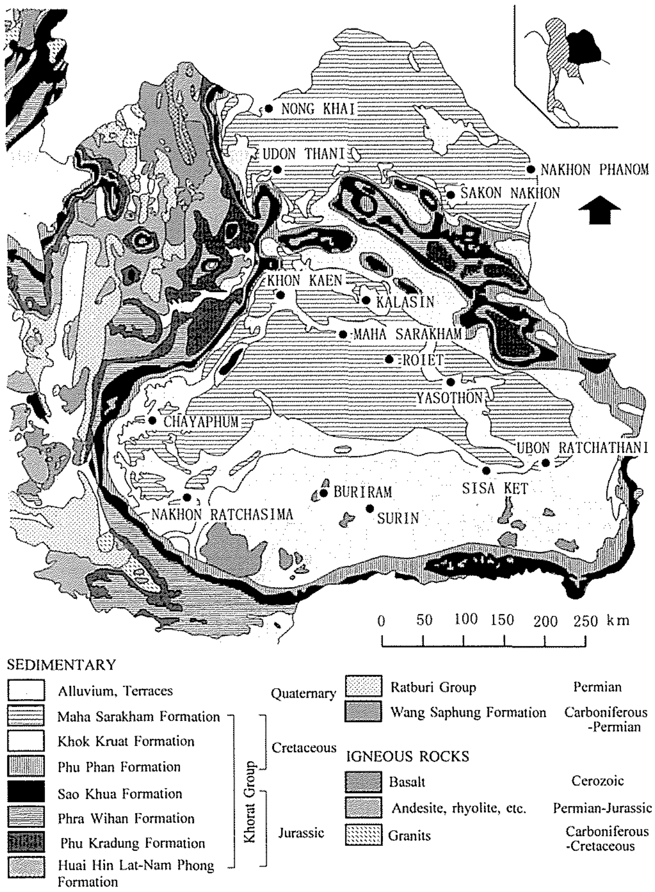


Fig. 5. Geological map of Northeast Thailand[29]

Agriculture in Northeast Thailand

The agriculture in Northeast Thailand consists mainly of rainfed agriculture and partly of irrigated agriculture. During the rainy season farmers normally plant rainfed rice, while during the dry season they plant cassava, kenaf, watermelon, tobacco and sugarcane in upland fields. In the limited area around consumption cities, farmers tend to grow rice, vegetables, sweet corn, peanuts and vegetable seeds with irrigation water.

Agricultural growth in Thailand was achieved almost entirely by deforestation and expansion of agricultural land into the forest area (Fig. 6). Statistical data show that the agricultural land area increased about three-fold over the 40 year period from 1950 to the present in Northeast Thailand[12]. On the other hand, the percentage of forest cover in Northeast Thailand decreased from 61.9% in 1950 to 13% (2.2×10^6 ha) or less at present. The forest cover rapidly decreased in the 1960s[3].

Paddy field area covering 1.1×10^6 ha has been added in the northeastern region by deforestation of which 1.0×10^6 ha consist of rainfed paddy fields. The ratio (7.6%) of the irrigated field area to the total paddy field area in the 1970s hardly changed by 1985 (9.4%)[3]. The rainfed paddy fields in the upland area are planted only once in several years due to the shortage of puddling water which is caused by the interruption of rainfall in the middle of the rainy season[1]. Every year more than half of all the paddy fields in Northeast Thailand are not cultivated due to the unpredictable rainfall pattern combined with insufficient water resources.

The average yield of rice was estimated at 1.2 tons/ha in 1984 (production/harvested area) in Northeast Thailand. It still remained at a low level, namely 1.66 tons/ha in 1998. The average paddy field area per household is 2.9 ha (18 rai)[3]. The fluctuation of production by year is very large. For example, rice production in Amphoe PhraYun fluctuated from 1,850 to 9,381 tons from 1986 to 1988. In 1986 this region experienced a severe drought (average annual precipitation at 11 stations: 862 mm). The planted area accounted for 26.4% and the harvested area for only 9.7% of the total paddy area in 1986. There was a high rainfall (average annual precipitation: 1099 mm) and production was very high in 1987, but the ratio of planted area to holding area was about 50%. Difference in precipitation of about 200 mm differentiates a best to worst harvest[1].

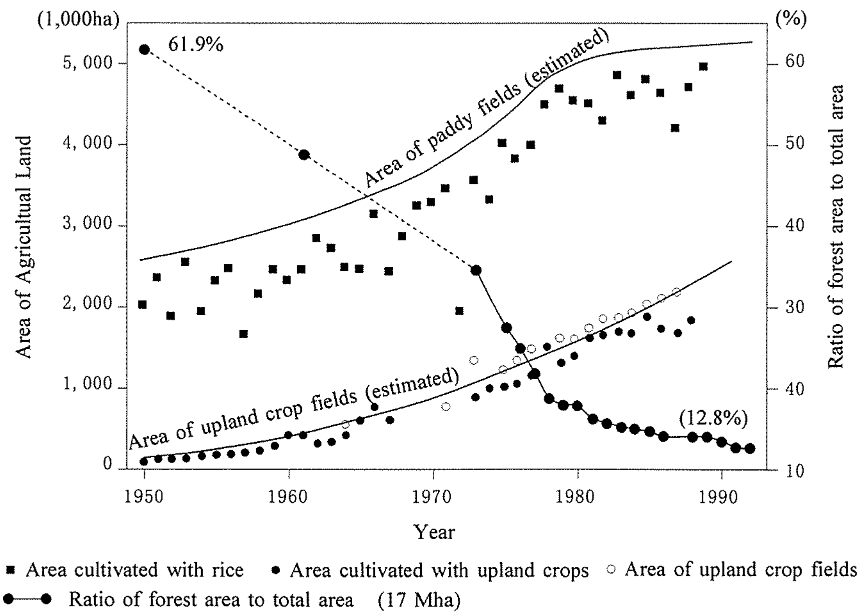
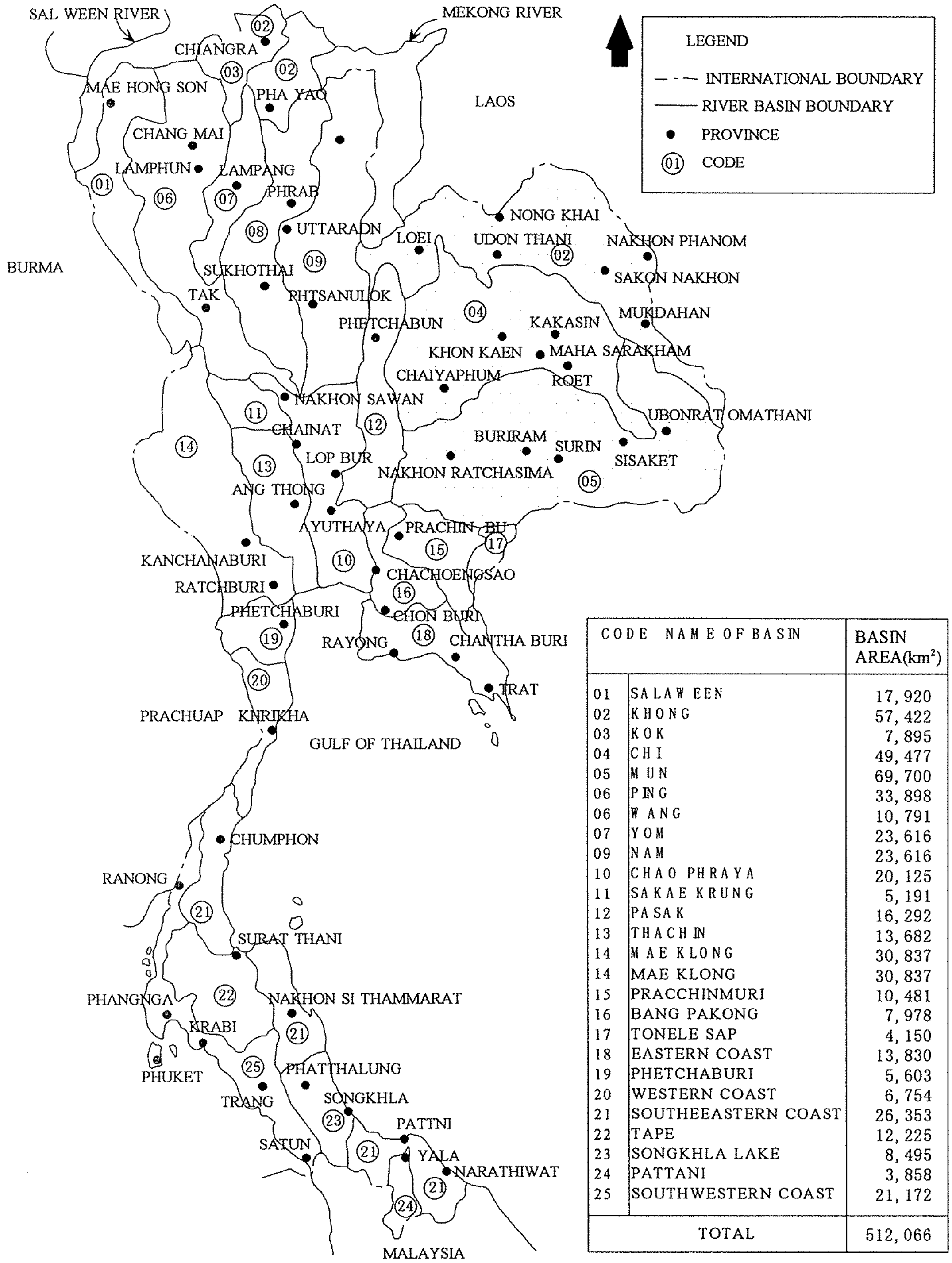


Fig. 6. Forest cover[3], area of paddy fields and upland crop fields[2]

Water resources in Northeast Thailand

1) Surface water

The average volume of rainfall in Thailand is 761.7×10^9 m^3. However, after subtracting losses such as those due to evaporation and infiltration, the average annual run-off is about 189.8×10^9 m^3, which accounts for 25% of the annual precipitation[13]. The National Water Resources Committee (NWRC) classifies the rivers of Thailand into 25 catchment areas according to topographical factors (Fig. 7). The total catchment



CODE	NAME OF BASIN	BASIN AREA(km²)
01	SALAWEEN	17,920
02	KHONG	57,422
03	KOK	7,895
04	CHI	49,477
05	MUN	69,700
06	PING	33,898
06	WANG	10,791
07	YOM	23,616
09	NAM	23,616
10	CHAO PHRAYA	20,125
11	SAKAE KRUNG	5,191
12	PASAK	16,292
13	THACHIN	13,682
14	MAE KLONG	30,837
14	MAE KLONG	30,837
15	PRACCHINMURI	10,481
16	BANG PAKONG	7,978
17	TONELE SAP	4,150
18	EASTERN COAST	13,830
19	PHETCHABURI	5,603
20	WESTERN COAST	6,754
21	SOUTHEEASTERN COAST	26,353
22	TAPE	12,225
23	SONGKHLA LAKE	8,495
24	PATTANI	3,858
25	SOUTHWESTERN COAST	21,172
	TOTAL	512,066

Fig. 7. Location of 25 catchment areas in Thailand[15]

area is about 512,000 km^2. The total average run-off from 25 rivers in 1993 was 229.6×10^9 m^3 which comprises 32% of the volume of the annual precipitation (Table 1). However, the average run-off coefficient based on various data in Thailand is about 15%[14]. The run-off coefficient of the Chi river in Northeast Thailand ranged from 6% to 18% according to data collected during the period 1967 to 1973 at three gauge stations[1]. The average value of the run-off coefficient in Northeast Thailand is considered to be 15%.

Some 648 dams including 28 dams with a storage volume of 10^8 m^3 or more were constructed for various purposes such as irrigation, flood control, and electric power generation in Thailand. The total storage volume of these dams is about 80.8×10^9 m^3. The total active storage volume is 45.0×10^9 m^3 [15]

The Thai government executed the following water resource development projects during the period covering the First to Sixth National Plans: 82 large-scale projects, 772 middle scale projects and 6,747 small scale projects (Fig. 8). These projects enabled to develop 3.5×10^6 ha of rainfed paddy fields into irrigated areas. During the period covering the Seventh National Plan (1992 - 1996), 32 large-scale water resource development projects; 7 in the northern part 7, 7 in the northeastern part, 11 in the central part, and 7 in the southern part were in progress. A large-scale project is defined as one with a budget of US$ 8 million or more, a dam with a storage capacity of 10^8 m^3 or more and an irrigated area of 12,800 ha or more[14].

Table 1. Water demand, supply in 1993 and 2006
(cited from Overseas Economic Cooperation Fund[15])

(MCM = $10^6 m^3$)

No.	Name of catchment area	Size of catchment area (km^2)	Annual average precipitation (mm)	Annual average outflow (MCM)	Present condition		Demand of water		Remainder	
					Storage volume (MCM)	Irrigation area (10^3Rai)	1993 (MCM)	2006 (MCM)	1993 (MCM)	2006 (MCM)
01	Salaween	17,920	1,330	8,566	24	177	622	664	7,944	7,902
02	**Mekhong**	**57,422**	**1,500**	**19,362**	**1,529**	**1,452**	**5,094**	**6,523**	**14,268**	**12,839**
03	Kok	7,895	1,457	5,280	30	550	416	574	4,863	14,706
04	**Chi**	**49,477**	**1,200**	**11,187**	**4,271**	**2,086**	**3,298**	**4,591**	**7,889**	**6,596**
05	**Mun**	**69,700**	**1,200**	**21,092**	**4,271**	**1,877**	**3,061**	**3,825**	**18,031**	**17,267**
06	Ping	33,898	1,056	7,965	14,107	2,043	3,014	4,992	4,951	2,973
07	Wang	10,791	1,048	1,104	198	476	602	1,016	502	88
08	Yom	23,616	1,118	2,957	98	1,073	928	2,473	2,029	484
09	Nan	34,330	1,241	9,158	9,619	1,843	3,290	4,814	5,868	4,344
10	Chao Phraya	20,125	1,200	22,200	33	7,989	12,510	18,700	9,690	3,500
11	Sakae Krang	5,191	1,240	1,297	161	576	1,170	953	127	344
12	Pasal	16,292	1,162	2,980	116	757	931	1,262	2,050	1,718
13	Tha Chin	13,682	1,200	2,500	15	2,385	—	—	—	—
14	Mae Klong	30,837	1,147	10,820	26,781	3,196	7,533	9,280	3,287	1,540
15	Prachinburi	10,481	1,700	5,268	39	621	849	1,793	4,419	3,475
16	Bang Pakong	7,978	1,359	3,713	74	1,353	2,307	2,521	1,406	1,192
17	Toan Lesap	4,150	1,192	6,266	96	119	219	457	6,007	5,809
18	East Coast	13,830	1,975	11,114	565	427	3,959	4,719	7,155	6,395
19	Phetchabburi	5,603	1,100	1,500	750	407	1,194	1,120	306	380
20	West Coast	6,745	1,075	1,411	526	377	1,443	1,319	-32	92
21	Peninsula East	26,353	2,250	23,270	5	1,774	1,194	2,999	22,076	20,271
22	Tapi	12,225	1,550	17,380	5,643	271	2,777	8,020	14,603	9,360
23	Thale Sap Songkhla	8,495	1,815	4,896	26	874	3,158	3,173	1,738	1,723
24	Pattani	3,858	1,800	2,738	1,144	273	1,177	1,183	1,561	1,555
25	Peninsula West	21,172	2,576	25,540	39	462	400	1,081	25,140	24,459
	Total	512,066	1,419	229,564	70,160	33,438	61,146	88,052	165,878	139,012

* 1 Rai = 1.16 ha.

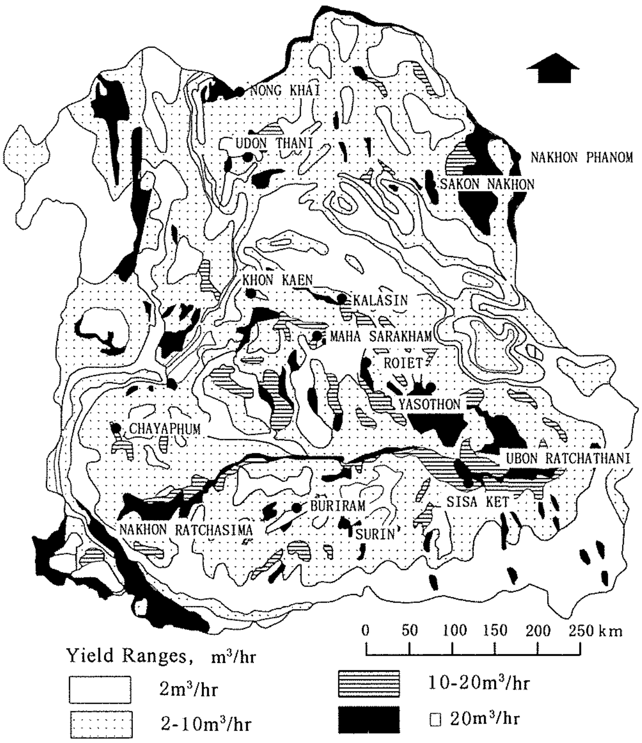


Fig. 8. Distribution of groundwater resources in Northeast Thailand[17]

Northeast Thailand has three catchment areas: Mekong River catchment area, Chi River catchment area and Muu River catchment area. There are nine large-scale dams managed by the Royal Irrigation Department (RID) in Northeast Thailand (Table 2). The largest dam is the Ubolatana dam with a storage capacity of 2.26×10^9 m^3. The total storage volume of these dams is 7.1×10^9 m^3. Table 1 shows the water demand and supply in 1993 and the predictions for 2006 by OECF (Overseas Economic Cooperation Fund)[15]. The water demand for most of the catchment areas in 2006 will be larger than that in 1993. However, the remaining volume is likely to be different in each catchment area. For instance, the forecast for the Chao Phraya River catchment area shows that the 9.7×10^9 m^3 remaining volume in 1993 will decrease to 3.5×10^9 m^3 in 2006. On the other hand, the decrease in the volume in the Mun River and Chi River catchment areas will be small. It is forecasted that the situation will hardly be improved in Northeast Thailand, mainly because the topographical conditions of the region limit the construction of new dams.

The strategy of agricultural development enacted in the First to Fifth National Plans was to put emphasis on large-scale projects with dam construction and integrated irrigation maintenance around the Bangkok suburban area. However, the government of Thailand switched from large-scale projects to small-scale projects including Small-Scale Irrigation Projects(SSIP) in the implementation of the Sixth National Plan. The budget for small-scale projects accounts for about half of all the projects now. SSIP were executed in about 6,000 areas, 3,000 of which in Northeast Thailand[16].

Irrigated areas amounting of only 64,000 ha in 1950 had increased to 608,000 ha by 1988. Thus, irrigated agriculture is gradually being promoted in Northeast Thailand. However, the irrigated area account for only 8% of the flat area (7,250,000 ha) in this region[3]. Since this ratio is unlikely to increase rapidly in the future, most farmers in the northeastern part will have to keep planting rice in lowlands and cropping in upland fields without irrigation water in the near future.

Table 2. Large-scale dams managed by the Royal Irrigation Department (RID) in Northeast Thailand[14)]

Name of Dam	Gross Reservoir Capacity ($\times 10^6 m^3$)	Effective Storage Capacity ($\times 10^6 m^3$)
LAMPAO	1,430	1,345
LAMTAKLONG	310	290
LAMPRAPLERNG	152	148
NAMOON	520	477
UBOLRATANA	2,263	1,854
SIRINDHORN	1,966	1,135
CHULABHORN	188	144
HUAILUANG	113	108
LAMNANGRONG	150	142
Total	7,092	5,643

2) Groundwater

The following brief description of the groundwater system in Northeast Thailand is based on the data of Wongsawat et al. (1992)[17)]. The groundwater in Northeast Thailand occurs mainly in cracks, joints, faults (fractures), and bedding planes of shale, siltstone and sandstone of the Khorat Group which mainly underlies the Khorat Basin. Opening of fractures shows a low magnitude, and in many places is not well connected.

The groundwater system in Northeast Thailand is mainly recharged by rainfall and affects seepage from streams. Tentative hydrological balance studies in different areas indicate that only about 5 to 10% of the total rainfall infiltrates into the soil.

Wongsawat et al. (1992)[17)] divided various aquifers distributed in Northeast Thailand into three broad classes in terms of potential for development.

Class 1: Aquifers providing large amounts of high quality water suitable for most uses. These included the Tertiary-Cretaceous Phu Tok aquifer, Phu Kradung aquifer, Carbonate aquifer or Ratburi limestone aquifer and Terrace aquifer.

Class 2: Aquifers providing low to medium yield of good to moderate quality groundwater suitable possibly for village water supply and for small-scale irrigation. These include the Sao Khua, Phu Phan, Kohku Kurat and Phrawihan aquifers.

Class 3: Aquifers containing essentially brackish to saline or limited groundwater with varying yields. Aquifers within the flood alluvium, Maha Sarakham aquifers and Igneous rocks aquifers belong to this group.

The Terrace deposit aquifer and the Phu Tok aquifer in Class 1 are distributed in upland and lowland areas. The Phu Kradung aquifer and the Carbonate aquifer are distributed in mountainous areas and mountain ranges.

The terrace deposit aquifer is composed of sand, gravel, and clay. Although a thickness exceeding 120 m has been recorded from borehole data, the average thickness appears to be about 40 m. This aquifer lies unconformably on the Maha Sarakham Formation and the Khoku Kruat Formation. Most of the boreholes in the terrace deposit aquifers have been set at about 2 - 20 m^3/hr by pumping tests. Coefficient of transmissivity ranges from 4 - 650 m^2/day. Total dissolved solids (TDS) amount to 500 mg/l or less. Specific yield in

Khon Kaen city is 80 - 1500 m^3/day/m.

The Phu Tok aquifer occupies about 30% of the total area of the Khorat Basin, occurring as outcrop and subcrop of fine- to medium-grained reddish sandstone and unconformably overlies the Maha Sarakham Formation. The average thickness of this aquifer ranges from 200 - 400 m. Vertical joint sets are well developed. In the discharge zone of the lower topographic regime, the piezometric surface of the Phu Tok aquifer is above ground level providing artesian flowing tubewells. Yields from individual boreholes in the Phu Tok aquifer range from 2 - 220 m^3/hr. Average coefficient of transmissivity is about 500 m^2/day. However, coefficient of transmissivity in areas without cracks is 0.5 - 100 m^2/day. The specific yield in Khon Kaen varies from 96 - 4000 m^3/day/m. The water quality is essentially very good, generally with less than 500 mg/l of TDS. However, the Phu Tok aquifer is highly susceptible to saline contamination in many areas both from saline soils of the overlying alluvium and from the inflow of saline water from the Maha Sarakham Formation.

As previously mentioned, the available yields of aquifers do not depend only on the lithology but also depend on local structures and locations of recharge and discharge areas. Fig. 8 shows the distribution of groundwater resources in Northeast Thailand. The groundwater resources are classified as follows.

1. Area where groundwater can be developed with a pumping rate of more than 20 m^3/hr in many areas up to 100 - 220 m^3/hr.
2. Area where groundwater can be developed with a pumping rate of 10 - 20 m^3/hr
3. Area where groundwater can be developed with a pumping rate of 2 - 10 m^3/hr
4. Area where groundwater can be developed with a pumping rate of less than 2 m^3/hr

The regions with a high pumping rate are roughly divided into five areas: a central zone in the NW-SE direction, a northwestern part and a northeastern part in the NS direction, a southern belt in the EW direction and a southeastern part. The direction of the central zone is coincides with the dominant NW-SE direction of the geological structure (fault and fold) in Northeast Thailand[18]. The northwestern and southwestern parts are underlain by the carbonate aquifer. The northeastern part and EW belt contain the terrace deposits.

Various government agencies and departments, such as the Department of Mineral and Resources (DMR) investigate and develop groundwater resources. By the end of 1991, about 45,000 wells had been drilled in Northeast Thailand, about 50% of which yield 5 m^3/hr or less. Besides, more than 90% of the wells drilled in the flood plain or relatively flat lands yield salty water[19].

Salinisation of land and groundwater

The deforestation which modified the ground surface and destroyed the balance of hydrological cycle reflects the expansion of salt-affected land. However, soil salinisation in Northeast Thailand is not a new problem and is not entirely induced by human activities. Soil salinisation in this region is at least partly a natural phenomenon which is related to the climatic conditions and the rock salt widely underlaid in this region. Because of the widespread salinity problem in the Khorat Plateau, many studies were carried out to explain the causes of the problem, estimate its extent and address its management. The following brief description of salinisation of land and groundwater in Northeast Thailand is based on these results.

Rimwanich and Suebsiri[20] described the nature and management of problem soils in Thailand and provided a soil salinity distribution map of Northeast Thailand (Fig. 9). Limpinuntana and Arunin[21] estimated the area of salt-affected soils based on satellite images. The distribution area is 2.85 Mha in Northeast Thailand, which represents approximately 17% of the total area and can be subdivided into three classes.

Department of Land Development (DLD) compiles salt-affected soil maps in each prefecture

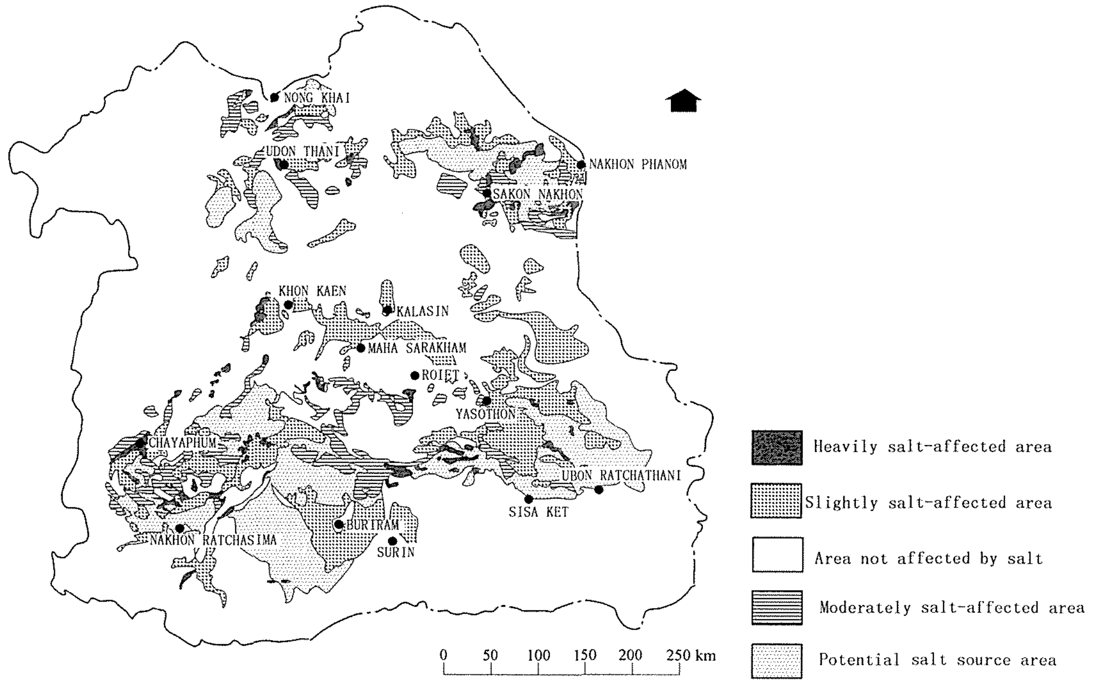


Fig. 9. Soil salinity distribution map of Northeast Thailand[20]

on a scale of 1: 250,000 and 1: 100,000 based on LANDSAT image analysis and ground surveys. In these maps, the soils undergoing salinisation are grouped into five classes based on the area of salt patches which appear as barren land.

Class 1: very severely salt-affected areas where salt patches cover more than 50% of the area,

Class 2: severely salt-affected areas where salt patches cover 10 - 50% of the area,

Class 3: moderately salt-affected areas where salt patches cover 1 - 10% of the area,

Class 4: slightly salt-affected areas where salt patches cover less than 1% of the area, and

Class 5: hilly area where rock of the Maha Sarakham Formation is distributed below the topsoil.

The strongly salt-affected areas are likely to be distributed in low-lying alluvial plains, while the potentially saline soils occur in elevated areas containing either salt-bearing shale, siltstone or sandstone in the subsoil. However, it should be noted that these maps do not enable to divide the salt-affected soils into primary and secondary classes[22].

Fig. 10 shows the distribution map of chloride concentration in groundwater in Northeast Thailand[17]. The saline water generally occurs in low-lying areas in the central part of the Khorat and Sakhon Nakhon basins. The distribution areas of the saline water overlap the areas of salt-affected land (Fig. 9) and the Maha Sarakham formation (Fig. 5).

Problems for development through the construction of small-scale ponds

As mentioned above, the construction of large-scale dams is not feasible in Northeast Thailand. Another method of developing water resources is to construct small-scale ponds[2, 4].

There are many small-scale ponds in Northeast Thailand, divided into the following two types: Type 1 is a small fill dam with which a mountain stream is dammed up or a gradual valley is closed. Type 2 is a pond dug without embankment. Most of the ponds of Type 1 are constructed and repaired by government organizations such as the RID. Type 2 ponds are

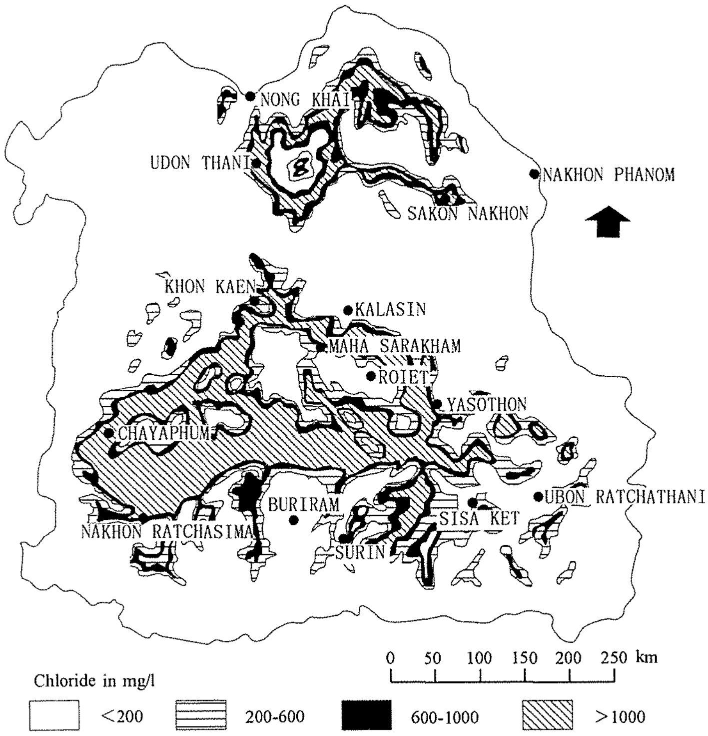


Fig. 10. Distribution map of chloride concentration in groundwater, Northeast Thailand[17)]

dug by the farmers.

JICA[1)] investigated small-scale ponds in the catchment area covering 341.5 km^2 around the Phura Yun area near Khon Kaen where salt-affected land and many ponds are distributed. The reservoir area of the largest pond is 6.8 km^2 and its storage capacity is 13×10^6 m^3. The smallest pond has a reservoir area of 2,500 m^2 and a storage capacity of 1,800 m^3. There are 6 SSIPs with 4 ponds. The total storage capacity of the ponds is 204,000 m^3. The total irrigated area is 200 ha. However, there were no operating facilities for irrigation and almost no ponds used for paddy field irrigation. Crops that could be possibly grown by irrigation using small-scale ponds in Northeast Thailand are vegetables in the dry season[12)]. However since the market for vegetable is limited to local cities, few farmers are using ponds for this purpose. Other usages of the ponds include water for domestic use, animals, fish breeding, and bathing of water buffaloes.

The reasons why the ponds are not used for irrigation, especially irrigation of paddy fields in Northeast Thailand seem to be the following;

①Since most of the ponds are constructed using a hollow topography near paddy fields or by excavation of a depth of several meters, the water level of the ponds is lower than the ground level of peripheral paddy fields. Therefore, pumping facilities and electricity charges for pumping are requested to use the stored water. The income from the rice yield is not sufficient to cover these costs.

②The water quality of some of the ponds is unsuitable for irrigation due to the seepage of saline groundwater.

The problem could be addressed partly by the use of newly designed half field and half dug reservoirs as proposed by Khogo et al.[31)]. However, there remain critical problems in the case of ②. Here, we consider the method of alleviating the natural phenomenon of ②.

Minami et al.[4)] conducted field experiments on preventing the salinisation of storage water in small-scale ponds in salt-affected land of Northeast Thailand where the groundwater is also saline.

Since the saline groundwater is uniformly distributed as groundwater vein flow, the location of fresh water was not known. They constructed 12 ponds with an average storage capacity of 7,000 m^3. The ponds were constructed by digging at 4 - 5 m depths from the ground surface to use the groundwater. The initial value of chloride concentration in the storage water ranged from 1,000 to 20,0000 ppm. By controlling the water level of the storage water above that of the watertable of the saline groundwater, the chloride concentration of storage water decreased to a suitable concentration for irrigation in 8 ponds. However, the annual rate of decrease of salinity in 4 ponds was small. They concluded that the water quality in the 4 ponds could not be improved.

JICA[1] studied the distribution of water quality of ponds in an area of 45.6 km^2 around Phura Yun, where ponds with various sizes are located in 200 areas or more(Fig. 11). F1 fault in the NW-SE direction is assumed to be distributed in the central part of the area. The electric conductivity of storage water ranged from several tens to 19,500 μ S/cm (Fig. 12). Ponds with high salinity where the values of water electric conductivity was 5000 μ S/cm higher were distributed along the F1 fault.

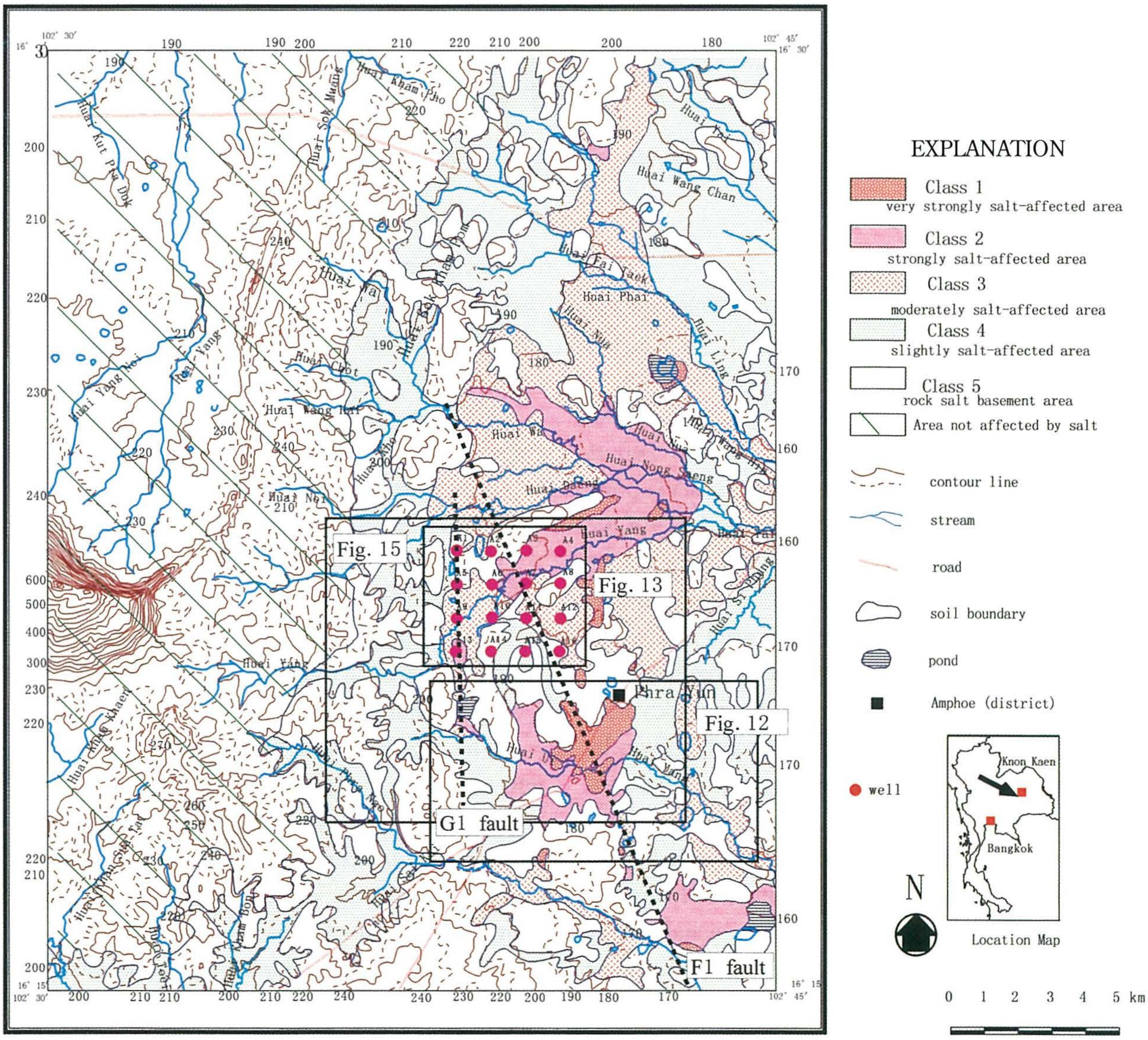


Fig. 11. Distribution of salt-affected soil[30], study areas by JICA and authors, and model district of subsurface dam

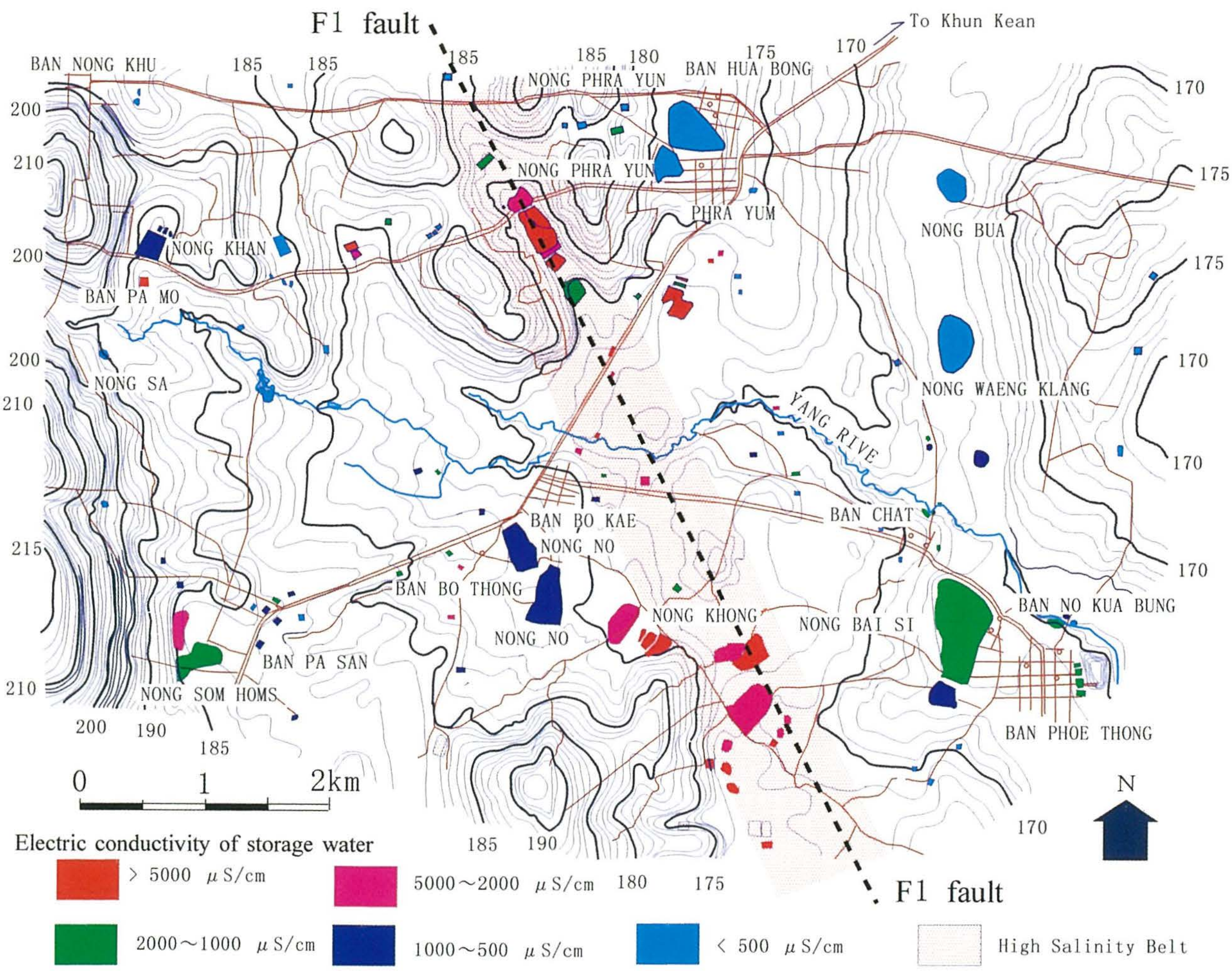


Fig. 12. Electric conductivity map of storage water of small scale ponds (original data from JICA)

The authors studied the relationship between the hydrogeological structure and salinity of groundwater in JICA's neighboring area on the northern side. The distribution of the G1, F1, and F2 faults was determined based on bore investigations and physical prospecting. The results showed that the saline groundwater had risen through the cracks of the G1 and F1 faults (Fig. 13). The movement of saline groundwater could be restricted by a vertical permeable zone such as fault fracture. The extension in the northwestern direction of this high salinity belt runs to the F1 fault of our study area.

Since high concentration saline water has risen through the fault in the salt-affected land of Northeast Thailand, it is necessary to build ponds far from the fault.

Proposal for water resource development by the construction of subsurface dams

1) Conditions for the construction of subsurface dams in Northeast Thailand

In the Amami and Ryukyu islands in the southwestern most part of Japan, rivers with steady flow do not develop due to geological conditions: the islands consist of Ryukyu limestone with a high permeability. Therefore, rainfed agriculture using rain brought by typhoons is applied in the islands. The islands often experience drought in years when there are few typhoons. Subsurface dams (Figure 14) could enable the development of irrigated agriculture in some of these islands where geological and hydrological conditions are suitable for the construction of subsurface dams[23, 24].

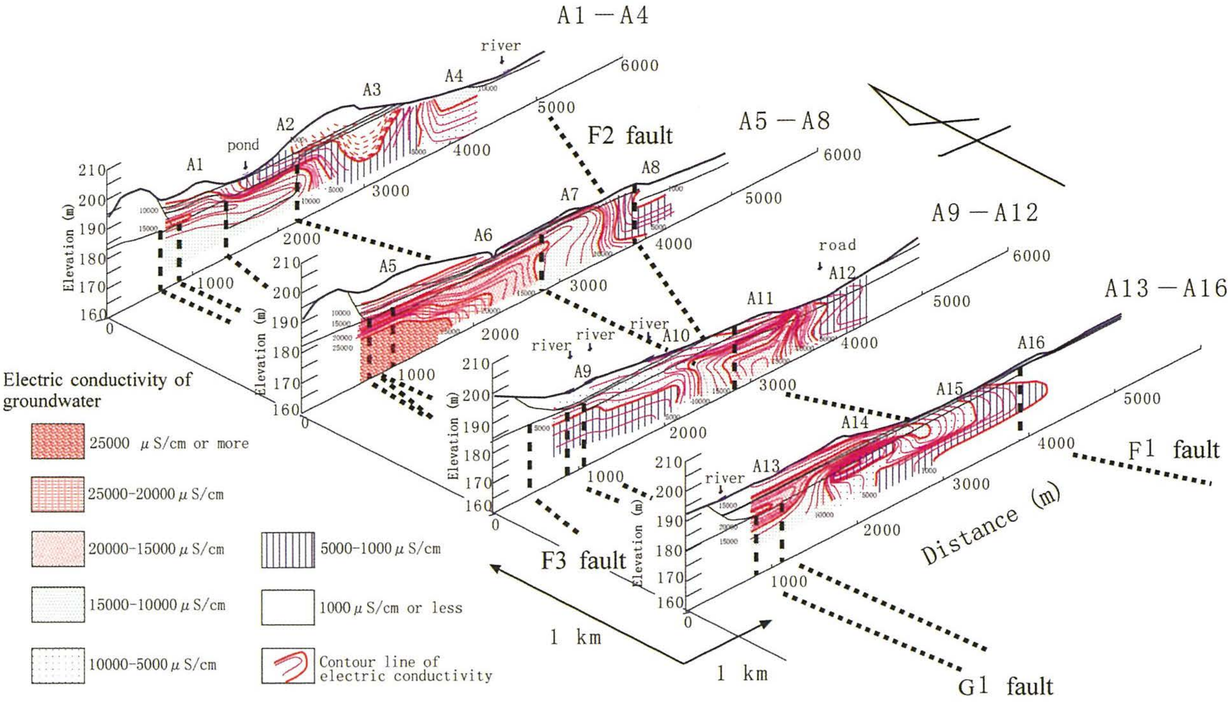


Fig. 13. Relationship between fault and distribution of saline groundwater in Phura Yun are

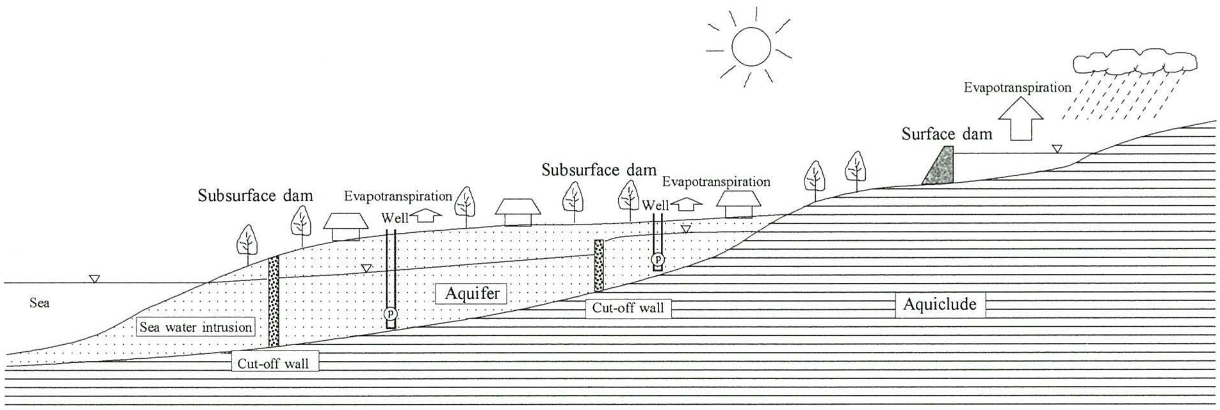


Fig. 14. Schematic representation of subsuface dam

The rate of precipitation in the rainy season to annual precipitation is about 80% - 90% in Northeast Thailand. An important problem for the agriculture in this region is how to store the excess water from August to September. Here, the possibility of effectively using this excess water by the construction of subsurface dams is considered.

A subsurface dam is a facility that dams up groundwater flow, stores groundwater in the pores of the stratum and uses groundwater in a sustainable way. A subsurface dam is composed of a cut-off wall by which the groundwater flow is dammed and facilities (well, intake tunnel and pump) which draw up the stored groundwater.

Since the utilization of stored groundwater in a subsurface dam requests pumping, operation cost is involved, which is different from the case of a surface dam. The reservoir area can be used in the same way before and after the construction of the subsurface dam. A subsurface dam allows the development of water resources in regions where the construction of surface dams is difficult due to geological conditions, and groundwater cannot be used in the current state.

For the construction of subsurface dams the following conditions should be met in terms of efficiency of storage and intake of groundwater, and technical feasibility of constructing the cut-off wall;

①**Storage aquifer**: An aquifer with large effective porosity and permeability must be available in the planned district. Effective porosity influences the storage volume. The permeability influences the ease of intake of groundwater. Moreover, it is necessary to confirm the absence of stratum whose volume could be changed by the storage and intake of groundwater in the reservoir area. The volume changes in a stratum cause subsidence due to desiccation associated with the intake of groundwater.

Suitable aquifers in Northeast Thailand for subsurface dams include the Class 1 terrace deposit aquifer and Phu Tok aquifer. The Phu Kradung aquifer and the carbonate aquifer which are located in the mountainous regions are omitted from the discussion.

②**Basement stratum with underground valley structure**: A relative aquiclude should exist under the storage aquifer. The partition with cut-off wall across the underground valley of the upper surface of the aquiclude enables efficient damming. The maximum depth for the construction of the cut-off wall up to the present in Japan is about 65 m. The construction limit seems to be about 100 m in depth.

The Maha Sarakham Formation, which is a Class 3 aquifer, could be considered as an aquiclude compared with the terrace deposit aquifer and the Phu Tok aquifer. Therefore, the area where the upper surface structure of the Maha Sarakham Formation forms an underground valley is suitable for the construction of a cut-off wall.

③ **Recharge to subsurface dam**: Sufficient recharge of the reservoir area of the subsurface dam is necessary. Rain which infiltrates into the soil over the maximum water holding capacity of the soil flows outside the root zone as excess water. The cumulative amount of excess water corresponds to the amount of groundwater recharge. Hayashi (1991)[9] calculated the water balance considering the soil moisture conditions using data on monthly precipitation in Khon Kaen. The following equation of water balance was derived. Annual precipitation during the year when the calculation was made was 1,177 mm.

Σ (precipitation) = Σ (evapotranspiration) + Σ (excess water) + Σ (shortfall volume of water)

In this calculation, the following assumptions were made:

a. The suction depth of soil by roots is 100 cm.

b. The soil moisture suction (pF 1.7～4.0) is 100 mm.

c. All the precipitation infiltrates into the soil.

The calculation results revealed the following: The evapotranspiration exceeded the precipitation for seven months during the period from October to April of the next year. The amount of shortfall volume of water for this period was 317 mm. The precipitation in the rainy season from May to September exceeded the evapotranspiration. However, the soil moisture finally reached a saturation condition in August. An amount of 150 mm of excess water flowed out from the root zone. Hayashi's assumption that all the precipitation infiltrates into the soil is an overestimation because some part of the rain quickly runs off into rivers. It is necessary to consider a run-off coefficient of 15% (see paragraph 4. surface water) from the infiltration of rain. Therefore, the amount of groundwater recharge from August to September was 150 mm×85%=127.5 mm. On the other hand, since the amount of groundwater recharge calculated based on hydrological balance studies accounted for 5 - 10% of precipitation[17], the amount of groundwater recharge assuming an average annual precipitation of 1,200 mm in Khon Kaen was 1,200 mm×10%=120 mm. The values calculated by the two methods were almost identical. It is reasonable to assume that 120 mm of annual precipitation is recharged to groundwater.

The following condition should be met in order to plan subsurface dams in Northeast Thailand, namely ④ **Salinisation:** The subsurface dam must not be located in an area where the storage groundwater causes salinisation of land and water resources. It is necessary to design the full water level of the subsurface dam below the critical water level. The critical water level is defined as the water level from which groundwater can move to the ground surface by capillary action[25, 26]. The critical water level is generally 1 - 2 m under the ground surface though it varies depending on the physical properties of the soil, etc. Saline groundwater often rises up through faults. It is necessary to confirm that there is no fault in the catchment area, especially the reservoir area.

2) Design of subsurface dam in model district

The Phura Yun region where the geological surveys were conducted by JICA, DLD, and JIRCAS was selected as the model district. Hydrogeological map around the model district is shown in Fig. 15. The storage aquifer is the Pa Mo gravel formation in the Quaternary. The aquiclude is the Maha Sarakham Formation. Based on the pumping test of well W-1 at a 30 m depth in the Pa Mo gravel formation, the specific capacity is 20 l/min/m. The coefficient of transmissivity is 70 m^2/day[1].

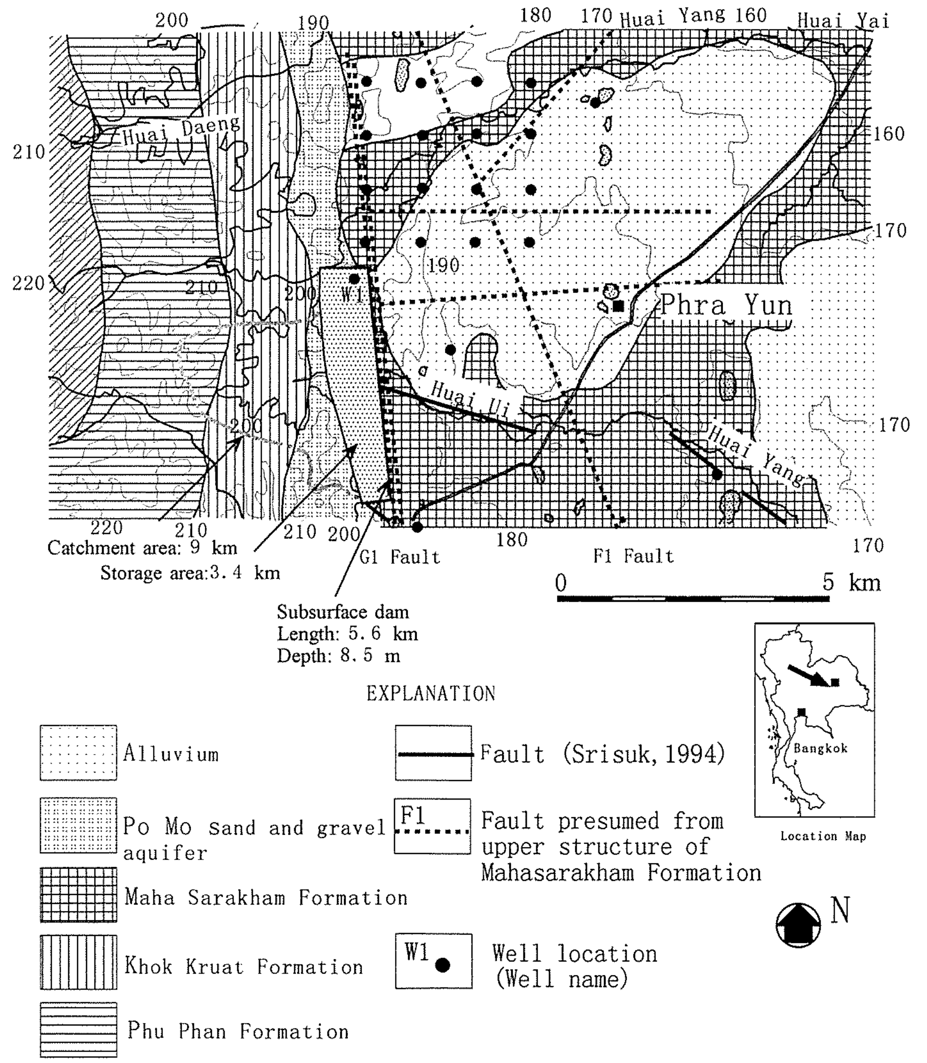


Fig. 15. Geological map around the model district of subsurface dam

Fig. 16 shows the upper surface structure of the Maha Sarakham Formation which is drawn from the well data around the model district. The upper surface structure reflects the ruggedness of the topography. However, fault topography such as lineament, horst and fault valley which are observed on the ground surface can be distinguished. The dotted lines in Figure 16 are assumed to correspond to faults from such fault topography. Bold lines along the Huai Ui river and Huai Yang depict faults in the geological map drawn by Srisuk[7]. The presence of the G1 fault is assumed based on the surface topography of the fault trench. An underground valley is observed near W-1 which might have been formed by erosion before sedimentation of the Pa Mo gravel formation occurred. The G-1 and F1 faults are distributed near the underground valley. Therefore, the site of the cut-off wall should be located toward the mountain side (the western side) from the G1 fault to satisfy condition ④ (salinisation).

The cut-off wall is set up in the underground valley at an elevation of 185 m above sea level on the upper surface of the Maha Sarakham Formation (Fig. 17). Therefore, the cut-off wall has three sides. The catchment area and the reservoir area are estimated to be about 9 km^2 and 2 km^2, respectively. The amount of groundwater recharge from the catchment area is estimated to be about 1,000,000 m^3. The volume of the storage capacity in the aquifer is about 10,000,000 m^3 when the full water level is located at an elevation of 185 m above sea level. If the porosity is assumed to be 10%, the volume of the storage groundwater is 1,000,000 m^3.

3) Construction of the cut-off wall

The curtain grouting method was used to build the cut-off wall at the initial stage of the construction of the subsurface dams in Japan (1970s), namely the Nomozaki subsurface dam (aquifer: gravel layer) in Nagasaki prefecture and Minafuku subsurface dam (Ryukyu limestone) in Okinawa prefecture. After tests were conducted for the construction, the mixed-in-place slurry wall method has been applied since the 1970s[23, 27]. The

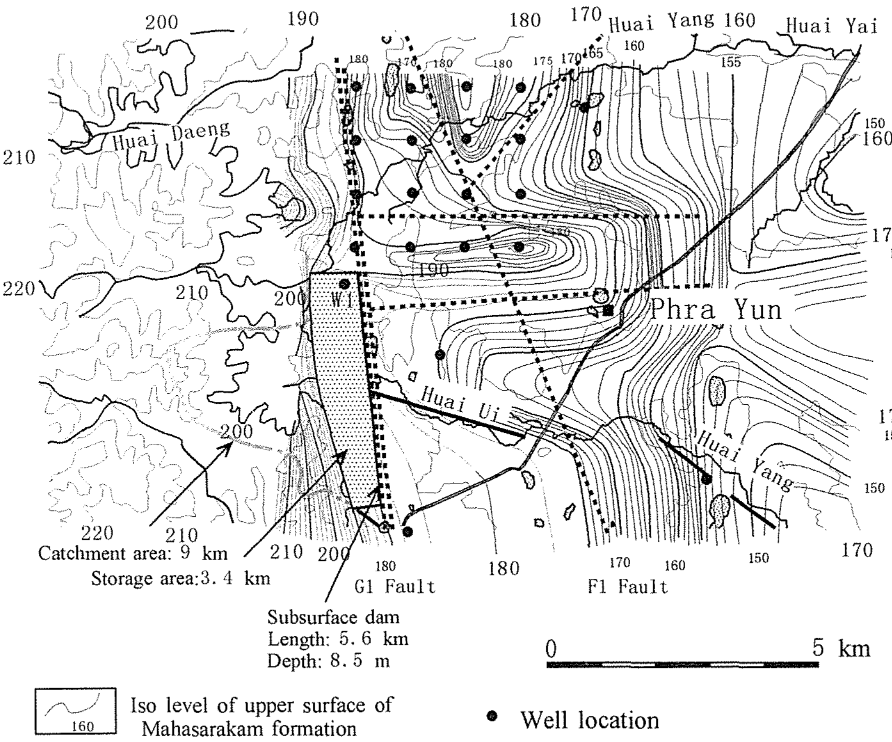


Fig. 16. Upper surface structure of the Maha Sarakham Formation

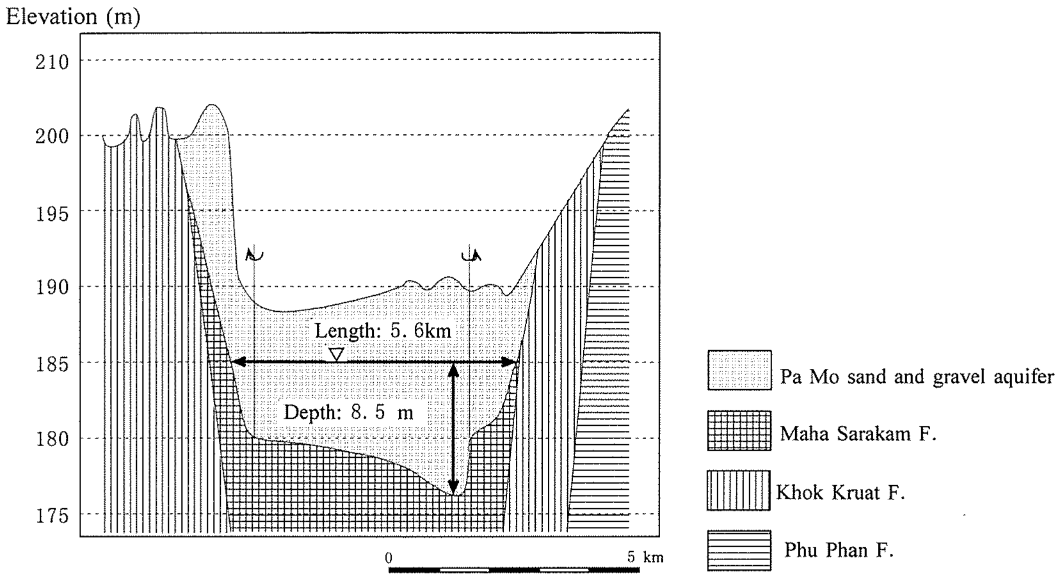


Fig. 17. Geological section along the designed cut-off wall

same method is suitable for the construction of cut-off wall in the model district. However, the method of open digging and construction of cut-off wall can be examined in the part where the depth of work is shallow.

Summary

In the hydrological cycle of Northeast Thailand, 15% of the precipitation consists of run-off, 10% of groundwater discharge, and 75% of the remainder of evapotranspiration. The total storage capacity of dams which have been constructed until now is 7.1×10^9 m^3. However, further development of water resources by the construction of large-scale dams is impossible because dam sites are limited by topographical factors in Northeast Thailand. Another possible method for the development of water resources is the construction of small-scale ponds.

There are many small-scale ponds in Northeast Thailand, but very few are used for irrigation. Moreover, there are abandoned ponds where storage water had been affected by seepage of saline groundwater. The ponds are not used for irrigation for the following reasons; ①Since water level of the ponds is lower than the ground level of surrounding paddy fields, the farmers would have to invest money for pumping facilities and operating cost. However, farmers can not earn enough to invest. This problem is characteristic of the subsurface dam. An official subsidy fund and system for managing crops is required. ② Unplanned construction of small-scale ponds in salt-affected land causes salinisation of storage water. To prevent salinisation, it is necessary to construct the ponds far from faults.

The ratio of precipitation in the rainy season to annual precipitation is about 80% - 90% in Northeast Thailand. An important problem for agriculture in the region is how to use the excess water from August to September. The construction of subsurface dams is proposed as a method of effectively using the excess water. The example shown in the model region was designed based on limited geological data. An error of several meters in the upper surface structure of the basement may affect the storage capacity by several tens of thousand m^3 because the subsurface dam stores groundwater in the aquifer over a broad area and at a shallow depth. Before the construction of subsurface dams in Miyako island in Japan, a structural map of the upper surface of the basement was drawn based on bore data of 4 - 6 wells/km^2. Note that the example shown here contains considerable errors.

Acknowledgments

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東北タイにおける水資源の現状と地下ダム建設の可能性評価

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摘　要

東北タイは，不規則な降雨，農業用水の不足，肥沃の劣る土壌のために，この地域の農業収入はタイで最も低い。灌漑水の不足が東北タイの貧困の主要な原因である。大規模なダムの新たな建設は，地形的な要因から期待できない。のこされた方法は，小規模ため池による水資源開発である。しかし，東北タイにはたくさんのため池があるにもかかわらず，これらを使った灌漑は希なケースでしかない。この報告では，東北タイの水資源についてレビューし，小規模ため池の現状と利用についての問題点を検討した。さらに，東北タイの雨期の過剰な雨水を貯蔵して乾期に使う方法として地下ダムによる方法を提案した。

キーワード：天水田，小規模ため池，塩性地下水，過剰降雨

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