KINGDOM OF THAILAND

Department of
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Federal Institute for Geosciences
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BGR
Hannover

TECHNICAL COOPERATION
PROJECT NO.: 93.2080.5

Environmental Geology for Regional Planning

TECHNICAL REPORT NO. 39

DMR REPORT NO.

HYDROGEOLOGY OF THE KHORAT GREATER CITY AREA AND INVESTIGATION OF THE CAUSES AND EFFECTS OF GROUNDWATER AND SOIL SALINIZATION

by

Tinnakorn Tatong and Dr. Armin Margane

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Authors: Tinnakorn Tatong (DMR) and Dr. Armin Margane (BGR)
Commissioned by: Federal Ministry for Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung, BMZ)
Project: Environmental Geology for Regional Planning
BMZ-No.: 93.2080.5
BGR-Archive No.:
Date of issuance: November 2004

Abstract

During the follow-up phase of the Thai-German Technical Cooperation Project 'Environmental Geology for Regional Planning' the groundwater resources availability and quality in the Khorat Greater City Area (3,000 km^2) were investigated for landuse planning purposes. This investigation also contributed to an analysis of the causes and effects of groundwater and soil salinization. Information is based on data from 520 groundwater wells and raises the understanding of groundwater flow in the two main aquifer types, the unconsolidated and the consolidated aquifers. The unconsolidated aquifers are recognized in Alluvial and High Terrace Deposits, confined mainly to the channels of the main streams and rivers. The consolidated aquifers are found in the Phu Thok, the Maha Sarakham and the Khok Kruat Formations. Depth to groundwater is less than 5 m in the northern part and deeper in the southern part. Recharge from rainfall is relatively high, due to the predominantly sandy soils, ranging from 15 to 30 %. Concerning their hydrochemical composition, the groundwater type in the recharge area is mainly Ca-HCO_3 water, whereas further along the flow path water is subject to cationic exchange processes with sediments and thus predominantly of Ca-Na-HCO_3, Na-Ca-HCO_3 or Na-HCO_3 type. In the salt affected discharge areas water is mostly of Na-Cl type. For landuse planning purposes, two groundwater related maps were prepared, showing the groundwater exploitation potential and the groundwater quality. A medium to high exploitation potential is observed in the central part. Freshwater of acceptable drinking water quality mainly occurs in the southern part of the project area. A close relationship between groundwater levels and groundwater and soil salinity is observed. Salt crusts frequently occur in areas where depth to groundwater level is less than 1 m. Saline soils also occur in areas covered with vegetation where groundwater levels are less than 2m. It is assumed that evapotranspiration from groundwater in such areas leads to the accumulation of salt in the soil and the shallow groundwater as observed in the piezometers of Land Development Department. It is assumed that the effect of soil and groundwater salinization is caused by the dissolution of rock salt which occurs in the Maha Sarakham Formation at shallow depth. The dissolved salt is brought to the surface with groundwater flow. The increase of groundwater recharge due to deforestation and major changes in the landuse pattern has brought about an increase in salt dissolution and discharge of saltwater. The extraction of saltwater for table salt production also has resulted in discharges of saltwater in the form of highly saline effluents into the environment. Whereas previously soil and groundwater salinization was kept at a low level due to the regular flushing out of saltwater during the rainy season, the blocking of surface water flow by numerous small and large dams which were constructed since the 1960s has resulted in a continuously growing accumulation of salt in the area and therefore in an increasing size of the areas affected by soil and groundwater salinization. A number of counter-measures are proposed by the project to mitigate groundwater and soil salinization.

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1. Introduction

This report documents the work of the Thai–German technical cooperation project 'Environmental Geology for Regional Planning' in the field of hydrogeology. The project started in 1996 and was divided into three phrases. During each phase different geological problems affecting the environment were dealt with. The third phase, or so-called follow-up phase focused on environmental problems in the Khorat or Nakhon Ratchasima Province, located in the northeastern part of Thailand. This part is mainly affected by soil and groundwater salinization and called Khorat Plateau because of its relatively high and flat topography.

The insufficient availability of freshwater resources has always been a problem in this area. The main reasons for this are the unfavorable meteorological, geological and topographical conditions. Although the area receives the same amount of precipitation as other areas, evapotranspiration, being higher than in many other areas of Thailand, consumes most of the rainfall for most times of the year. Moreover the Maha Sarakham Formation, which sometimes is found at shallow depth throughout the Khorat Plateau, contains layers of rock salt that reach a combined thickness of up to around 300 m. During the passage through the underground groundwater dissolves this salt, especially in areas where rock salt is found at shallow depth. In the groundwater discharge areas, which are located in topographic lows, highly mineralized groundwater then rises to the surface. The dissolution process seems to be favored in areas with elevated permeability, such as along faults and fractures, and in areas where the rock salt is found at shallow depth below ground surface. Even though the thickness of sediments overlying the salt sequence is mostly not very thick, it is assumed that salt pillows and domes have developed, especially at zones of structural weakness, such as along major fault zones and intersections thereof. Due to the general groundwater flow from topographically high to low positions, groundwater is commonly of good quality on the recharge mounds, whereas it is highly mineralized in the depressions and topographic lows.

Over the past century landuse has changed considerably in the northeastern part of Thailand. The rapid development of the infrastructure during the 1950s and 1960s was followed by a dramatic increase in cultivated land. The land, previously mainly covered by forests, was converted into arable land, mostly paddy fields. This conversion process commenced in the valleys and rapidly expanded to higher areas. Nowadays there is almost no forest left and even the hilltops are covered with cultivated land. On the other hand soil and groundwater salinity seem to have started in the low-lying areas of the valleys and have then spread farther upland. Therefore, landuse change is seen as the major factor causing soil and groundwater salinity in northeastern Thailand. The processes which are believed to have caused the increased soil and groundwater salinity as well as measures to alleviate the situation will be discussed in more detail in chapters 4 and 5.

Salty water influences human life to a considerable extent. There are few types of crops which can be grown on saline soil. Secondly, crop production is reduced. For humans and animals, freshwater is a necessary commodity for daily life. The availability of water in adequate amounts and quality confines human development and livestock production to freshwater areas. Sometimes water has to be imported at high costs from outside areas. Due to the low agricultural production and the higher living costs, the people in the Northeast are the poorest in Thailand. This study is intended to contribute to a more sustainable and environmental friendly development and use of the natural resources in the Khorat area. It is hoped that, if the recommended counter-measures are being implemented, the environmental and economic situation in the Northeast will recover. This recovery process, however, may take a long time since soil and groundwater salinity has already affected around 50 % of the region.

The work conducted during the follow-up phase extends the scope of environmental geological work of DMR much further than in the previous two phases and is the result of a comprehensive and multi-disciplinary approach. The main aim of the follow-up phase was to contribute to an explanation of the processes that have led to increased soil and groundwater salinity in the Khorat Plateau. To this end the work was divided into four major fields of work: **hydrogeological, geophysical, and remote sensing investigations as well as the study of landuse change**.

The task of the geophysical work was to answer the following two questions: 1) Do salt domes occur in the Khorat Plateau or is the top and bottom of the rock salt layer more or less flat ? 2) How can the spatial distribution of brackish/salty and fresh water be characterized? Remote sensing was used to delineate the areas affected by soil salinity. These areas can be identified on satellite images by the spectrum of the reflected light. Landuse change was analyzed using aerial photographs taken at different times: 1955, 1967 and 1999. Deforestation was identified as the most critical factor in this context. The hydrogeological work was aimed to characterize the aquifer systems and to provide the base data for groundwater modeling to be conducted at a later stage.

The results of the above mentioned studies, the geophysical work, the remote sensing work, the assessment of landuse changes and the groundwater study are documented in separate reports.

Important for the overall understanding of the salt dissolution and transport problems is also the knowledge about the history of development of the area:

- What were the different steps of development (construction of infrastructure, such as roads, canals and reservoirs, development and exploitation of water resources)?
- How has the landuse changed over the past century (expansion of agriculture, deforestation)?
- Which crops are mainly grown, what is the agricultural productivity, and how and where did it decrease over the past 20 years due to increased soil/groundwater salinization?
- Facts about the socio-economic development: What is the income of the local population, how has it changed over time, and what forms the basis for this income? Where has the number of inhabitants increased/decreased with time and what is the reason for this?

Some of these questions could be answered by questioning the local population and using statistical data from the Department of Statistics, the Department of Agriculture and the Department of Forestry.

1.1 Objectives

The main objective of the hydrogeological study were to
- delineate and characterize the groundwater system
- asses groundwater quality and groundwater abstraction potential and prepare corresponding maps
- estimate the impact of landuse changes on groundwater recharge and evapotranspiration
- understand the interrelation between landuse changes and groundwater and salinity problem in this area.

1.2 Study area and physiography

Khorat, also called Nakhon Ratchasima, is the largest province in the northeastern part of Thailand. The province covers an area of 20,548 km² and has a population of about 2.5 million. It is located at the southwestern border of the Khorat-Ubol basin, about 260 km northeast of Bangkok.

Due to the very large size of the Khorat province it was too large to be studied in detail. Since one of the main aims of the project is to study fast growing areas an area of 3,000 km² around Nakhon Ratchasima City, in the following called Greater City Area, was selected as study area. The following boundaries were chosen for this Greater City Area: latitude 101° 50' to 102° 20', longitude14° 45' to 15° 15'. (Figure 1.1)

The hydrogeological study area covers the following topographic map sheets of 1:50,000 scale:
- Amphoe Non Thai (5439III),
- Changwat Nakhon Ratchasima (5438IV),
- Amphoe Non Sung (5439II, western part),
- Ban Saraphi (5438I, western part),
- Amphoe Dan Khun Thot (5339II, eastern part) and
- Amphoe Sung Noen (5338I, eastern part).

The UTM system was used as grid reference, like in all previous studies. This, however, bears some difficulty, since along latitude 102° the UTM zone changes from zone 47 to zone 48. It was therefore agreed to use zone 47 for the entire project area. Concerning the political boundaries, the hydrogeological study area covers 9 districts: Muang Khorat, Kham Thale So, Chaloem Phrakiat, Dan Khun Thot, Non Thai, Non Sung, Sung Noen, Chok Chai and Pak Thong Chai.

Figure 1.1: Location of the hydrogeological study area

With regard to its physiography, the studied area is a low relief area without any major mountains. The elevation of ground surface ranges between 163 and 282 meters a.s.l. with the highest point in the southern part of the hydrogeological study area. According to its elevation, the area can be generally divided into lowland area and hilly area. The lowland area occupies the northern part and the hilly area the southern and western parts. The elevation also controls the direction of surface water flow. In the hilly area, small streams flow in radial directions. There are a few big rivers in this area. The biggest is the Mun River, flowing from south to north in the hilly area, and then bending to eastern direction in the lowland (Figure 1.2). The Lam Takhlong is a major river which flows in west-east direction through the project area. It joins the Mun River in the Chaleom Phrakiat district. Another main river is the Lam Chiang Krai, flowing from west to east in the northern lowland area. Another important surface water feature is the occurrence of small natural lakes in the lowland area.

These lakes are believed to result from land subsidence caused by salt dissolution. They often contain brackish water and its water is used for washing and for cattle.

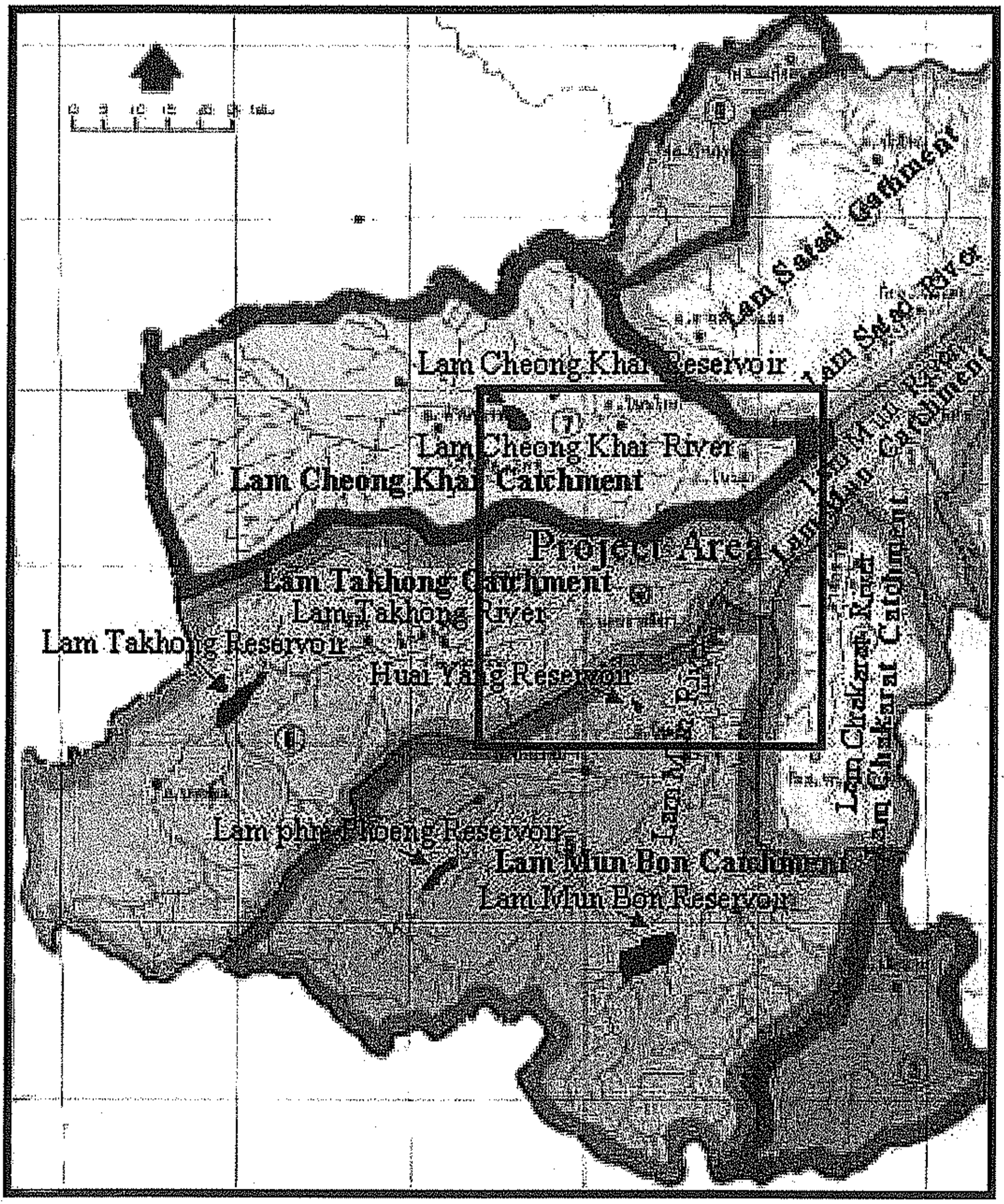

Figure 1.2: the hydrography with the boundaries of the catchment areas, the location of large reservoirs and the main streams.

1.3 Climate

The hydrogeological study area is located in the tropical zone, influenced by monsoons from three directions: NE, SW and W, and by wind from the south. There is a cyclic change of directions of monsoons and winds during the year. The rainfall, and thus the season, depends on the wind direction. Accordingly three seasons are distinguished: winter, summer and rainy season.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991	NE	NE	S	NE	S	SW	SW	SW	W	NE	NE	NE
1992	NE	S	S	S	S	SW	SW	W	W	NE	NE	NE
1993	NE	NE	S	S	S	SW	W	SW	W	NE	NE	NE
1994	NE	NE	NE	S	SW	SW	SW	SW	W	NE	NE	NE
1995	NE	NE	S,NE	S	SW,S	S	W	SW	NE	NE	NE	NE
1996	NE	NE	S	S,NE	SW	SW,S	SW	SW	SW	NE	NE	NE
1997	NE	NE	NE	S	S	SW	SW	SW	W	NE	NE	NE
1998	NE	NE	S	S	S	SW	S	W	NE	NE	NE	NE
1999	NE	NE	S	E	SW	SW	SW	SW	SW	E	NE	NE
2000	NE	NE	NE	S	SW	SW	W	W	W	NE	NE	-
average	NE	NE,S	S,NE	S,NE,E	S,SW	SW,S	SW,W,S	SW,W	W,NE,SW	NE	NE	NE

Table 1.1: Wind directions prevailing in the study area

The winter season lasts from November to February, when the NE Monsoon prevails in the area. The monsoon, carrying dry cool air, moves southward from China to Thailand. This causes a decrease of the average temperature and the minimum temperature can drop to 13° C during this season (Figure 1.3).

Summer season starts in March or April. In this period there are no monsoons. The area is warmed up by southerly winds. The temperature can rise to 40° C. The highest temperatures are reached in April, afterwards they are declining. Thunderstorms sometimes can occur when cool air from the NE pushes the warm wind southwards.

The rainy season lasts from May to October, when West and South-West monsoons coming from the Andaman Sea blow over the area. The average rainfall is 1,051 mm/yr having two peaks: one in May, the other in August (Figure 1.5).

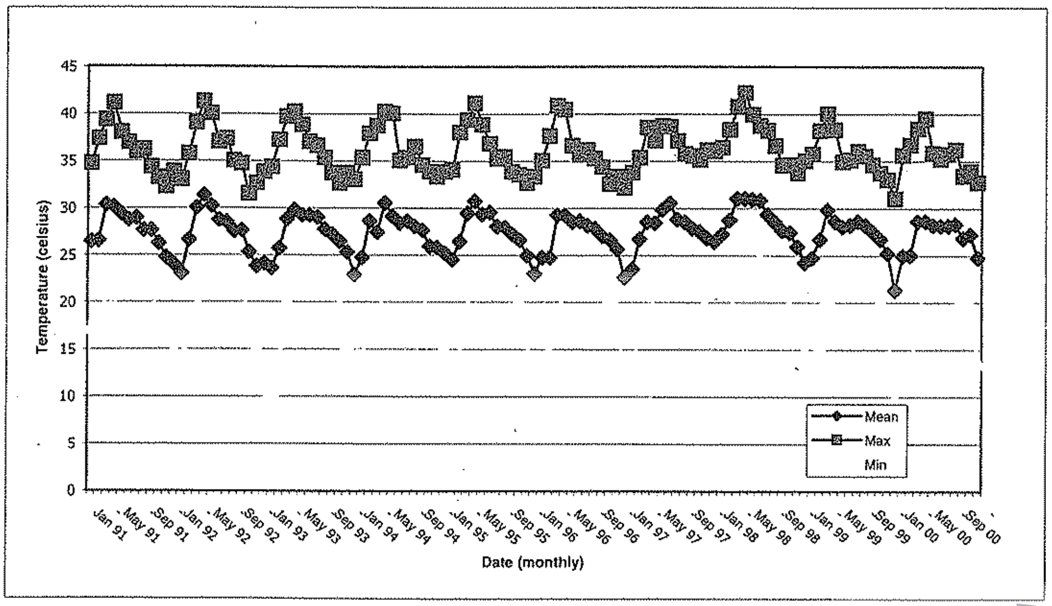

Figure 1.3: Monthly temperature at Nakhon Ratchasima (1991-2000).

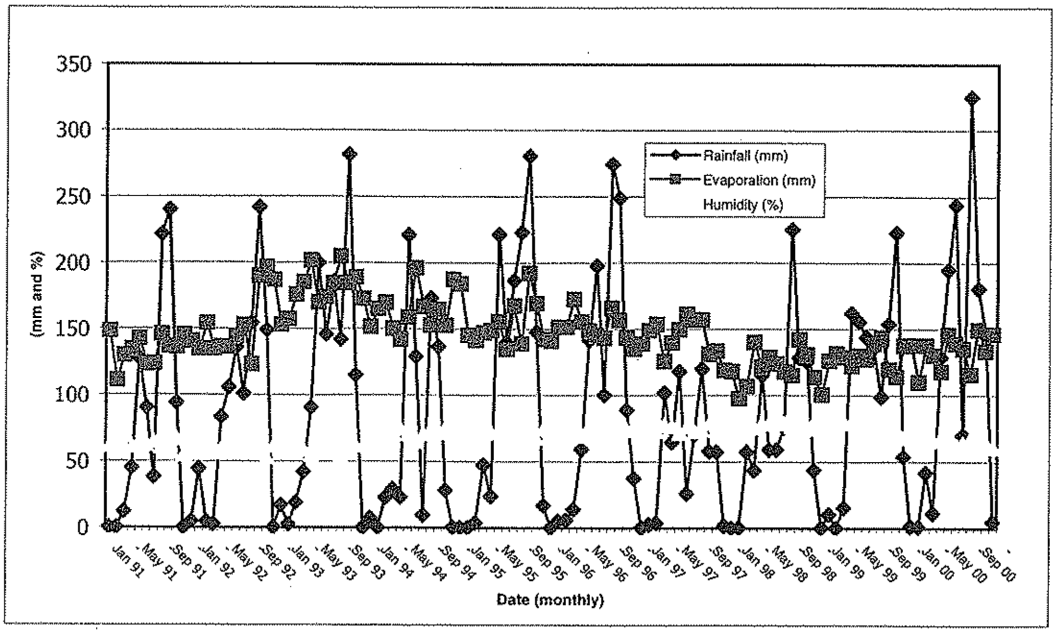

Figure 1.4: Monthly rainfall, evaporation and humidity at Nakhon Ratchasima (1991-2000).

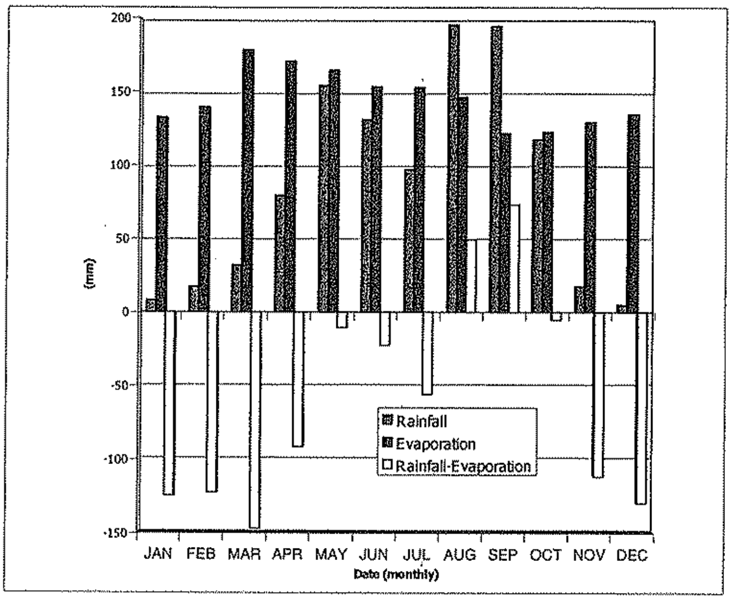

Figure 1.5: Relationship between average rainfall and average evaporation at Nakhon Ratchasima (1991-2000).

In comparison with other areas rainfall is not much lower than elsewhere. However, the potential evaporation is considerably higher, reaching around 1,750 mm/yr (Nakhon Rachasima station, 1991-2000). During most times of the year potential evaporation exceeds rainfall so that all of the rainfall is consumed by evaporation, except during August and September when evaporation is slightly lower than rainfall. Only during these two months groundwater recharge may occur.

1.4 Surface Water Resources

Surface water is very important for the project area because groundwater is limited by both quality and quantity. There are 3 large rivers flowing through the project area, Lam Mun, Lam Takhong and Lam Chiang Krai. The catchment area of Lam Mun River is separated into Lam Mun Bon (Upper Part) and Lam Mun (Lower Part). The Lam Mun Catchment covers southern part and eastern part of the project area. The Lam Takhong Catchment is in the middle part and western part and Lam Chiang Krai Catchment is in northern part of the project area.

Even there 3 large rivers flow through this area, water from the rivers can be used in small areas and in short period of rainy season. Therefore the Royal Irrigation Department constructed dams in the upper or middle part of those rivers to keep water for using in dry season and distributing to irrigated areas.
The important dam in Lam Ta Khong Catchment is Lam Takhong Dam which was constructed to control water in the upstream of Lam Takhong River at Sikhiu District, around 57 km west of Khorat in 1964. It was finished in 1969. Its dimension is 40.3 m in height and 521 in length. The dam created a reservoir containing 310 million m^3 of water that supply irrigated area about 79.71 km^2 in rainy season and 31.25 km^2 in dry season. Moreover the water is used for supplying the municipality waterworks of Sikhiu, Non Sung, Kham thale So and Khorat.

The large dams in Lam Mun Bon Catchment are Lam Phra Phoeng, Lam Mun Bon and Lam Chae.

Lam Phra Phoeng Dam was build in 1963 and finished in 1970. Its dimension is 50 m in height and 575 m in length. It can reserve water around 152 million m^3 and can distribute water to irrigated area around 53.1 km^2 in wet season and 12.5 km^2 in dry season.

Lam Mun Bon Dam and Lam Chae Dam are finished in 1995 and 1999 respectively. They are in upstream of Mun River in Khon Buri District about 80 km south of Khorat. The Lam Mun Bon Dam is 30 m in height and 800 m in length. The maximum volume of Lam Mun Bon Reservoir is 141 million m^3 which can supply 27.9 km^2 of irrigated areas. The Lam Chae Dam is 2400 m in length and has capacity to hold 275 million m^3 of water. It can supply water to irrigated area around 71.1 km^2.

In the Project area, there are only Weirs (Fai in Thai) (Figure 1.7) creating large to small reservoirs. The largest reservoir in the project area is Lam Chiang Krai located in northeastern part of the project area. Another large reservoir is Huai Yang in southern part. Other reservoirs are ponds (Sra in Thai) and swamps (Bung in Thai). All of these reservoirs are used for both domestic and irrigation in surrounding areas. Surface water quality depends on areas and on seasons. The water quality in salinity soil areas or in northern part of the project area is poorer than southern part and in wet season is better than dry season. Unfortunately villagers in the northern part of the project area do not have other chances. They have to use water from reservoirs even water quality is very poor in the dry season (Figure 1.6). The electrical conductivities of the water from soil salinity area are mainly higher than 1,000 µS/cm and it can rise up to 11,5,00 µS/cm but its quality is better than that of groundwater. The conductivity values of surface water from non soil salinity area are only below 400 µS/cm. The conductivity of water in rivers is also raised when the rivers flow through the soil salinity area for example the water in the Lam Takhong River. The conductivity of water in Lam Takhong River when it enters the soil salinity area is only 319 µS/cm. The conductivity is raised to 616 µS/cm when the water reaches Khorat City and becomes 1,190 µS/cm when it arrives at Chaleom Phrakiat District.

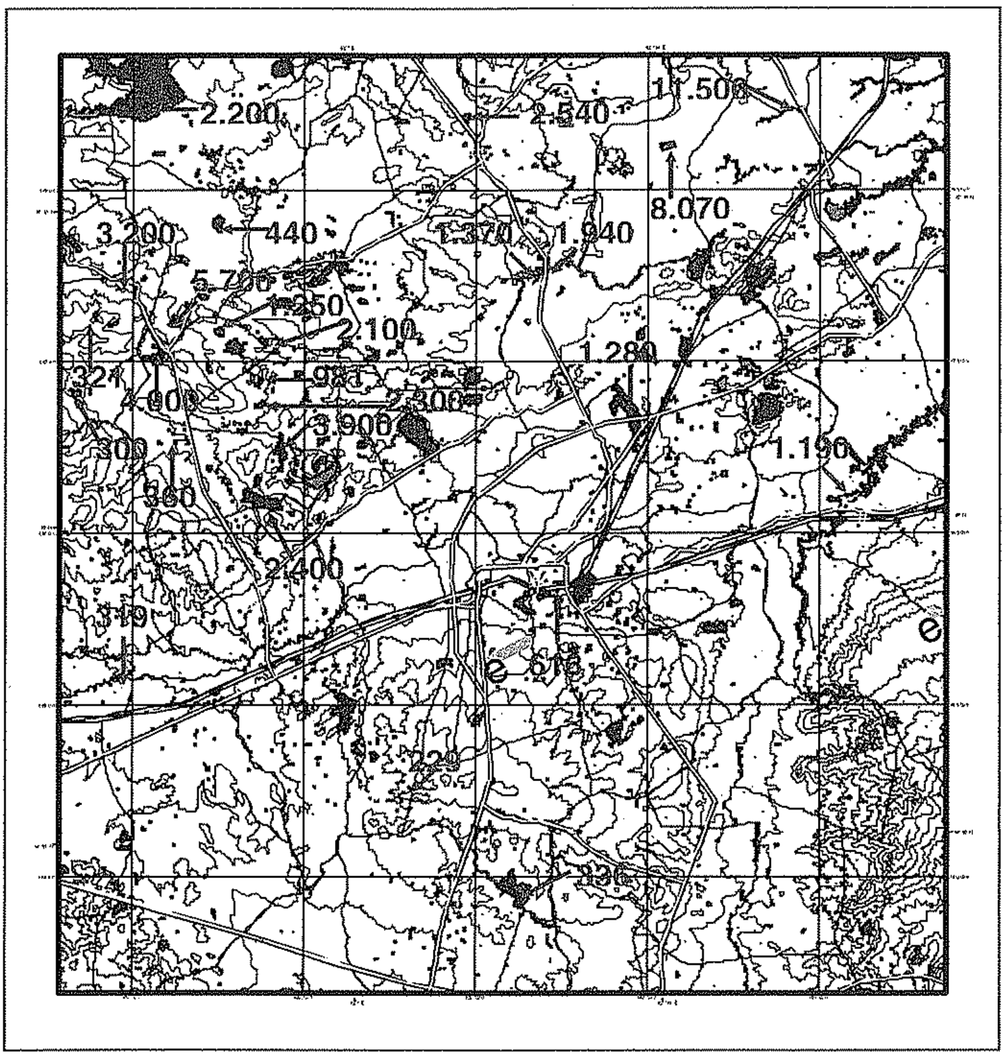

Figure 1.6; Electrical conductivity of surface water in the project area.

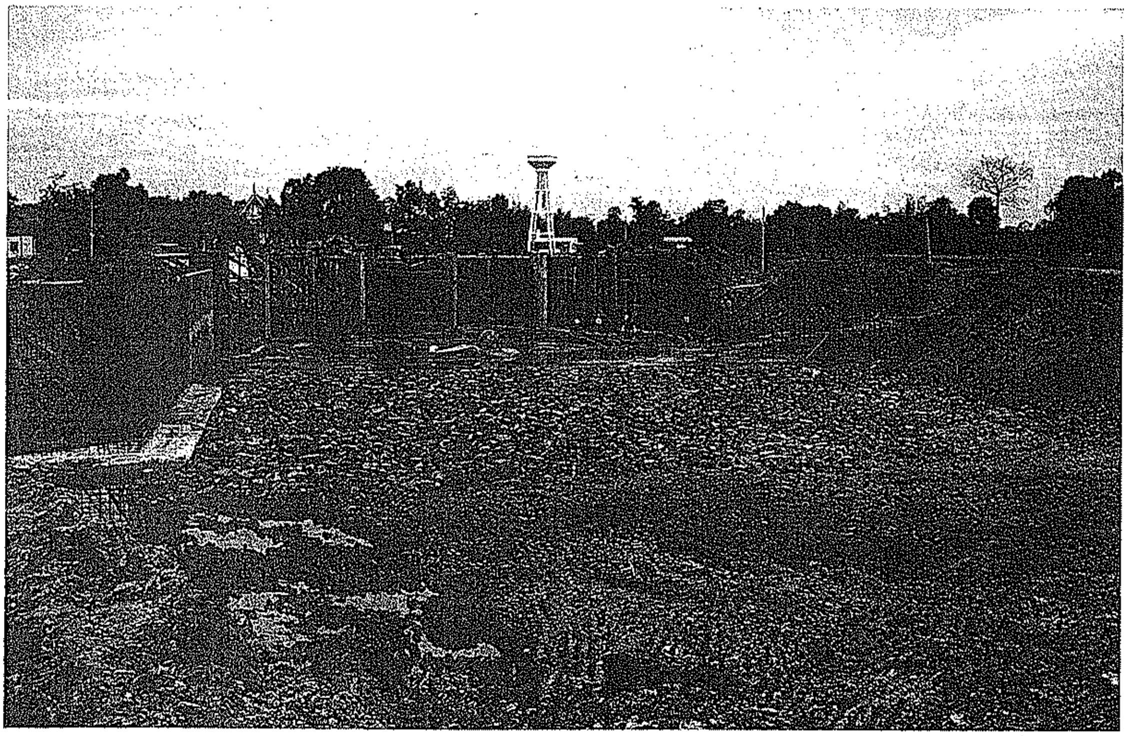

Figure 1.7: Construction of a weir in the Lam Chiang Krai River near Ban Na (June 2002)

1.5 Land use

The process of land use change closely related with the growth of population and economic. Forest areas in lowland areas were changed to be rice field for feeding family in the early time then maize was cultivated in upland areas as cash crops in the first half of the 1950s (Prodeus, 2003). After growing maize around 10 year, they changed to be cassava growing very well in dry-land areas. Moreover, cassava could substantially export to European countries for feeding animal. This raised the prize of cassava and increased the new growing cassava areas. The need of new agricultural land resulted in clearing forest areas by logging and burning. From 1961 to 1982, the forest areas were reduced from 56 % to 11 %. Presently cash crops growing in this area are mainly cassava and sugar cane. The extension rate of agricultural area is very small but land for constructing settlements is expanding. Normally the expanding of settlement is in the same direction of roads or lay beside main roads. However, Khorat city area cannot enlarge to south part because it is mainly military areas. Therefore the city area expanded in north direction to lowland areas which are agricultural areas.

Year	Forest Area [km²]	Percentage
1961	11378	55.5
1973	5713	27.9
1976	4477	21.8
1978	3653	17.8
1982	3036	14.8
1985	2826	13.8
1988	2582	12.6
1989	2577	12.6
1991	2340	11.4
1993	2294	11.2
1995	2258	11.0
1998	2223	10.8

Table 1.2: Statistical data showing deforestation in the Khorat Province (Royal Forestry Department, total area of Khorat Province: 20.494 km^2)

1.6 Previous Works

The Greater City Area was studied by many researchers, however, most results are related to the Khorat Plateau or the Khorat-Ubol basin. There are a few works that concentrate only on the Nakhon Ratchasima Province. These reports can be divided into three groups, as follows

Hydrogeology:

Wongsawat et al. (1988) published a groundwater map of the Nahkon Ratchasima province at a scale of 1:100,000. The map shows: type of aquifer, TDS distribution using different colors and expected well yield using color strength.

Geology:

Parry (1996) compiled a report on 'The high terrace gravels, Northeast Thailand – a re-evaluation and an integrated theory of their origin'. He proposes that the High Terrace in the Korat-Ubol Basin was formed by debris floods which were injected through water gaps at the western edge of the basin.

Wongsomsak (1986) published a report on the salinization in northeast Thailand. The report classifies saline areas into three types: hill, valley and basin. It also describes sources and mechanisms of salinization for the whole region. According to the author a major source of salt is the rock salt from the Maha Sarakham Formation. The mechanisms are short distance interflow of salty water and capillary force.

Sattayarak et al. (1987) wrote an article on the influence of the rock salt to the groundwater in the northeastern part of Thailand. Their study is based on seismic data and data from salt exploration wells. They concluded that the occurrence of saline groundwater is correlated to the depth to rock salt and salt domes. [in Thai]

Suwanich (1992) published results from potash exploration in the northeastern part of Thailand conducted between 1973 and 1983. The report includes geologic history, tectonic evolution of the Maha Salakham Formation and mineral reserves for the whole region. [in Thai]

Surinkham (2000) conducted a geophysical survey at Ban Wang, Amphoe Non Thai, Nakhon Rachsima province to clarify the cause of land subsidence from saltwater mining using vertical electric soundings (VES) and ground penetrating radar (GPR) surveys. From geophysics interpretation, 15 underground cavities were detected surrounding the saltwater mining area and rock salt is believed to be at a level of between 50 to 100 m below ground surface. [in Thai]

Soil sciences:

Arunin (1993) complied the book about salt-affected soils. The book is composed of papers from Department of Land Development and Department of Mineral Resources. Contents of the paper include salt-affected soils in central part and coastal area and northeastern part of Thailand, salt-affected area development project, rehabilitation salt-affected areas, hydrogeology of northeastern part, influences of rock salt layers to groundwater and methodology in decreasing salt content in soil. [in Thai]

The Land Development Department (LDD, 1995) published an article on soil salinity. The article explains salinization mechanism, distribution, classification of saline soil and problem solution. [in Thai]

Dissataporn (2002) issued the thesis on application of electromagnetic method to detect soil salinity and the rehabilitation of salt-affected soils in northeastern Thailand. The thesis concluded that the electromagnetic technique can be roughly identified the salt distribution. For the rehabilitation of salt-affected soils, the thesis suggests to grow tree in recharge area and to use engineering option which includes ditch and canal area that promote the leaching of soluble salt from soil profile.

2. Geological Setting

Geologically, the Greater City Area is located in the Indochina continent which collided with the Shan-Thai continent during the late Triassic (Mantajit, 1997). Afterwards the two continents were uplifted. Therefore most sedimentary rocks in the Cretaceous period are of non-marine origin, known as Khorat Group. This group contains 9 formations (Meesuk et al., 2000): Huai Hin Lat, Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, Khok Kruat, Maha Sarakham and Phu Thok. They are widely exposed throughout the northeastern part of Thailand particularly on the edge of the Khorat Plateau.

In the Khorat Greater City Area, encompassing approximately 3,000 km^2 around Khorat City, only two formations are cropping out. The oldest rocks in this area belong to the Khok Kruat formation of Cretaceous age, followed by the Phu Thok Formation of Cretaceous-Tertiary age. However, the two formations are covered by Quaternary sediments in some areas.

2.1 Stratigraphic Rock Units

As mentioned above, the Greater City Area is only underlain by sediments and sedimentary rocks. Their ages range from Cretaceous to Quaternary. According to the Geological Map of the Khorat Greater City Area, scale 1:100,000 (Chaimanee, 2003)(Figure 2.2), the stratigraphic units can be divided as follows;

The Khok Kruat Formation (K_{kk}, Early Cretaceous) is broadly distributed in the southern portion of the study area except for areas nearby large rivers. The formation crops out in Amphoe Muang Nakhon Ratchasima, Amphoe Pak Thongchai, Amphoe Chodchai and Amphoe Kham Thalaeso. It comprises sandstone, siltstone, mudstone and conglomerate. The formation is reddish-brown to purplish-red in color. In the uppermost part of the mudstone bed, there are some calcrete nodules and caliches. The formation is famous for dinosaur remains. Results from vertebrate dating suggest that this formation was deposited in the Aptian and Albian period of the Lower Cretaceous. At that time, sediments were deposited by meandering rivers under arid conditions (Meesuk et al., 2000). The total thickness of this formation is between 430 and 700 meters.

The Maha Sarakham Formation (KT_{ms}, Late Cretaceous-Tertiary), according to the strtigraphic classification of the geologic map of Thailand (1999 or previous version) (Figure 2.1), is composed of rock salt layers and the Upper Clastics layer. The formation is found in the northern and central parts or low-lying areas of the Greater City Area. Even in areas where it is covered by alluvial sediments, the formation can be recognized in ponds or trenches. The thickness of alluvial sediments in this area is usually less than 3 meters except for areas nearby major rivers. The formation can be found in Amphoe Dan Khun Thot, Amphoe Non Thai, Amphoe Non Sung and the northern part of Amphoe Muang Nakhon Ratchasima. It is composed of evaporates and sandstones which are interbedded with siltstones and mudstones. The sandstones are red to reddish-brown in color and cemented with salt and gypsum. Sedimentary structures are laminated beds and small-scale cross-beddings. The total thickness of the Maha Sarakham Formation varies between 610 and 1,000 meters. The formation unconformably overlies the Khok Kruat Formation. There is no report on fossil finds in this formation except for pollens dated as Upper Cretaceous.

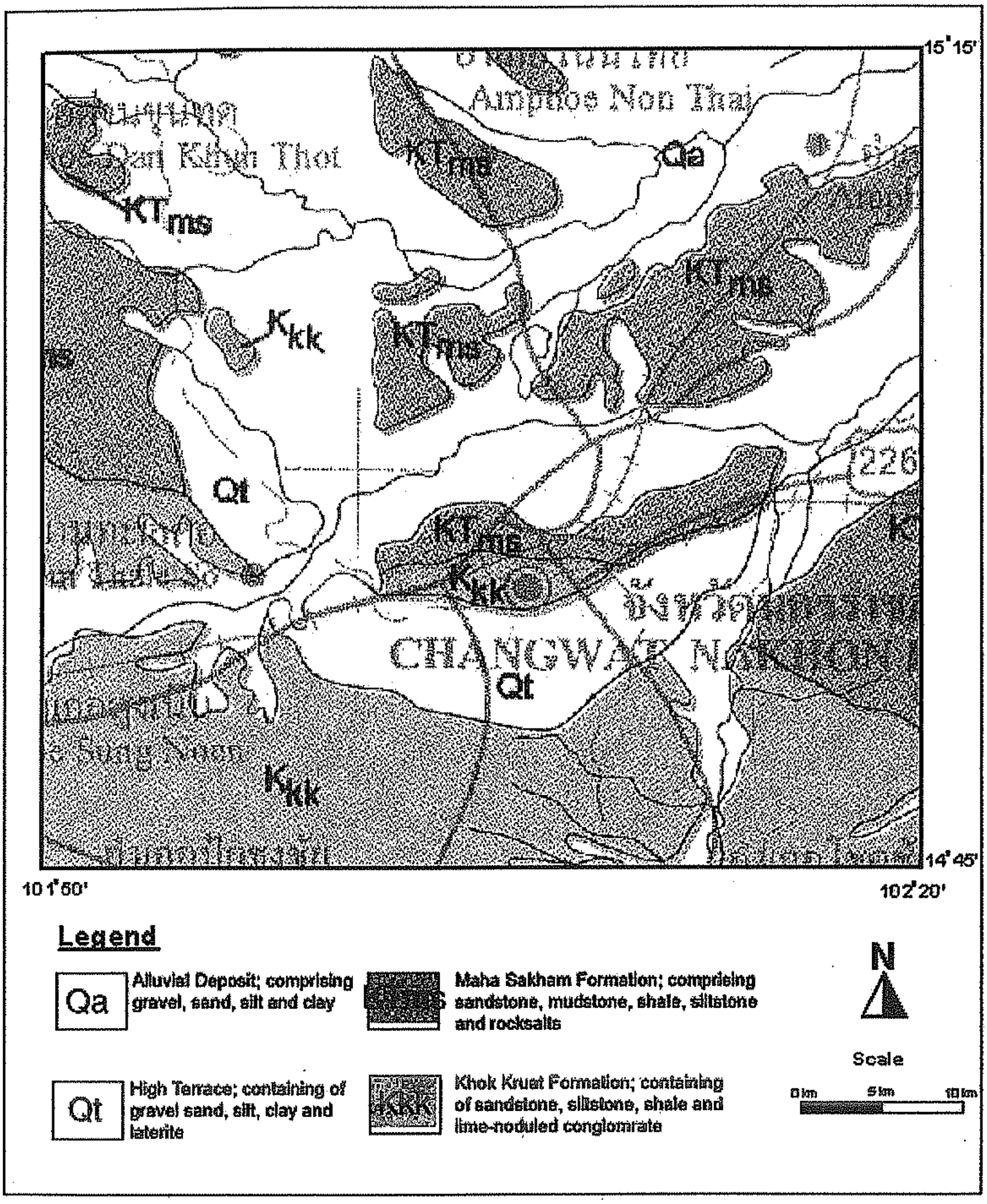

Figure 2.1: Geologic map of the Khorat Greater City Area (DMR, 1999)

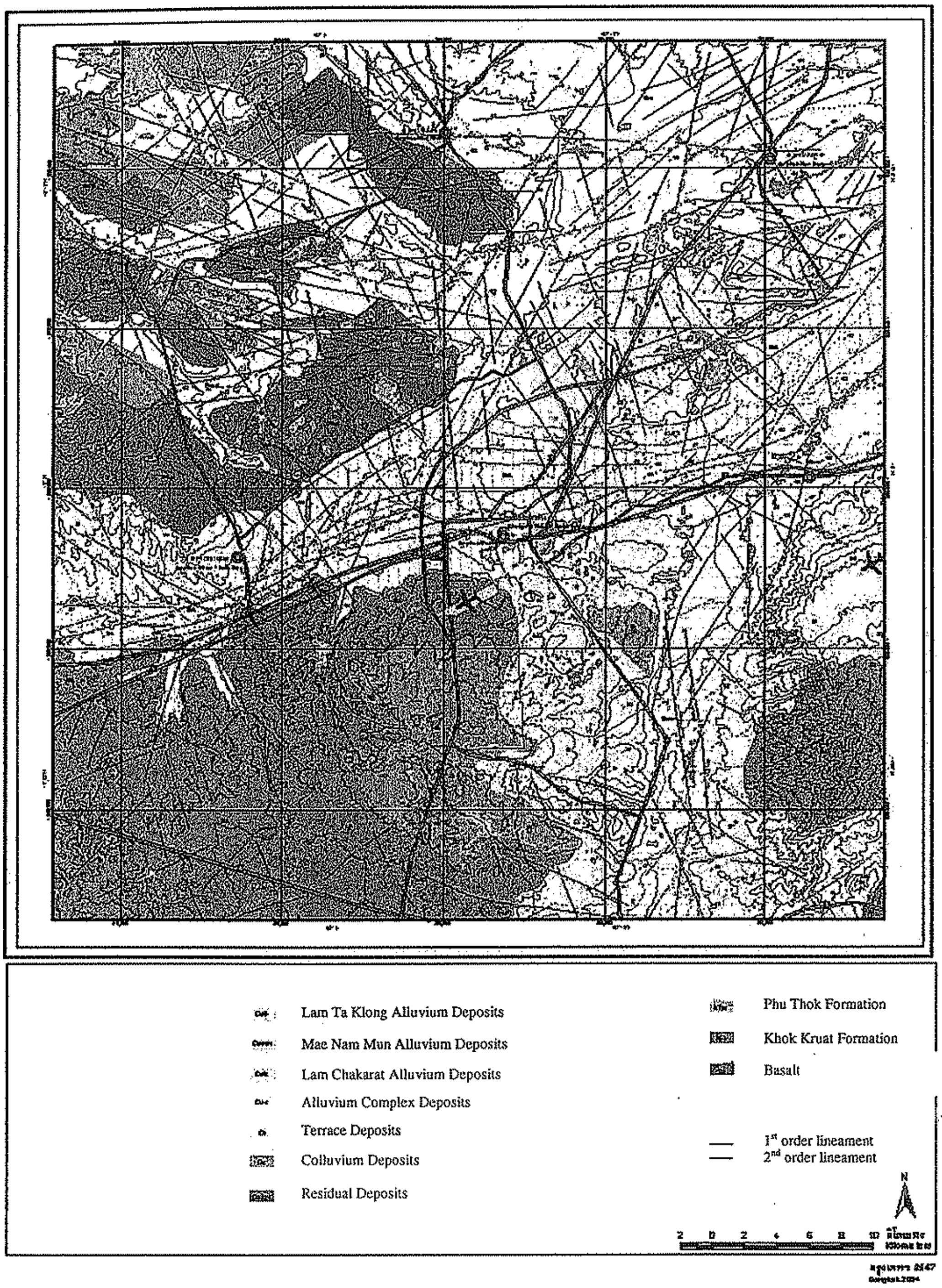

Figure 2.2: Updated geologic map of the Khorat Greater City Area (Chaimanee, 2003).

Recently Meesuk et al. (2000) and Chaimanee (2003) have divided the Maha Sarakham Formation into two formations, the 'new Maha Sarakham' and the Phu

Thok. According to this classifiaction the new Maha Sarakham Formation starts from the lower anhydrite and includes three rock salt layers and clastic layers interbedded between the rock salt layers. The Phu Thok Formation comprises all clastics which overlie the uppermost rock salt layer. The details of the two formations, according to Sattayarak et al. (1987), are as follows:

The new Maha Sarakham Formation (Late Cretaceous) contains three rock salt layers, potash, anhydrites and interlayer clastics.

The rock salt layers are named Lower, Middle and Upper Salt. The Lower Salt layer is widely found throughout the Khorat Plateau. From its chemical composition it is purer than the Middle and Upper Salt layer and its thickness is very high in some areas. The Lower Salt layer can form a dome-like structure in some areas due to its plasticity. The Middle and Upper Salt layers are composed of impure salt, mixed with organic matter and clay. Their color is light brown to black. The thickness of the Middle Salt layer is higher than that of the Upper Salt layer (Figure 2.3).

FORMATION	MEMBER	UNIT	SYMBOL	RANGE OF THICKNESS (m)	AVERAGE THICKNESS (m)
	Top Soil or Alluvium			0-140.21	18.19
PHUTOK	Upper Clastic			25.18-352.81	165.26
MAHA SARAKHAM		Upp. Anhy.		0-5.94	1.32
	Upper Salt			2.74-64.76	20.98
	Middle Clastic			8.97-83.72	38.39
		Mid. Anhy.		0-0.07	0.005
	Middle Salt			21.55-114.91	85.76
	Lower Clastic			0-61.35	21.9
		Low. Anhy.		0-1.10	0.06
		Col. Salt		0-8.75	2.33
	Potash Zone	Upp. Sylvite		0-3.04	-
		Upp. Carn.		0-5.28	1.24
		Tachyhydrite		0-17.73	6.44
		Low. Carn.		0-72.16	14.2
		Low. Sylvite		0-3.20	-
	Lower Salt			17.47-148.47	61.88
	Basal Anhydrite			1.02-1.40	1.21
KHOK KRUAT	Cgl. Sst.			-	-

Figure 2.3: Details of the complete Maha Sarakham section (Suwanich, 1992).

Anhydrites are found as basal and cap anhydrites. The basal anhydrite is the lowest part of the Maha Sarakham Formation and is overlain by the Lower Salt layer. It is white to gray in color and has a thickness of around 1 meter. Cap anhydrites occur at the top of each evaporite layer.

The potash layer comprises sylvinite, carnallite and tachyhydrite. The sylvinite, white to light orange in color, forms a secondary mineral, generated from carnallite which is orange, red or pink in color. The tachyhydrite, easily dissolving in water, is orange or yellow in color. The potash layer can only be found in the upper part of the Lower Salt layer.

The various color rock salt is a thin layer of rock salt that is found above the potash layer. It occurs as thin strip of red, orange, brown, grey and white color.

The clastics layers consist of two layers, the Lower and the Middle Clastics. The former 'Upper Classics' layer is now being reassigned to the Phu Thok Formation. The Lower and Middle Clastics consist of reddish brown soft clay. Salt, gypsum and carnallite can generally be found in this layer.

The Phu Thok Formation (Late Cretaceous-Early Tertiary) is the former 'Upper Clastics' layer, which comprises brick-red or reddish brown sandstone including mudstone and shale in some places. The sandstone is fine to medium grained, well to very well sorted and friable. In thick sandstone beds, large cross-bedding can be recognized. The cross-bedding has a dip angle higher than 25 degrees with varying dip directions. This suggests that the sandstone was deposited by wind.

The Residual Deposits (Q_r) are derived from the Phu Thok Formation by in-situ weathering processes. The deposit can be recognized in the northwestern part of the Greater City Area. Its sequence comprises clayey silt or clayey fine sand layers which overlie laterite and saperite with relics of internal sedimentary structures.

Colluvium Deposits (Qc) were separated from the old High Terrace Deposits by Chaimanee (2003). The sequence of Colluvium Deposits is thick and composed of a loose reddish sand layer overlying a gravelly laterite layer with some tektites. The two layers are underlain by an angular gravel bed.

The High Terrace Deposits (Q_t, Late Tertiary-Middle Pleistocene) can be seen as elongated hills in the central part of the study area especially along the southern bank of the Lam Takhong River. At Ban Phu Khao Thong, Amphoe Muang, the High Terrace Deposits overlie the Khok Kruat Formation, being weathered to mottled clay. The High Terrace Deposits are composed of fluvial sand and gravel and can be separated into two parts, the lower part or older gravel beds and the upper part or younger gravel beds.

The lower part, named by Sataragsa (1987) Phu Khao Thong Formation (Figure 2.4), consists mainly of bedded sand and gravel which is semi-consolidated. Bedding of this formation is tilted gently to the north. The sediments are grey to yellowish grey in color with some red mottles. Cross bedding can be seen clearly in sandstone beds. In gravel layers, fragments are usually composed of black chert, quartz and petrified wood. The rock fragments are subrounded to rounded and poorly sorted. The formation age is believed to be Late Tertiary.

The upper part is bedded gravel and sand overlain by laterite and eolian deposits (according to Udomchoke, 1989, the eolian deposits are suggested to be deposited between 2,000 and 3,500 years B.P.). The upper part is in erosional contacted with the lower part. The gravel and sand is reddish brown in color, subrounded to rounded and well sorted. Its fragments generally comprise quartz, chert and some tektites. The tektites, dated by K/Ar isotopic and fission method, provide an age of 0.68 to 0.73 million years B.P.

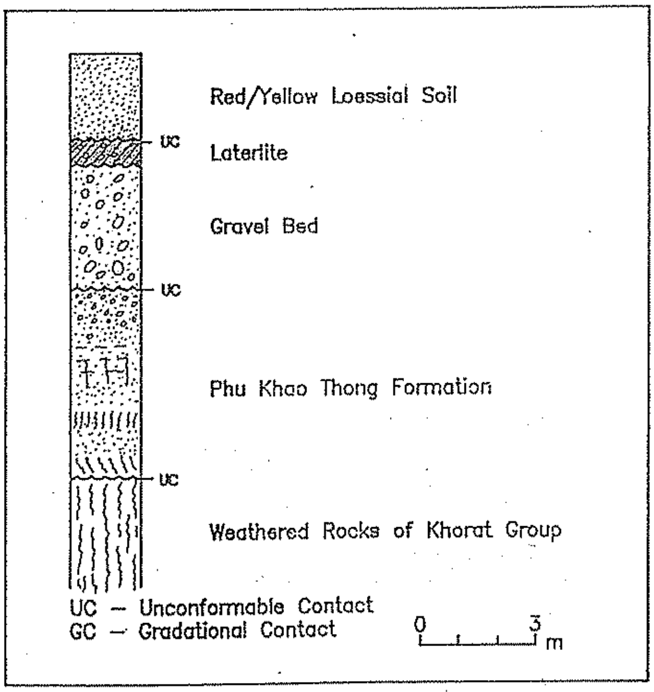

Figure 2.4: Stratigraphic section of the High Terrace at Ban Phu Khao Thong, Amphoe Muang Changwat Nakhon Ratchasima. (After Sataragsa 1987)

Alluvial Deposits (Q_a, Holocene) can be recognized in areas nearby large rivers and in the floodplain of the Mun, Lam Takhong and Lam Chiang Khai Rivers especially in the northern part of the study area. In the flood plain it generally consists of silty clay, sandy clay, and clayey sand. In channel deposits it mainly comprises sand and gravel. Its color varies from grayish-brown to reddish-brown. According to Chaimanee (2003), the alluvial deposits are divided into 4 units: Lam Takhong alluvial, Mae Nam Moon alluvial, Lam Chakkarat, and Alluvium Complex, by their sedimentary sequences and contents due to different sedimentary sources. The main sediments in these sequences are fine sediments which sometimes mix with sand and gravel. Generally the sediments become coarser gains in lower part.

2.2 Tectonic Evolution

As mentioned above, the Khorat Greater City Area is located on the Indochina platform that collided with the Shan-Thai continent, located to the west, at the end of the Triassic era. This event caused compression and folding in the Khorat Plateau. After that the Indochina platform seems to have been stable with simple structures and uniform topography. Therefore structures occurring in Mesozoic formations deposited in the Khorat Plateau are mainly related to the Indian-Eurasian collision during the early Tertiary (Charusiri et al. 1997). This event also created the Phu Phan Range, an uplift that divides the Khorat Plateau into two basins, the Sakhon-Nakhon Basin and the Khorat-Ubol Basin (Figure 2.5).

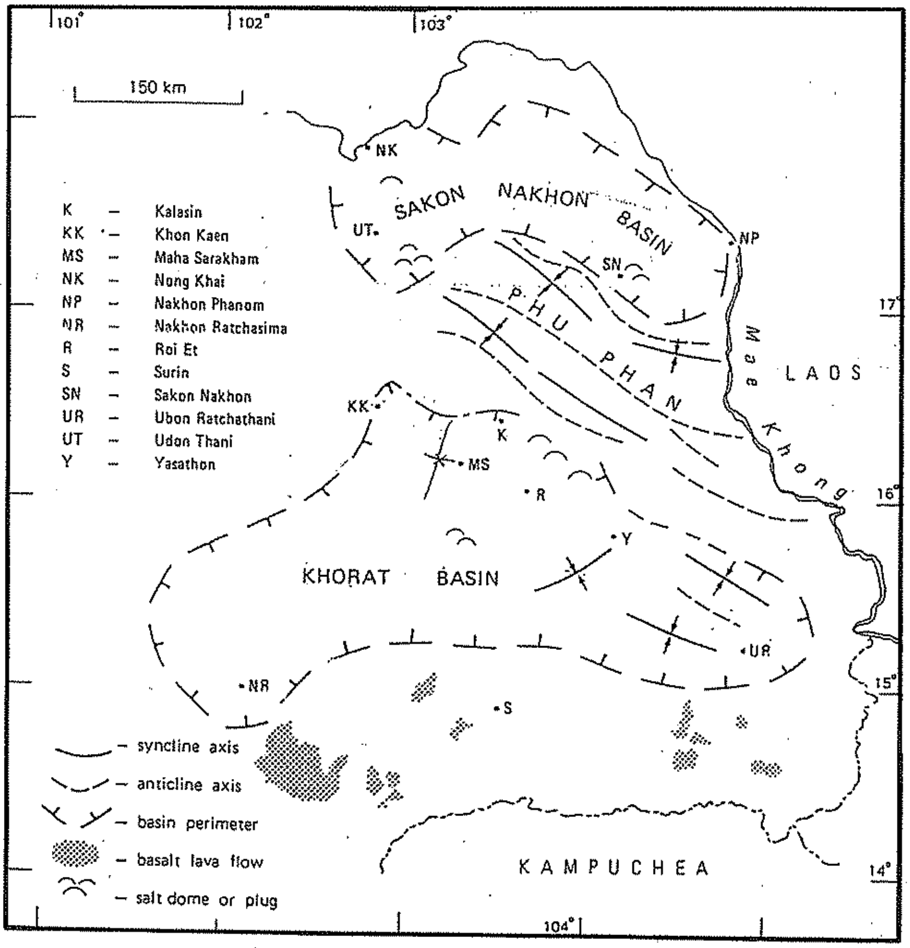

Figure 2.5: Geologic structures in the Khorat Plateau (after Parry 1996)

Folding in the Mesozoic rocks and several NNE-SSW strike-slip faults were also activated successively as the Indian continent moved northwards against the Eurasian continent. At that time, the Southeast Asian crustal block was rotated clockwise and then extruded several hundred kilometers southeastwards.

In the southern part of the Khorat Plateau basaltic rocks were extruded through the Mesozoic rocks and formed volcanoes which erupted between 3.2 and 0.9 million years B.P. This might be the peak of the last tectonic event in this region.

In the study area, bedding of the Mesozoic rocks is slightly tilted to northeastern directions with a dip of about 5 to 15 degrees (Tansuwan et.al., 2002), towards the center of the Khorat Basin.

The geologic structures in this region can be grouped into three deformations (Chuaviroj, 1997). The first deformation (F1 in Figure 2.6) is related to the collision between the Shan-Thai and the Indochina blocks, since compression was directed E-W, resulting in fold axes of N-S direction.

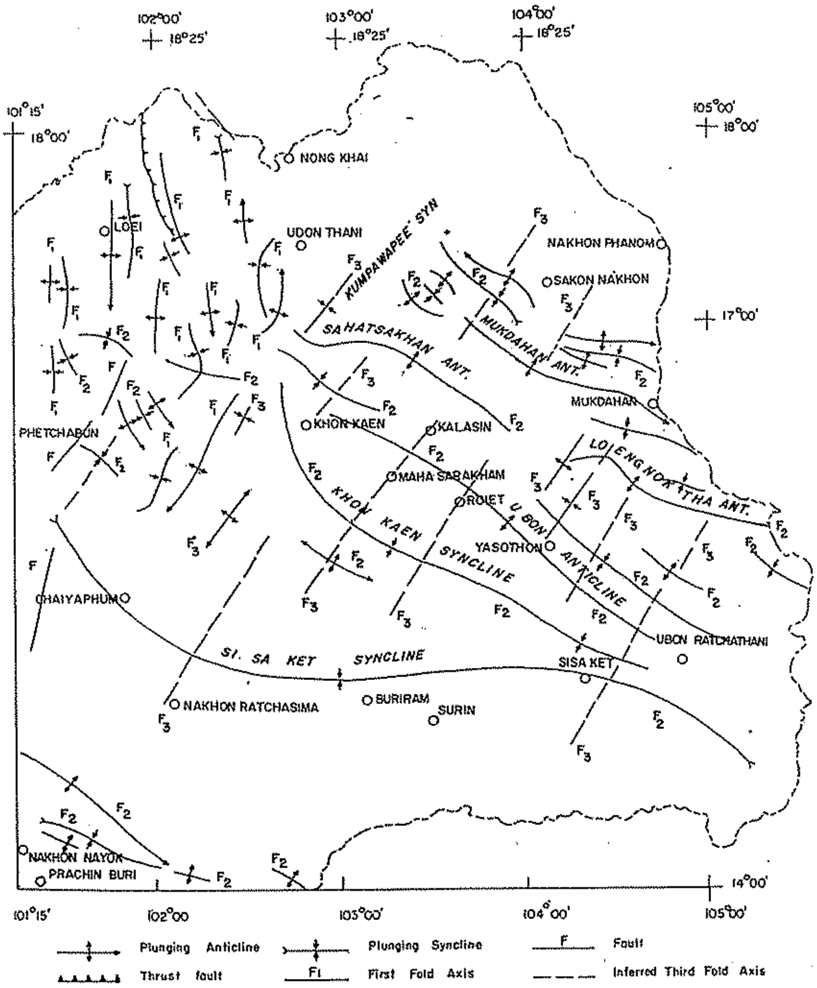

Figure 2.6: Deformations in Khorat Plateau (after Chuaviroj 1997)

The second (F2) and third (F3) deformations were induced by the Himalayan Orogeny or the collision between Indian and Eurasian plates. However, the time of occurrence is different. The second deformation occurred in the early Tertiary and the third deformation in the Miocene –Pleistocene, when the Himalayan Orogeny induced the up-doming in this area.

2.3 Rock Salt and Potash

Rock salt and Potash can be found only in Northeastern Thailand. The rock salt was deposited in the Maha Sarakham Formation, the uppermost part of the Khorat Group. The areas of deposition were separated by the uplifting of the Phu Phan Range into two basins, the Khorat-Ubol Basin and the Sakhon Nakhon Basin. The formation was investigated in detail by Department of Mineral Resources between 1973 and 1983. During that time, around 194 exploration wells were drilled through the different clastics and rock salt layers. The complete section of the Maha Sarakham Formation was established based on these wells (Figure 2.3).

As already mentioned above, the Maha Sarakham Formation comprises 3 rock salt layers, the Upper, Middle and Lower Salt. In the upper layer the thickness of rock salt is much less than in the lower layer. The average thicknesses are 21, 86 and 62 meters respectively. The complete sequence of all three layers can only be found at some places. This is usually the case where the Upper Clastics are very thick. Mostly only 1 or 2 layers of rock salt occur such as in the exploration well at Ban Fai, about 6 km north of Khorat City (Table 2.1). Based on Suwanich (1992), the approximate areas for both basins underlain by 3, 2 and 1 salt layers are 9,280, 22,680 and 18,040 km² respectively. The total area in which salt occurs is around 50,000 km² and the estimated reserve of rock salt is estimated at 18,785,349 million tons.

Intervals (m)	Thickness (m)	Description
0.00-54.86	54.86	Clay & sand: Brownish yellow, fine to coarse grains, subangular to subrounded of mainly quartz. Pebbles of quartz and rock fragments were found from 8.5 to 11.3 m. Clay is reddish-brown.
54.86-57.91	3.05	Anhydrite or Gypsum
57.91-86.18	28.27	Claystone: Reddish brown, greenish gray clay as mottling. Gypsum fragments were found at intervals.
86.18-93.02	6.84	Claystone: Greenish gray to gray, partly reddish brown claystone interbedded.
93.02-98.82	5.80	Rock salt: Mostly halite of colorless. Blue halite has been found as big crystals and patches at intervals. Some traces of red carnallite.
98.82-191.34	92.52	Rock salt: Mostly halite of colorless. Anhydrite and gypsum occur as white bands, stringers and inclusion averaging 2-3 mm thick of about 3-5 percents. Dark organic matter associated as smoky halite at intervals.
191.34-192.30	0.96	Anhydrite: White, with alternation of dark gray carbonaceous matter layer.
192.30-192.75	0.45	Siltstone: Greenish gray, soft, massive.
192.75-196.60	3.85	Siltstone: Reddish-brown, soft, massive.

Table 2.1: Lithologic log of the exploration well at Ban Fai, Muang District, Khorat. (Japakasetr & Suwanich, 1982)

Potash usually occurs in the upper part of the lower salt layer in forms of sylvinite (mixture of KCl [sylvite] and NaCl [halite]), carnallite ($KMgCl_3 * 6H_2O$) and tachyhydrite ($CaMg_2Cl_6 * 12H_2O$). The potash layer is already dissolved in areas where the overlying Upper Clastics are very thin because potash has a high solubility and is therefore easily dissolved and washed out by groundwater. The content proportion of the three potash forms is different in each area and depends on the number of salt layers. The carnallite and tachyhydrite which are primary evaporitic deposits will be transformed to sylvinite in areas where there are fewer salt layers. The estimated mineral reserves for sylvinite, carnallite and tachyhydrite are around 35,154, 1,088,171, and 429,000 million tons respectively.

The occurrence of salt is well known to the northeastern people since long time. It is harmful to crops and trees but is useful for the local people as a source for table salt. In the traditional way of table salt making, the local people collect salt rich soil from the land surface, put it into a wooden container and then dissolve it with water. The salt solution is filtered through sand and becomes clear saltwater. This saltwater is boiled until salt precipitates from the solution. In the new, industrial method, salt is not collected from the land surface but brine water is pumped from deep wells. All of these wells are drilled into the upper part of a rock salt layer. At this level, some part of the rock salt is dissolved where in contact with groundwater. The brine water is either being boiled in large containers or evaporated in large evaporation pans (Figure 2.7 and 2.9). This method is called salt mining. There are several places of salt mining in the Khorat Greater City Area. The most renowned place is located in the Ban Wang area. In recent years there have been conflicts between the local farmers and the mining companies about the impacts of salt mining. The farmers claim that the salt mines discharge saltwater into the natural surface water drainage system causing groundwater and soil salinization, and the formation of sinkholes. After heavy protests, the area was investigated and delineated as a high-risk area for the formation of sinkholes. Due to this, salt mining was prohibited in this area. However, salt mines in the other areas are still operating.

Figure 2.7: Salt production from evaporation pans at Ban Phon Pai

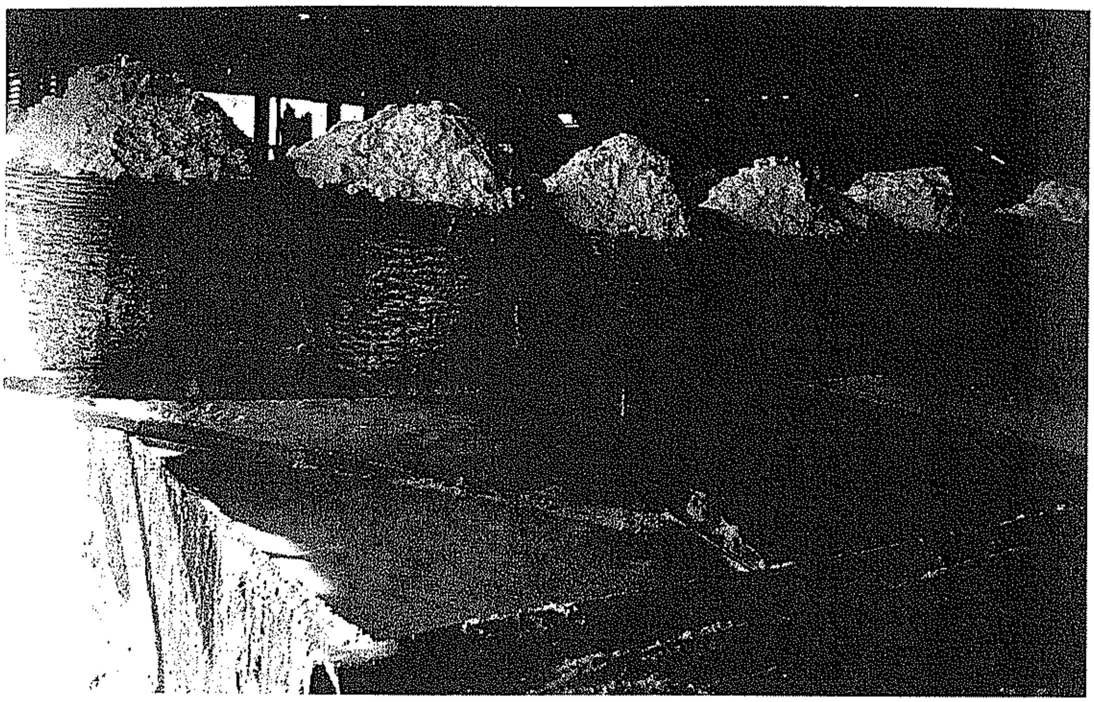

Figure 2.8: Salt production by boiling in large containers at Ban Phon Plai

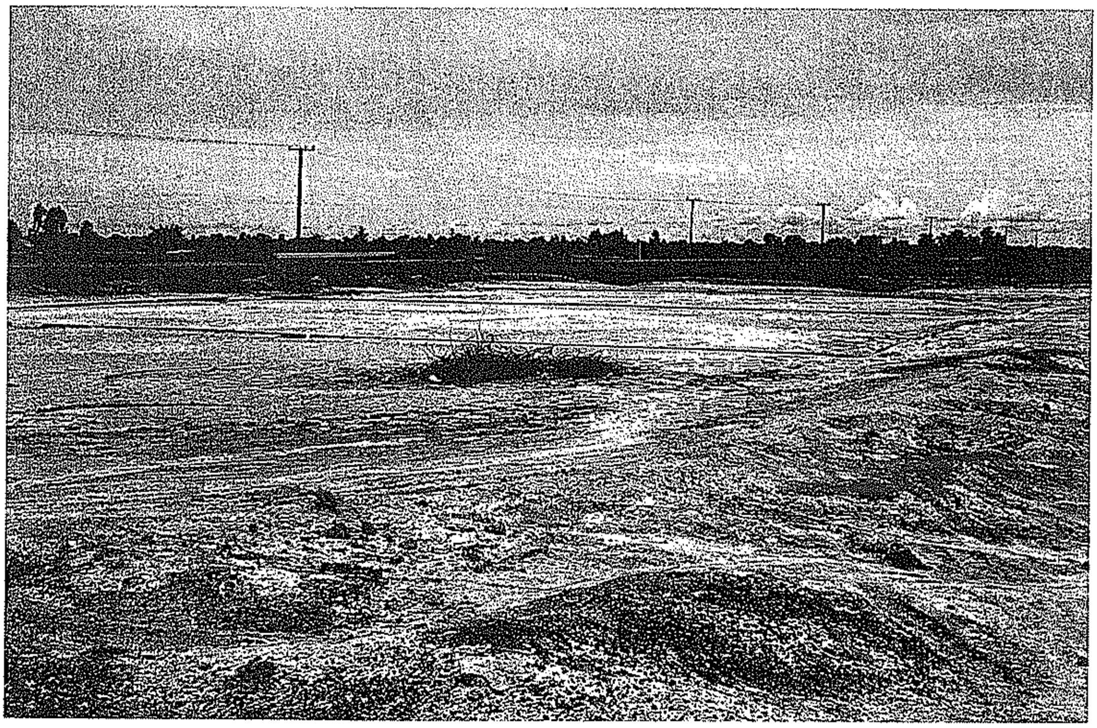

Figure 2.9: Development of salt crusts at the abandoned illegal salt mine south of Ban Sa Chorakhe (Dan Khun Thot district)

2.4 Results of Geophysical Investigations

Within the framework of this project, seismic surveys were conducted by DMR team together with German expert in 2 lines. The total length of investigation line is 10 km. The First line is about 5 km which lays in East – West starting from Ban Bu to Ban Dan Nok and the second line is North – South starting from Ban Dan Nok to north direction. The data from seismic investigation were interpreted by the team and were shown in form of seismic profile. The profile of the first line suggests that the top of rock salt layer is in depth of 70 to 100 m from ground surface. The top surface of rock salt layer is relatively smooth. (Figure 2.10)

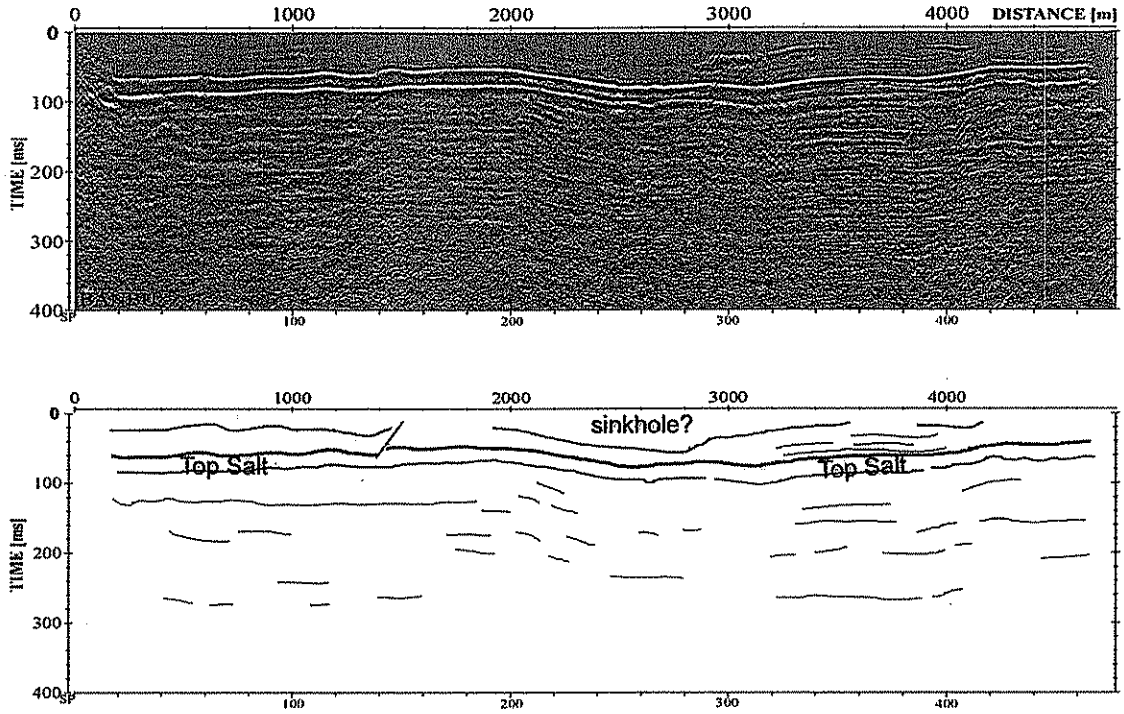

Figure 2.10: The seismic section profile of reflection seismic survey along Ban Mai to Ban Dan Nai.

Another seismic campaigns in this area were conducted by the WADIS project (Waste Disposal: Investigation of abandoned landfills and proposed areas for new waste disposal sites in Thailand). The WADIS project was investigated 4 lines in east-west and North-South direction in the area nearby Ban Thanon Hak Noi, Dan Khun Thot District. From the 4 lines of seismic sections, they show strongly reflection on the upper boundary of the rock salt layer at depth between 80 to 100 m. Generally, the top surface of rock salt declines towards north-east direction. The rock salt layer is overlain by sediments and by sedimentary rocks which are intercalated sediments in eastern part and relatively monotonous succession of sediments in western part (Figure 2.11). Paleochannels are also present on the section. These channels indicate that this interface was exposed to fluvial erosion. The upper sedimentary unit unconformably overlies the lower unit. The unit is characterized by discontinuous reflections, low amplitudes and low frequencies, indicating relatively homogeneous and rather fine grained sedimentation.

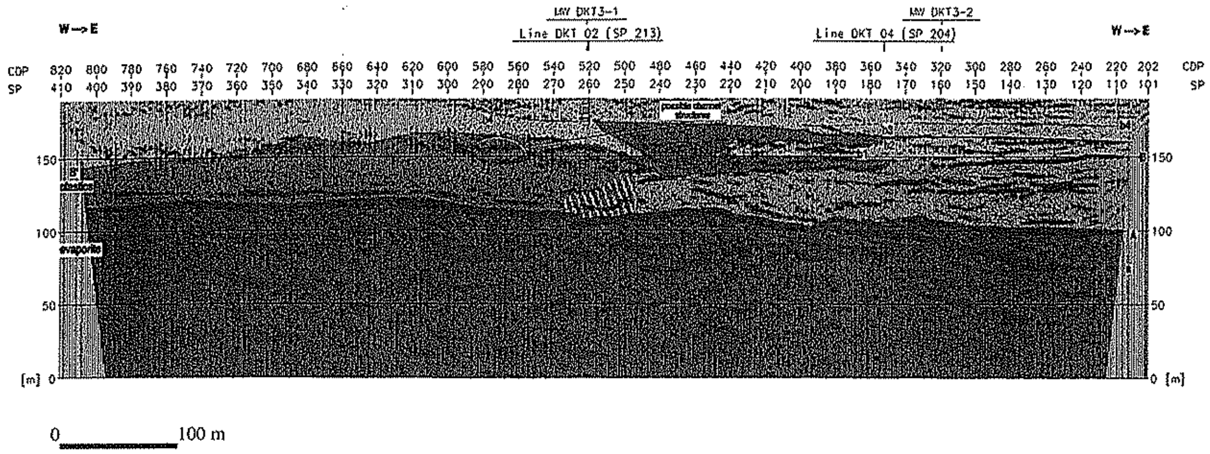

Figure 2.11: The seismic section profile of reflection seismic survey at Ban Thanon Hak Noi, 6 km east of Dan Khun Thot. (Blue color showing rock salt layer) (WADIS, 2003)

3. Hydrogeology

Hydrogeology or the study of groundwater is dealing with water that is accumulated in rocks or in sediments in the saturated zone. Generally, groundwater is formed where rainwater infiltrates into the underground and can accumulate in pores or fractures in rock units. Groundwater moves with gravity through the sediments or rocks and is subject to chemical reactions, dissolution and cation exchange processes. Therefore its composition changes, usually resulting in increasing mineralization with groundwater flow. This phenomenon depends on sediment or rock composition, flow distance, and residence time. The hydrochemical composition of groundwater is of importance for the use of groundwater. Groundwater which is used as drinking water needs to meet certain criteria, which are usually regulated by National drinking water standards.

Concerning the extractable groundwater quantity, the lithological composition, the physical properties of the rocks, especially the grain size, the total and effective porosity, the weathering and fracturedness are of importance. Furthermore, the spatial interconnectivity of pore spaces plays a major role.

Groundwater is a significant issue for environmental geology because it is an alternative source for water which crucially supports human development. Water is consumed as drinking water, cleaning substance, processing substance in factories and for irrigation. In the Khorat area, there are three main water sources: surface water, groundwater and rainwater. Surface water is the main source of water for irrigation and domestic uses and can be used in areas close to rivers and ponds. The rolling and uneven topography, however, prevents the distribution of surface water over large areas for irrigation. Rainwater can be used during about six months of the year. However, the number of rainy days and the amount of rain varies significantly from year to year.

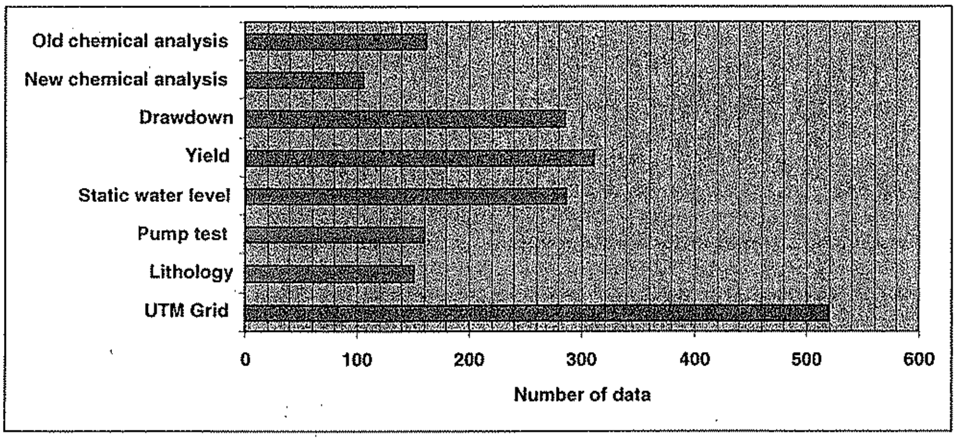

Figure 3.1: Availability of groundwater data in the Khorat Greater City Area.

To understand the groundwater system, the subsurface geology, the hydraulic parameters of the aquifers and the hydrochemical composition of the groundwater needs to be known. Much of this information can be obtained from groundwater wells. In Thailand, many organizations are dealing with well drilling but only few institutions are keeping reliable data, such as the Groundwater Department (GWD), the Public Works Department (PWD) and the Accelerated Rural Development Department (ARD).

Concerning the basic data, the exact well location (UTM grid) is mostly not available (only the name of the nearest village). Therefore wells had to be surveyed by the project for location and elevation. The total number of groundwater wells surveyed by GPS was 520. During the field survey groundwater samples and groundwater levels were collected (Figure 3.2).

Figure 3.2: Field measurements for groundwater levels.

3.1 Description of the Aquifer Systems

The Khorat Greater City Area is mostly underlain by consolidated rocks, composed of sandstone, shale and siltstone of Mesozoic age. Unconsolidated rocks are found only along the Mun and Lam Takhong Rivers. They can be divided into two types of aquifers.

Unconsolidated Aquifers are found in two deposits: Alluvial Deposits and High Terrace and Colluvium Deposits.

- Alluvial Deposits: aquifers in these deposits occur along the Lam Takhong and Mun Rivers. Therefore the aquifer is formed as a narrow and elongated strip following east-west directions. Groundwater is stored in sand and gravel layers at depths between 10 and 30 m. The layers were built up by meandering streams. They mainly consist of sand and gravel which is interbedded with thin layers of clay. However, groundwater in these layers is hydraulically interconnected.

- High Terrace and Colluvium Deposits: These deposits form aquifers in the hilly areas south of Khorat City and in the flood plain area where they are overlain by Alluvial Deposits. Groundwater is commonly found in sand and gravel at two distinct depth intervals: 20-40 m and 50-70 m below ground surface (Groundwater Div., 1988). The two sand and gravel layers are separated by a layer of fine-grained material with a thickness of about 10 m.

Consolidated Aquifers are recognized in three formations Phu Tok, Maha Sarakham and Khok Kruat Formation.

- Phu Thok Formation: The formation occupies nearly half of the northern part of the studied area. It is not well cemented and slightly soft when compared to the underlying formations. It mainly comprises of claystone, siltstone and sandstone. Where at outcrop it usually forms a flat to slightly undulating topography. The formation is competent and usually forms a good aquifer. Groundwater can be trapped in both primary and secondary porosity (Srisuk et al., 2003). The formation is underlain by rock salt layers which may result in groundwater salinization. Groundwater quality in this formation is usually poor, due to high sodium chloride content (Na-Cl type water). In some areas the local people pump salty water to produce table salt. Groundwater of low salinity can be found in areas where rock salt layers are situated at greater deep or where freshwater forms a shallow lens above the saltwater in the recharge mounds. The hydraulic conductivity of the formation ranges from 3.0E-07 to 4.6E-04 m/s or 0.025 to 40 m/d (Srisuk et al., 2003).

- Maha Sarakham Formation: The formation is not at outcrop in the project area. Its most shallow occurrence is found at a depth of around 80 to 100 m below ground surface near Ban Wang. From the seismic section profile, the upper surface of the rock salt is generally smooth and gently inclined to the north-east. Principally, the formation acts as an aquitard due to the non existing primary porosity. Groundwater can only be trapped above the formation where it may be in contact with overlying porous rock units. Most salt mines pump brine water from such aquifers.

- Khok Kruat Formation: The formation is recognized in the southern part of the Khorat Greater City Area in a large hilly area. Groundwater mainly occurs in spaces of factures and bedding planes of sandstone, shale and siltstone. Groundwater quality in this formation is generally good. However, saltwater can be found in the areas where the rock is in contact with the Maha Sarakham Formation.

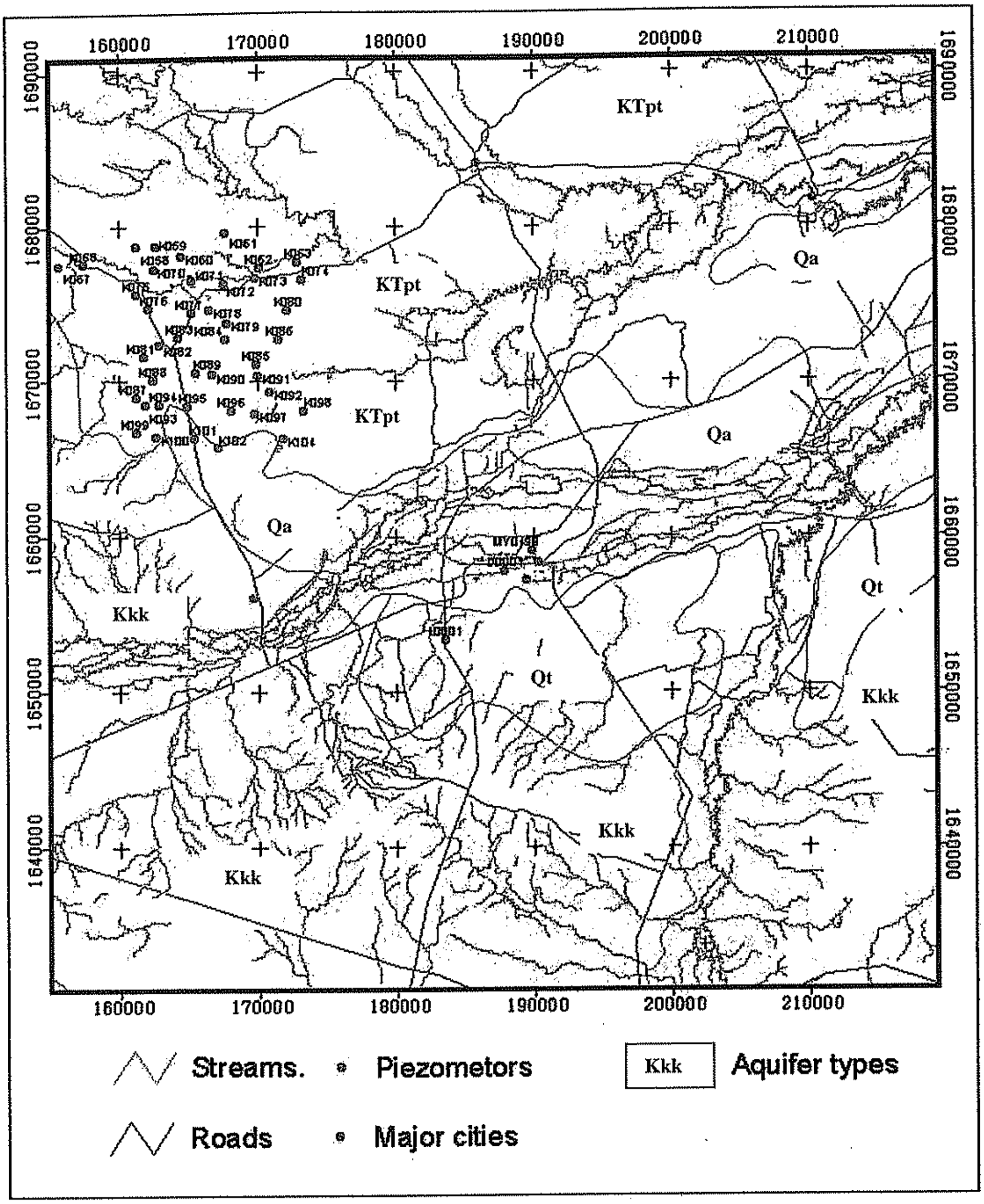

Figure 3.3: Aquifer system and piezometer locations.

3.2 Groundwater Piezometry

There are 46 sites of piezometer wells in the study area. Most of them belong to the LDD, while there are only 4 sites belonging to the DMR (now Department of Groundwater, DGW). The LDD piezometers are distributed over a relatively small area in the southern part of the Dan Khun Thot District while the 4 DMR piezometers are distributed around Khorat City (Figure 3.3). The purposes the LDD and DMR piezometers are different. LDD monitored its wells only over a time period of 3 years from 1995 to 1997 to investigate groundwater quality and flow direction in the low-lying areas. DMR observed its wells over the past 38 years in order to monitor groundwater level fluctuations in the Alluvium and High Terrace Deposits which are the most productive aquifers in this area.

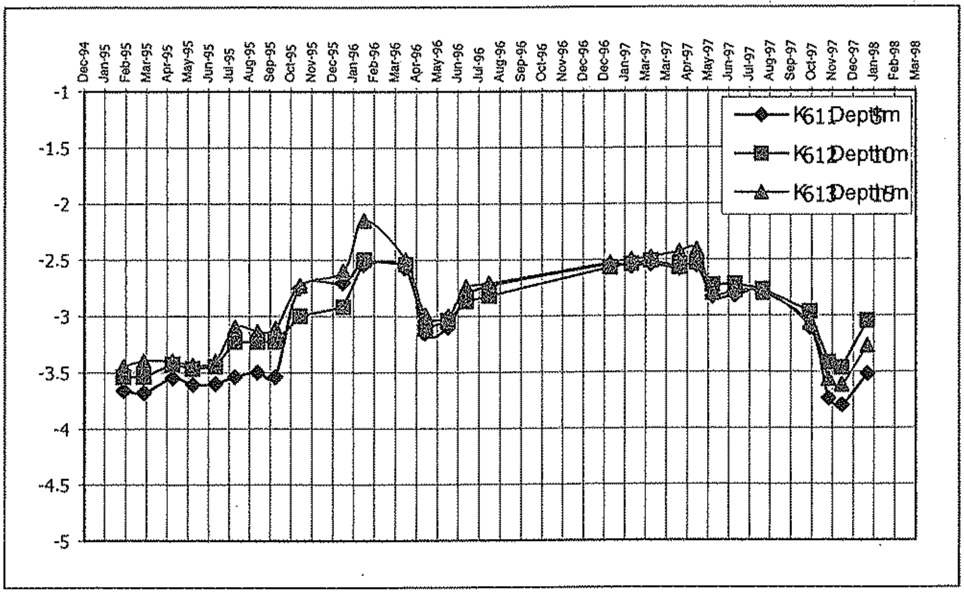

Figure 3.4: The groundwater level fluctuation in LDD wells no. K611, K612 and K6133 at site no. K61 (showing water level in meters below ground).

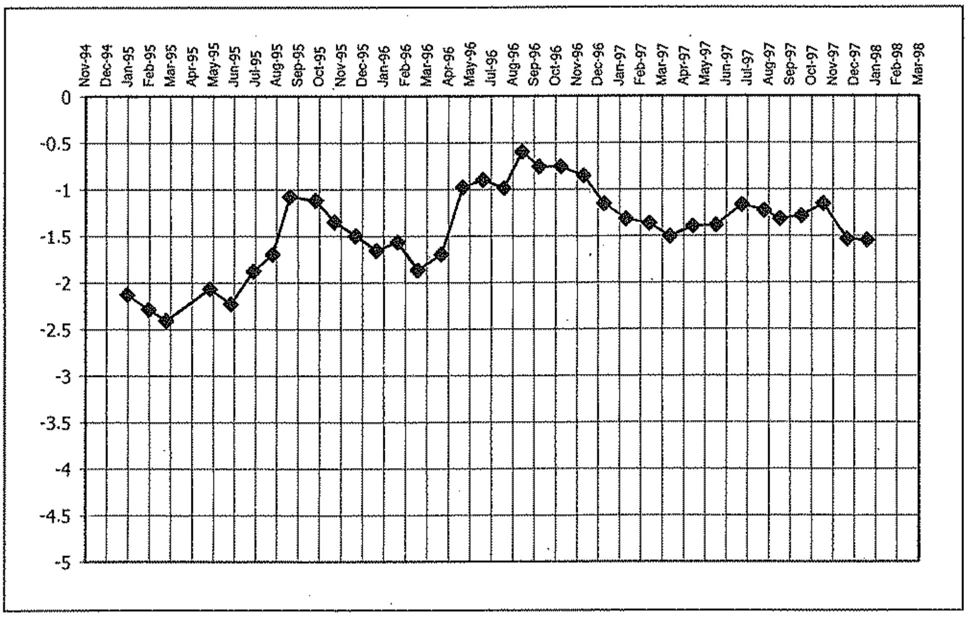

Figure 3.5: Groundwater level fluctuation of DGW monitoring well L0001 (showing water level in meters below ground). The depth of screens is from 42 to 51 m.

LDD installed piezometers at 46 sites, each site consisting of a group of piezometers encompassing 3 to 5 wells. In one site, piezometers were drilled close together and fitted with 2" diameter PVC casings which are open at the bottom. Depth varies between 5 m and 30 m. The piezometers were fitted with filter packs for 1 m at the bottom and clay packs in the upper part (to seal off the upper part of the aquifer). Monitoring started in February 1995. Every two months the two parameters static water level and electric conductivity were measured. Monitoring lasted until January

1998. Some results are shown in figures 3.4, 3.5, 3.7, 3.8 and 3.9. Water level fluctuation in this area reaches up to 2 meters depending on the topographic position and hydrogeological conditions. The first half of the graphs coincides with seasonal effects in this area but the second half of the graphs is not realistic because the peaks of the second half occur during the dry season. When comparing this part to the groundwater fluctuations from DMR monitoring wells, which are fitted with automatic recorders, it becomes evident that there is no coincidence. Therefore only the first half was used in this report. The error might come from changing of people who are responsible for measuring water levels. For the first half, LDD managed by itself. Later LDD had decided to hire local people to monitor the wells.

Figure 3.6: Group of monitoring wells of LDD.

The depths to groundwater of two wells at the same site are plotted on the same graph in order to recognize the hydraulic pressure gradient between the two piezometers. The hydraulic pressure can be measured in wells as the static water level with reference to a specific reference level, usually the mean sea water level. The hydraulic pressure indicates the direction of groundwater flow at a specific location. If the hydraulic pressure is higher in the deeper piezometer compared to the more shallow one, it indicates that groundwater flow is directed upwards. This is commonly the case in the low-lying areas. Groundwater flow is commonly directed upwards in discharge areas while it is directed downwards in recharge areas.

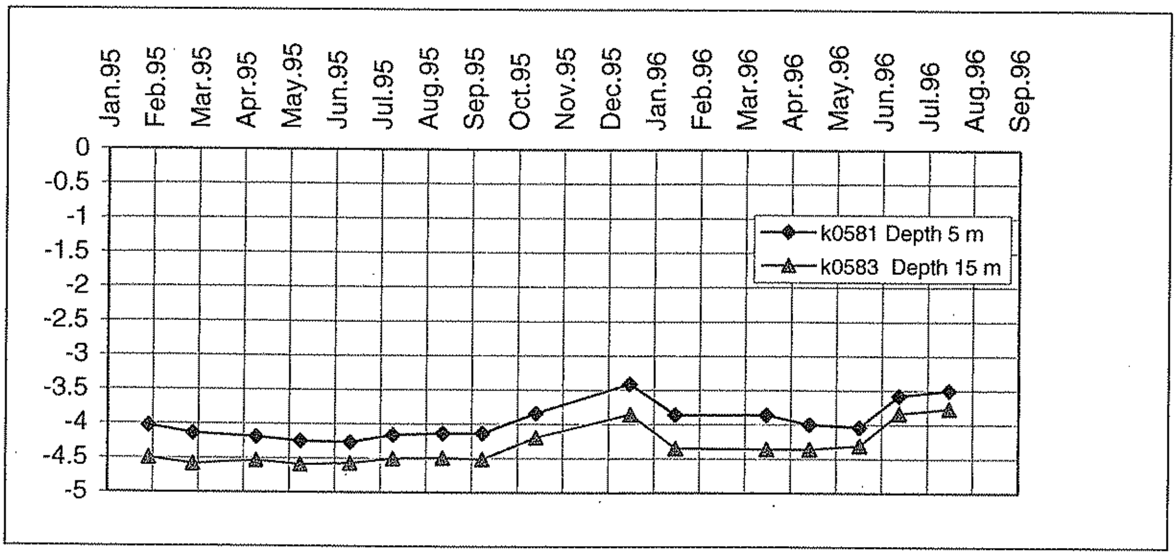

Figure 3.7: The groundwater fluctuation in LDD wells no. K581 and K583 at site no. K58 (showing water level in meters below ground).

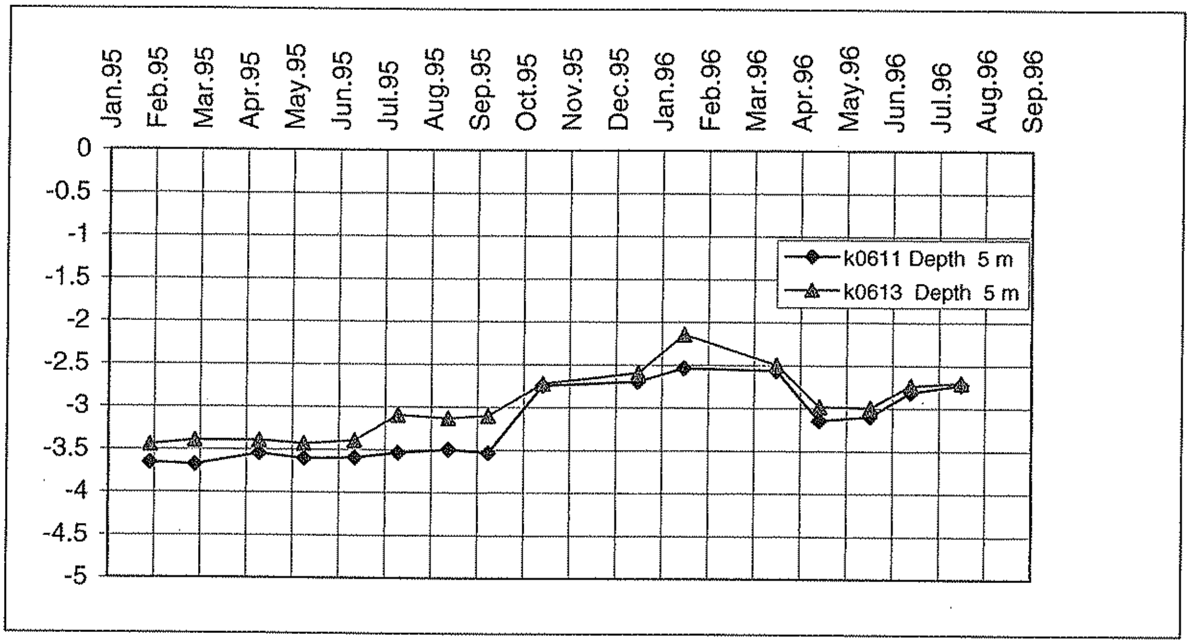

Figure 3.8: The groundwater fluctuation in LDD wells no. K611 and K613 at site no. K61 (showing water level in meters below ground).

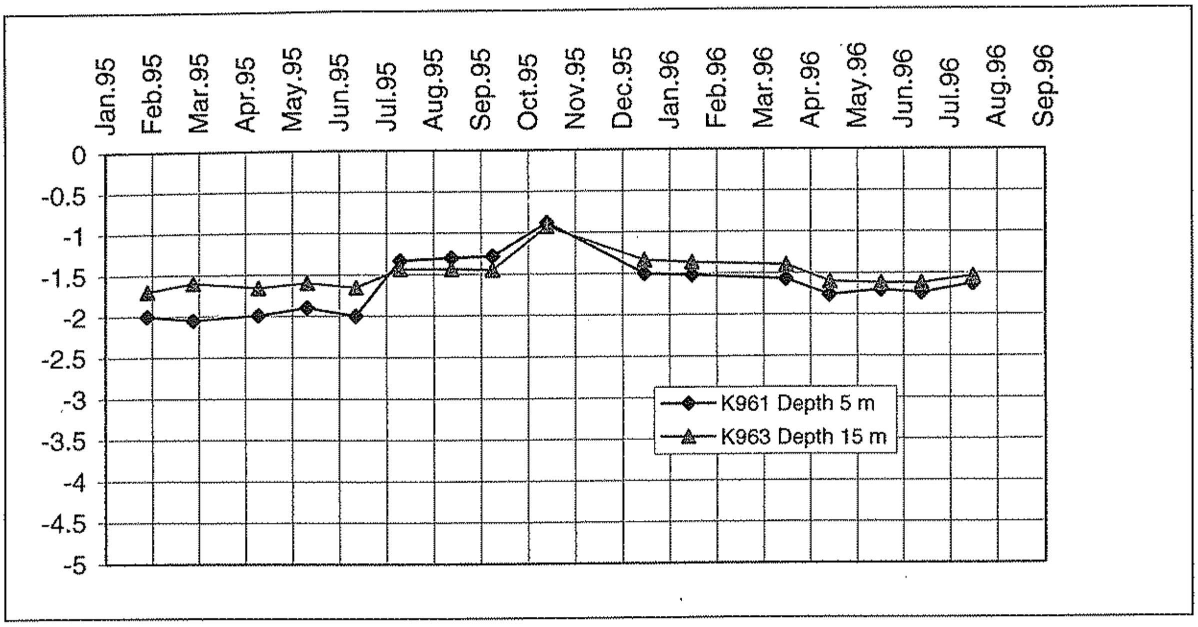

Figure 3.9: The groundwater fluctuation in LDD wells no. K691, and K693 at site no. K69 (showing water level in meters below ground).

At site no. 58 for instance, which is located in the highland area, the shallow well (K581) has a higher pressure than the deeper one (K583), indicating that the site is located in the recharge area. Concerning site no. 61, groundwater flow is directed upwards throughout the year. This site is located in the discharge area. Site no. 69 shows recharge conditions only during a short period in the rainy season while discharge conditions prevail in the dry season. Such conditions can be found in the transition zone between the highland and the lowland.

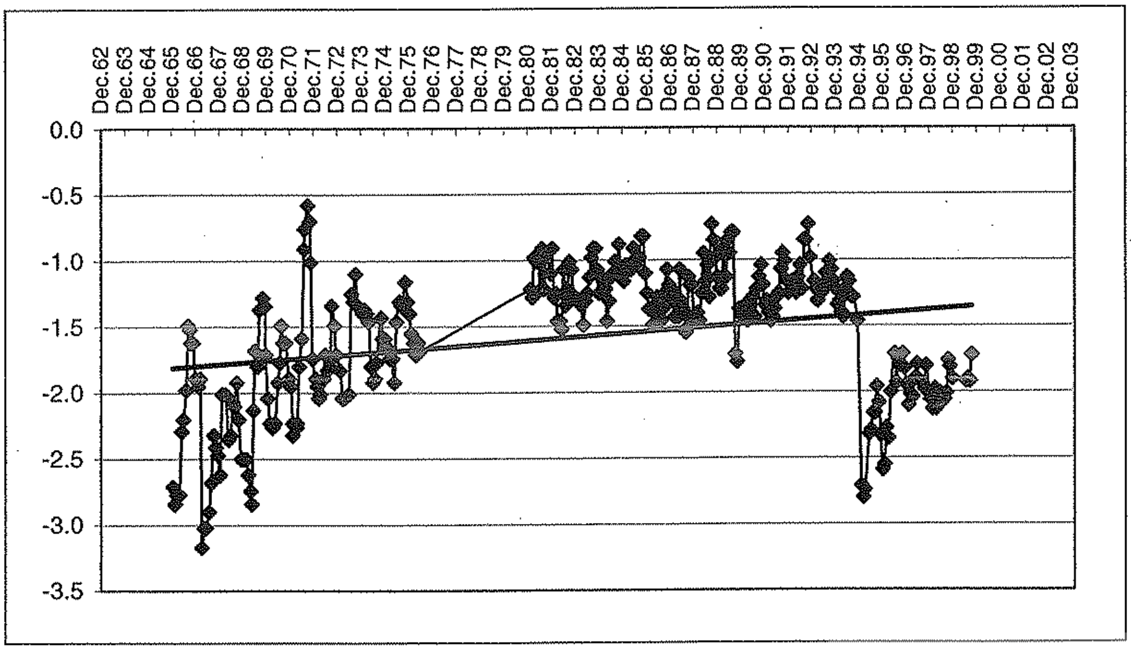

Figure 3.10: Groundwater fluctuation in DGW well no. D0001 (showing water level in meters below ground).

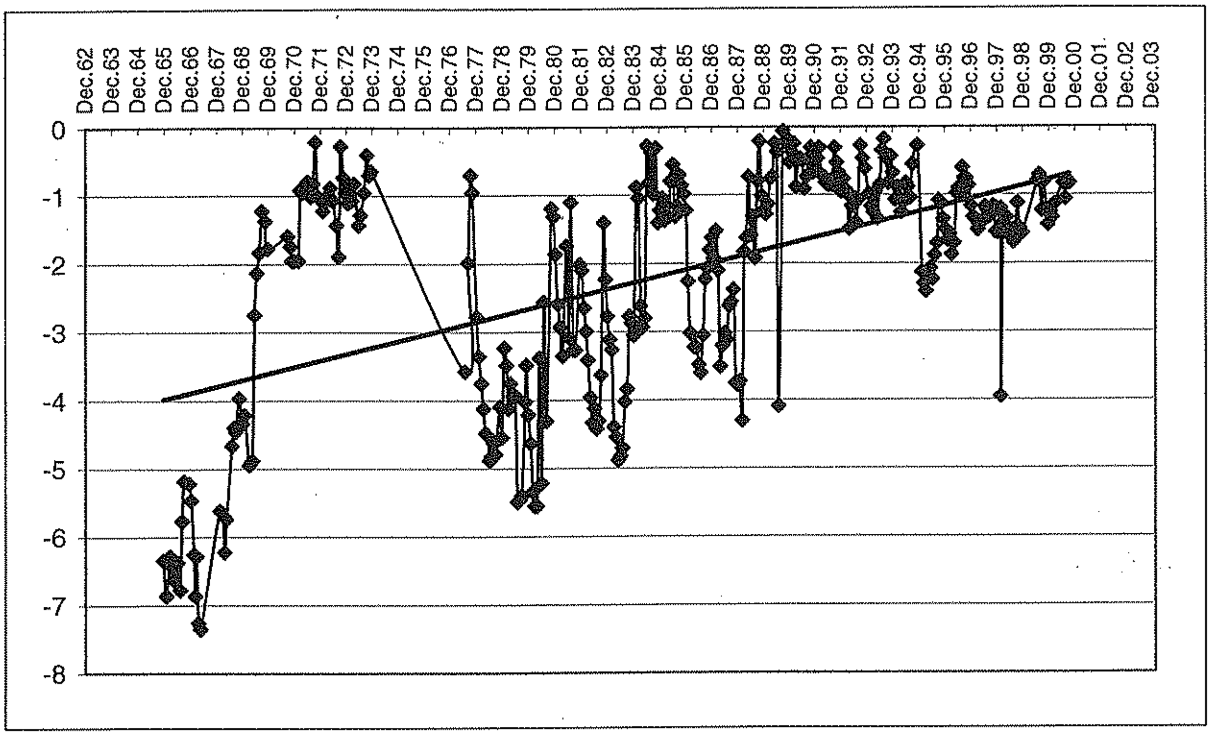

Figure 3.11: The groundwater fluctuation in DGW well no H0001.

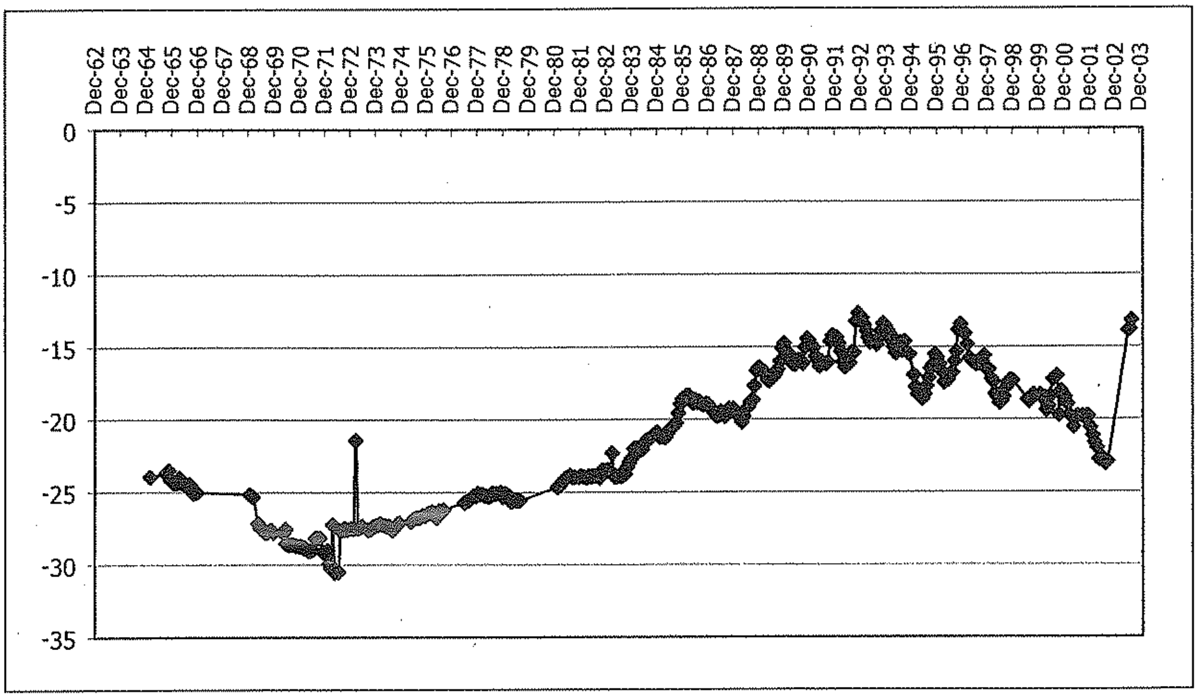

Figure 3.12: The groundwater fluctuation in DGW well no L0001.

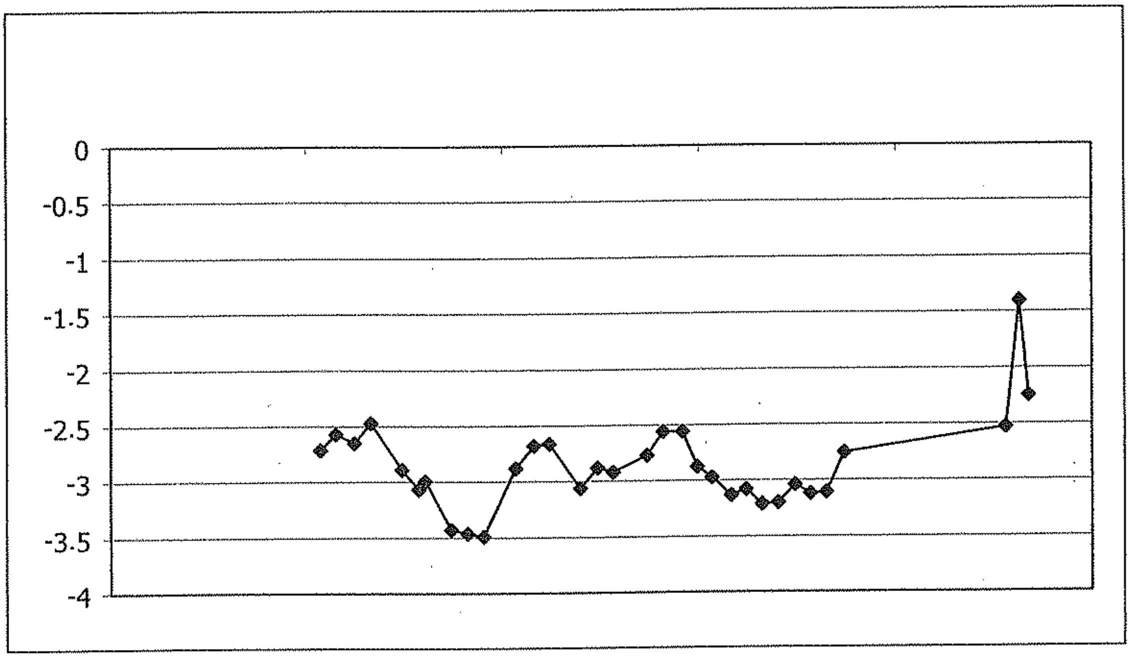

Figure 3.13: The groundwater fluctuation in DGW well no MY0490.

The piezometers of DGW have been monitored from 1965 to present. They are equipped with automatic recorders. Results of monthly measurements are shown in Figures 3.10 - 3.13). Annual groundwater level fluctuation in DGW wells ranges from 1 to 5 m depending on depth of well and topographic position. In lowland area (wells, D0001, H0001 and MY0490) fluctuation ranges only from 1 to 2 m. Well L0001 also shows a fluctuation of 1-2 m/yr. From 1965 to 1971 groundwater level in this area gently declined by about 5 m (Figure 3.12). However, from 1972 to 1992, groundwater level recovered and was raised by around 15 m. Although it declined again between 1993 and 2002, it recovered strongly in 2003. When looking at the long-term trend in the DGW hydrographs it is recognized that groundwater levels were raised.

3.3 Depth to Groundwater

In the dry season of 2002, groundwater levels were measured in 80 wells, especially DMR wells. Other wells belonging to PWD, ARD and DOH do not have facilities for measuring the groundwater level since there is no hole or space for inserting electric trap to measure the water level. Groundwater levels were plotted on a base map and contour lines of depth to groundwater were drawn using an interval of 5 meters. Groundwater levels at time of well construction were added to check the areas not covered by groundwater level measurements from the above mentioned 80 wells.

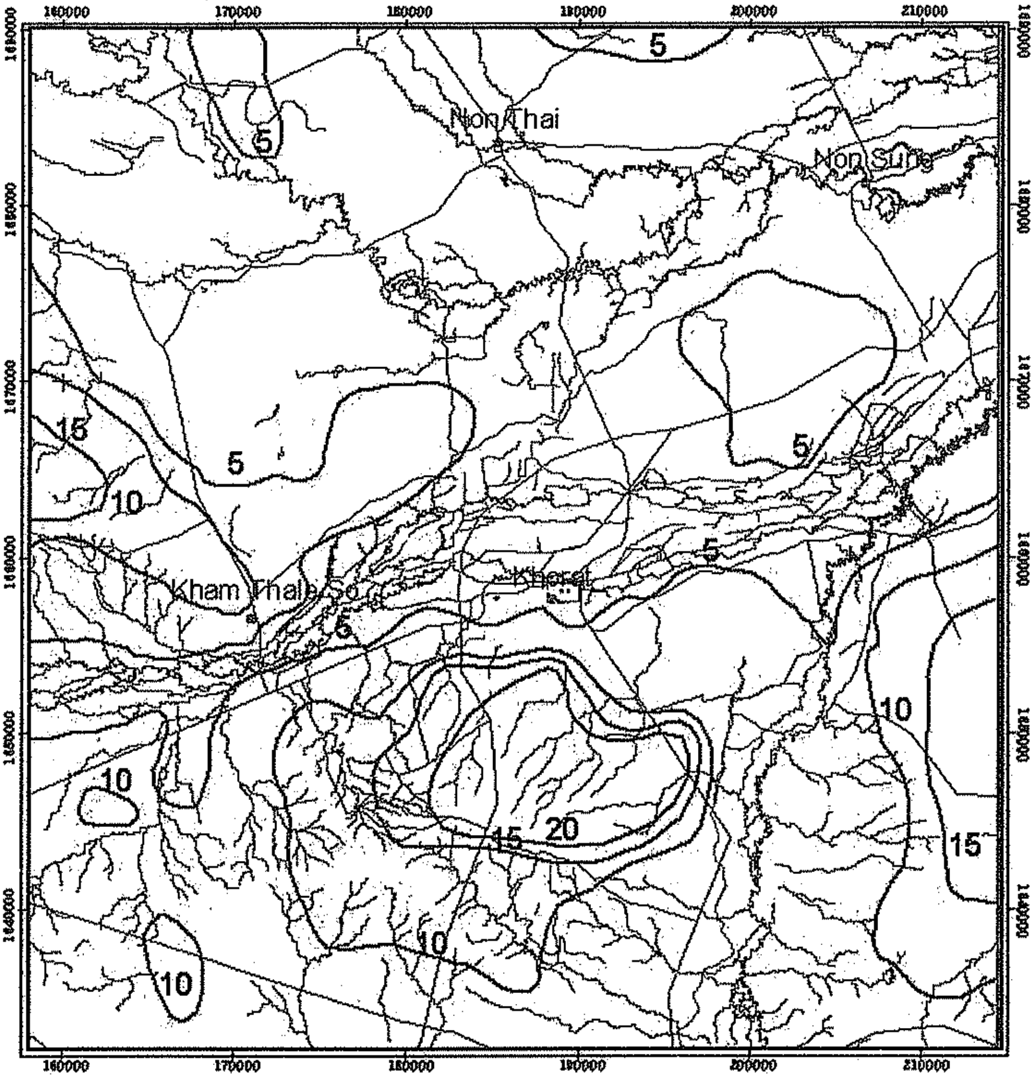

Figure 3.14: The Depth to Groundwater Map.

Depth to groundwater in this area ranges from less than 5 to 30 meters below ground surface, depending on the topographic position. Generally, it can be stated that the higher topographic levels are, the deeper are groundwater levels. The deepest groundwater area is found south of Khorat City in the area of High Terrace Deposits. In this area groundwater level is about 30 meters below ground surface. The groundwater level is shallower in areas close to rivers or in low-lying areas. Shallow groundwater areas are recognized in the northern part of the studied area and the areas close to the Lam Takhong River. Here, groundwater level is commonly less than 5 meters below ground surface.

3.4 Recharge and Discharge Conditions

Recharge: From the study of Srisuk (1995) concerning the Phu Thok Formation, recharge from rainfall ranges from 0.03 to 60%. High recharge is believed to be caused by direct recharge through rock fractures. The sediment cover in this area is predominantly sandy which also enhances recharge capacity. Surface water runoff is seemingly low, which can be been seen from the limited number of streams in this area. The recharge in this geological unit was reevaluated using the hydrographs of monitoring wells (Dissataporn, 2002). Results of this recharge estimation range from 15.5 to 29.06 % based on landuse as shown in Table 3.1. From the result, it can be seen that recharge in cleared land is twice as high as that in forest covered areas.

Landuse	% of recharge
Forest	15.50
Shrub	19.62
Eucalyptus	22.98
Barren land	29.06

Table 3.1: The percentage of recharge from different landuse types

Recharge from rainwater in this area can be enhanced by method of rice growing especially in sandy soil areas. Based on interviews with local farmers, rainwater is very important for rice growing. Usually farmers construct small dams in the surrounding of a rice field to retain rainwater. By this method rainwater is kept inside the fields where one part will be evaporated and the other recharged to groundwater.

Groundwater can also be recharged by surface water in reservoirs and irrigation systems. Many large reservoirs have been constructed by blocking the Lam Takhong, Lam Chiang Krai and Lam Phra Phlueng rivers. Furthermore, plenty of small reservoirs or ponds were constructed. The main irrigation systems have been established and distributed surface water in this area since completion of the Lam Takhong Dam in 1969. Since these distribution systems are not fitted with a low permeable base (clay, cement or plastic lining), water can easily infiltrate into the ground and recharge groundwater.

Discharge: The rainwater recharged to groundwater in high topographic areas flows by gravity to the low-lying areas. In these areas groundwater is discharged, contributing to the natural surface water runoff of streams or forming lakes or swampy areas. The Mun, Lam Takhong and Lam Chiang Kai Rivers are among those rivers being supplied by groundwater. Due to groundwater discharge there is still some water in these rivers during the dry season, the so-called baseflow. Other forms of discharge result from evapotranspiration (transpiration of plants) and human abstractions. The amount of water abstracted by plants depends on type of plants and their rooting depth. Therefore, the evapotranspiration in rice fields and in cassava areas is less than in forest covered areas. The total amount of groundwater abstraction for drinking purposes is rather low because of its poor quality. Groundwater in the studied area is mostly not favorable for drinking and for washing. Due to this shortcoming, the local population has reverted to the use of rainwater which is intercepted from roofs and stored in large jars for drinking and washing purposes (Figure 3.15). In many villages, large excavated ponds are used as additional water source (Figure 3.16). These ponds are fed by rainfall but may also be in contact with groundwater. Especially in the northern part, people totally rely on rainwater and surface water. This population is therefore highly dependent on rainfall, which can vary strongly. In the dry season, water comes mainly from ponds or surface water resources whereas in the rainy season, rainwater nearly covers nearly half of the water uses as shown in Figure 3.17 (November).

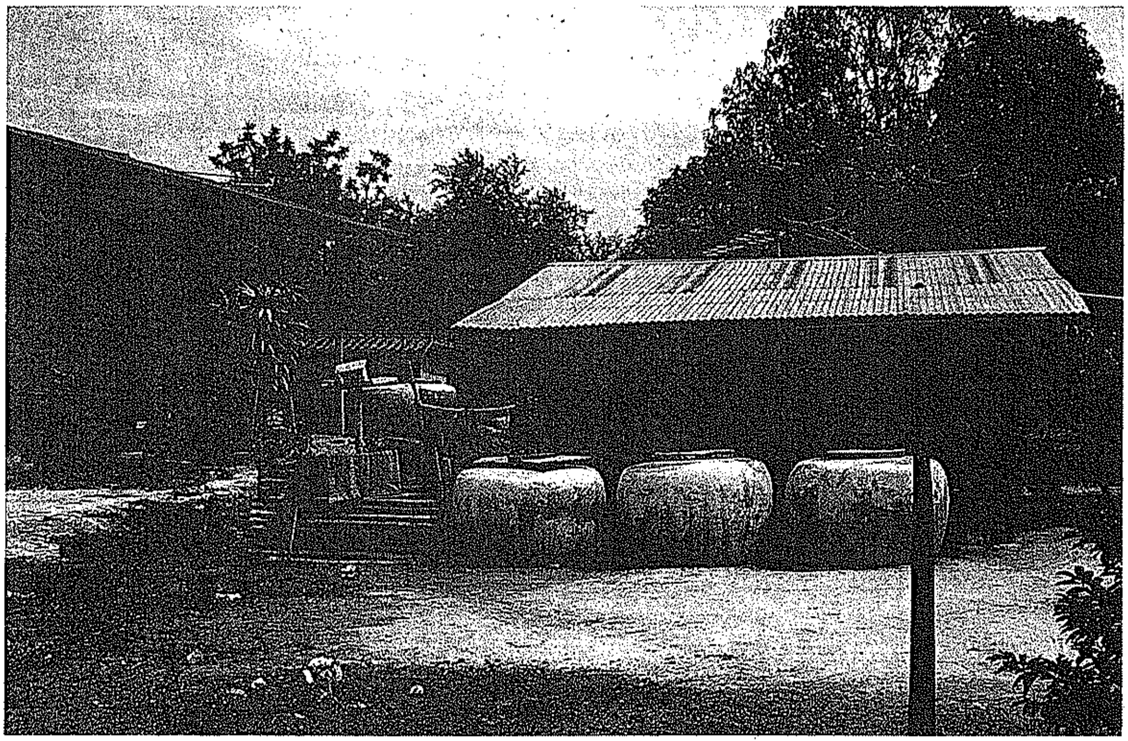

Figure 3.15: Rainwater harvesting from rooftops in northeastern part

Figure 3.16: Addition water source from excavated pond

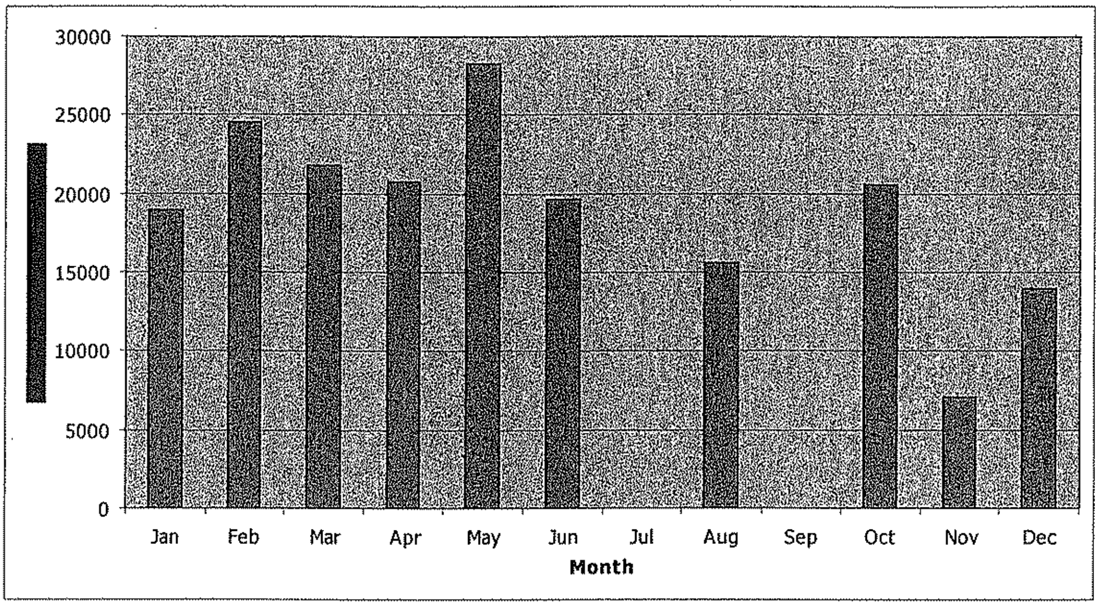

Figure 3.17: Surface water consumption of Tambon Nong Srong, Dan Khun Thot District.

3.5 Groundwater Properties

In 2002, 114 groundwater samples were collected mainly from DMR wells in the southern part of the studied area. The samples were analyzed by the Chemical Analysis Division of DMR for all major ions and some minor ions, such as Fe, Mn, F and NO_3. Water samples with ionic balance errors exceeding 10 % were excluded from evaluation.

Groundwater Types

The attribution of water types is based on the concentration percentage (meq%) of each ion on the total sum of anions or cations in meq/l. The anion/cation with the highest percentage is eponymous for the water type name. However, in some cases a second ion was added to the name if its concentration is equal or higher than 30% of the total concentration of anions/cations.

The predominant cations are calcium and sodium. Magnesium type water is found only at a few locations. The amounts of samples for each type are 59, 49 and 5, respectively. Concerning anions, the main water type is hydrogen carbonate (HCO_3). Chloride and sulfate water types are of minor importance. The numbers of water samples for each type are 75, 26 and 12. Altogether 15 water types can be differentiated. However, only 6 large groups are of importance (Figure 3.18):

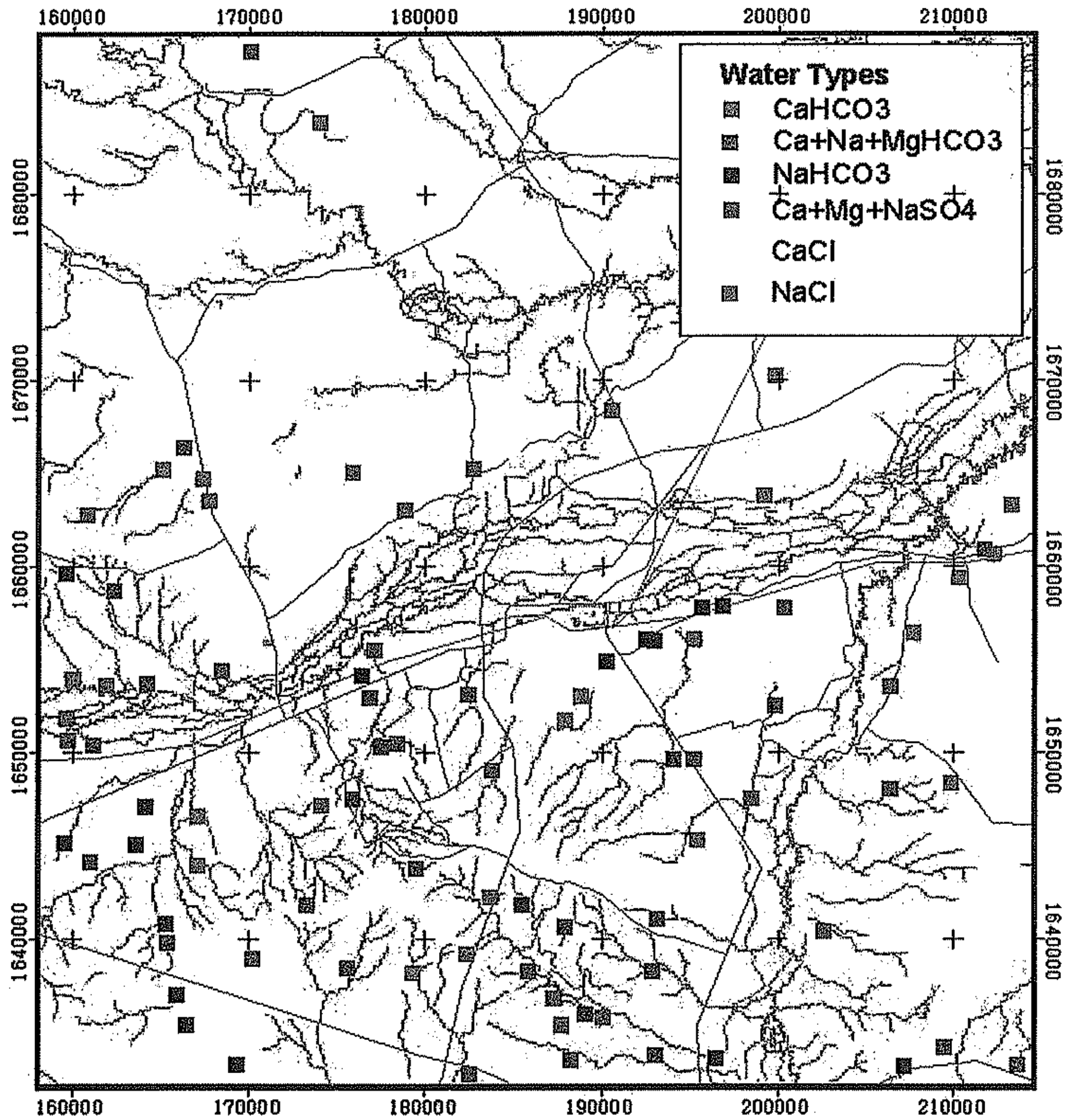

Figure 3.18: The groundwater types from chemical analysis

1. Calcium Bicarbonate (Ca-HCO_3) Type
2. Calcium-Sodium-Magnesium Bicarbonate (Ca-Na-Mg-HCO_3) Type
3. Sodium Bicarbonate (Na-HCO_3) Type
4. Calcium-Magnesium-Sodium Sulfate (Ca-Mg-Na-SO_4) Type
5. Sodium Chloride (Na-Cl) Type
6. Calcium Chloride (Ca-Cl_2) Type

Calcium Bicarbonate (Ca-HCO_3) groundwater is predominant in topographical highlands in the southern and eastern part of the study area. The formation of calcium bicarbonate water results from dissolution of calcite contained in sediments and hard rocks. According to the study of Srisuk (1996), rainwater in the study area is of calcium bicarbonate type and its total dissolved solids content (TDS) ranges from 15 to 140 mg/l. The TDS of this type of groundwater ranges from 123 to 2,130 mg/l. Those samples with low TDS contents exhibit similar composition to rainwater, showing that they represent conditions of recharge areas. Those samples with high

TDS contents of this type might result from dissolution of calcium and bicarbonate from calcite contained in the Khok Kruat Formation in the form of calcite nodules and concretions.

Calcium-Sodium-Magnesium Bicarbonate ($Ca\text{-}Na\text{-}Mg\text{-}HCO_3$) type water is the second largest group and occurs in the same area as calcium bicarbonate type water. Its TDS varies between 116 and 2,160 mg/l. This type of groundwater is a mixture of different types created by dissolution and cation exchange processes in clay-rich layers. In the process, the calcium and magnesium ions in the water are adsorbed by clay minerals while sodium ions are released into the water.

$$CaMgHCO_3 \longrightarrow CaMgNaHCO_3 \rightarrow NaCaMgHCO_3 \longrightarrow NaHCO_3$$

In the process the concentration of calcium and magnesium is reduced while the concentration of sodium in the water is increased. If the residence time of the water in the zone with clay-rich minerals is long enough and the clay minerals have a sufficient cation exchange capacity, sodium bicarbonate water will be formed (see below). Generally, $Ca\text{-}Na\text{-}Mg\text{-}HCO_3$ type water occurs in the transition zone between $Ca\text{-}HCO_3$ and $Na\text{-}HCO_3$ type water.

Sodium Bicarbonate ($Na\text{-}HCO_3$) Type water is the end product of the cation exchange process. Therefore the occurrence area is the same as of the two types mentioned above. The concentration of TDS is slightly higher than the two previous types. It ranges from 445 to 4,340 mg/l. In general, this type of groundwater should occur farther downgradient from $Ca\text{-}Na\text{-}Mg\text{-}HCO_3$ type water.

Calcium-Magnesium-Sodium Sulfate ($Ca\text{-}Mg\text{-}Na\text{-}SO_4$) Type water is seen locally in the southern part. The sulfate originates from gypsum dissolution which frequently occurs in the sediments. Therefore sulfate can be often found in association with calcium and magnesium.

Sodium Chloride (Na-Cl) Type water is recognized predominantly in the northern part influenced by rock salt and thus mainly in association with the Maha Sarakham Formation. This type occupies a large area. Due to the poor groundwater quality, most groundwater wells tapping such water have been abandoned or are out of operation. Collecting samples from such wells was a difficult task so that only few representative samples could be obtained. TDS of this water generally exceeds 3,000 mg/l and can rise up to 10,000 mg/l.

Calcium Chloride ($Ca\text{-}Cl_2$) Type water occurs only in the narrow strip along rivers in the eastern part. This type of groundwater is also a result of cation exchange processes. It will occur when saltwater intrudes into freshwater aquifers. In freshwater aquifers, Ca^{+} ions are mostly absorbed by clay minerals. In salt water Na^{+} and Cl^{-} ions are dominant. When saltwater intrudes into a freshwater aquifer, the following cation exchange process takes place :

$$Na\text{-}Cl + Ca\text{-}Clay \longrightarrow Na\text{-}Clay + Ca\text{-}Cl_2$$

The sodium ions are taken up by the clay minerals and calcium is released into the groundwater. Thus, water type changes from Na-Cl type to $Ca\text{-}Cl_2$ type.

4. Hydrogeological Maps for Landuse Planning

Hydrogeological landuse planning maps are maps specifically designed for landuse planning purposes and are different from traditional hydrogeological maps. After long discussions with the intended users, the landuse planners, these maps were designed to be easily understood by geological laymen. Therefore the maps can also be used by other individuals who would like to use this kind of information. Based on the experience gained by the project in the previous project areas in Thailand, the maps of most interest for landuse planners are those showing the available quantity and the quality of groundwater. Hence, the following maps were prepared in the Khorat Greater City Area :

- **Groundwater exploitation potential map**: It shows the expected yield of a well with a standard configuration at any location.

- **Basic groundwater quality map**: it shows whether there are any limitations for the use of groundwater due to its natural hydrochemical composition. Parameters limiting the use of groundwater are all components that exceed the maximum allowable limits of the Thai drinking water standard.

In the previous project areas, Chiang Mai – Lamphun and Surat Thani, two other maps were prepared: groundwater vulnerability maps and maps of hazards to groundwater. These two maps deal with the natural protection of groundwater resources against pollution and the existing pollution hazards in an area. However, due to low availability of base data and to insufficient funding and staffing these maps could unfortunately not be prepared in the framework of this project.

4.1 Groundwater Exploitation Potential Map

The exploitable or available quantity of groundwater at a specific location is based on the hydraulic conductivity (transmissivity/aquifer thickness), aquifer condition and well design. The most important parameter to estimate the exploitation potential is the transmissivity of an aquifer. The transmissivity can be obtained by the evaluation of pumping tests. Usually DMR wells are pumptested only for around 6 to 8 hours and some wells for even shorter durations to determine the specific well capacity for pump installation. Many of these pumping tests were not conducted until steady-state conditions were reached so that the transmissivity cannot be evaluated properly. Moreover, the total number and spatial distribution of transmissivity data in the studied area was not enough to delineate the exploitation potential based on aquifer transmissivity.

Another way to estimate the exploitation potential is to utilize the specific well capacity. The advantage of this method is that these values are easy to obtain from pumping tests. The formula for calculating the specific well capacity is as follows:

$$\text{Specific well capacity (SC; } m^2/h) = \text{Yield } (m^3/h) / \text{Drawdown (m)}$$

The productivity or yield of a groundwater well depends on the length of screens. However, most groundwater wells are not screened over the entire aquifer thickness and screen length in each well is different. The longer the screen length, the higher the extractable yield will be. Thus the screen length has to be used as a correcting factor to make SC values comparable to one another. In this case, the equivalent of SC/screen length is called normalized specific well capacity (SCn) :

Normalized specific well capacity (SCn) (m/h) = SC (m^2/h)/screen length (m)

The values of normalized specific well capacity were plotted on a base map and the values were grouped into three classes according to their potential (Table 4.1). The potential or expected yield of a groundwater well can be estimated by multiplying the normalized specific well capacity with the average drawdown and screen length. In this area, the average drawdown and screen length are 17 m and 12 m, respectively.

SCn	Expected yield (m^3/hr)	Potential
<0.049	<10	High
0.049-0.098	10-20	Medium
>0.098	>20	Low

Table 4.1: Classes of normalized specific capacity for the groundwater exploitation potential map

The areas of <u>high expected yield</u> can be seen as small areas in the central part of the studied area along the Lam Takhong River, in the Kham Sakae Saeng District, Muang District and Saloem Phrakaerati District (Figure 4.1). High groundwater exploitation potential might result from intensive fracturing in hard rocks or high porosity in sediments. Streams and rivers are usually controlled by fractures and often follow fracture zones.

<u>Medium exploitation potential</u> areas cover a large area in the central part of the studied area. This area also follows stream and river patterns with east-west and northeast-southwest directed axes plains, coincident with the main directions of fracture zones.

The areas with <u>low exploitation potential</u> are recognized in three areas in the southern part, in the northern part and the northeastern part of the project area. These areas are usually found at higher topographic positions than the high and medium exploitation potential areas. The associated aquifers are hard rocks of the Khok Kruat and Maha Sarakham Formations.

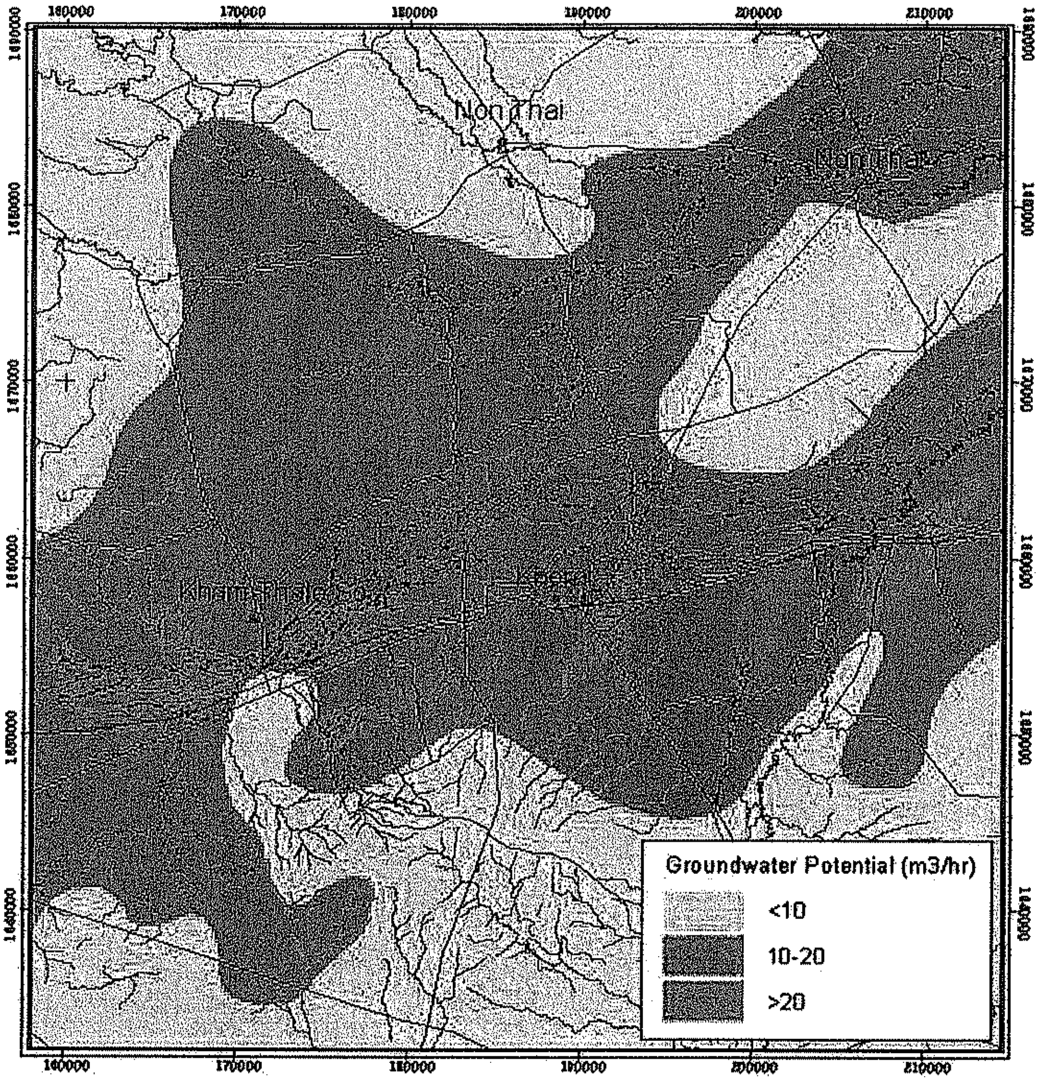

Figure 4.1: Groundwater exploitation potential map

4.2 Groundwater Quality Map

The groundwater quality map shows the quality of groundwater based on basic parameters, such as the total dissolved solids (TDS) and some other elements which could be detrimental to human health. In the Khorat area, a potentially harmful element is nitrate (NO_3). The locations of wells with high iron content are also shown on this map, although high iron contents are not harmful to human health but cause bad smell, clogging in the distribution system, and staining of clothes.

Total Dissolved Solids (TDS): is a value which is obtained from a water analysis by adding up all ion contents. In practice it is obtained by evaporating a water sample until only the dissolved minerals remain. The TDS value reflects the total amount of all dissolved elements in groundwater. This value is frequently used to assess the basic quality of groundwater. In this report, groundwater quality is divided into 3 classes by referring to the Drinking Water Standard of the Groundwater Department (Table 4.2).

TDS Values (mg/l)	Classes
<750	Low
750-1500	Medium
>1500	High

Table 4.2: TDS classes used for groundwater quality mapping

Areas with high TDS cover large parts of the northern study area and some small areas in the southern part showing that groundwater in the Maha Sarakham Formation is usually brackish to saline (Figure 4.2). High TDS areas are generally situated at low topographic levels or near large rivers where TDS values can rise up to 13,800 mg/l. In the northern part the main components of TDS are sodium and chloride originating from rock salt dissolution. However, in the southern part the main components are calcium, chloride and carbonate. Groundwater of this class is not suitable for drinking purposes.

Medium TDS areas are transitional areas between high and low TDS areas. The largest area of medium TDS is situated in the western part of the studied area. There is a small area of medium TDS inside the high TDS area in the northeastern part as a small freshwater lens above saltwater. This area is topographically slightly higher than the surrounding areas. Groundwater of this class is allowable for drinking purposes.

Low TDS concentration groundwater is only found in the southern part especially at high topographic positions. These areas are generally underlain by High Terrace Deposits and by the Khok Kruat Formation. The largest area occurs in the southern part of Khorat City which extends to the southwestern boundary of the studied area. The other two areas are in the eastern part of the Lam Takhong catchment and in the northern part of the Sung Noen District. Groundwater of this class is generally suitable for drinking purposes.

Nitrate (NO_3): it is a harmful substance especially for babies. Excessive intake will cause methemoglobinemia or blue baby syndrome which prevents oxygen from being carried with the blood stream of the baby. Low oxygen in the blood will cause babies to have a blue-colored skin, which is why the disease is commonly called "blue baby" disease. However, the color change may be hard to recognize on babies with dark skin.

The maximum allowable limit for nitrate in drinking water is 45 mg/l. Groundwater containing nitrate higher than 45 mg/l is not suitable for drinking. Groundwater exceeding this limit is found in areas near streams and rivers especially along the Lam Takhong and Mun rivers. In nature nitrate derives from decomposing organic matter as follows :

Organic matter is decomposed by bacteria $\rightarrow$ NH4 $\rightarrow$ NO2 $\rightarrow$ NO3

High nitrate concentration normally originate from human and agricultural contaminations. Areas close to rivers generally are used for agriculture, especially for growing rice which needs a lot of water and fertilizer. Farmers often use excessive doses of nitrate fertilizers, which are then washed out and contaminate groundwater. The highest observed nitrate content was 2,700 mg/l. This value is extremely high. So far, high nitrate concentration waters occur only in medium to high TDS areas. Therefore this water is commonly not used for drinking purposes. Due to the fact that nitrate transforming bacteria do not like saltwater environment nitrate concentrations in saltwater areas are rather high.

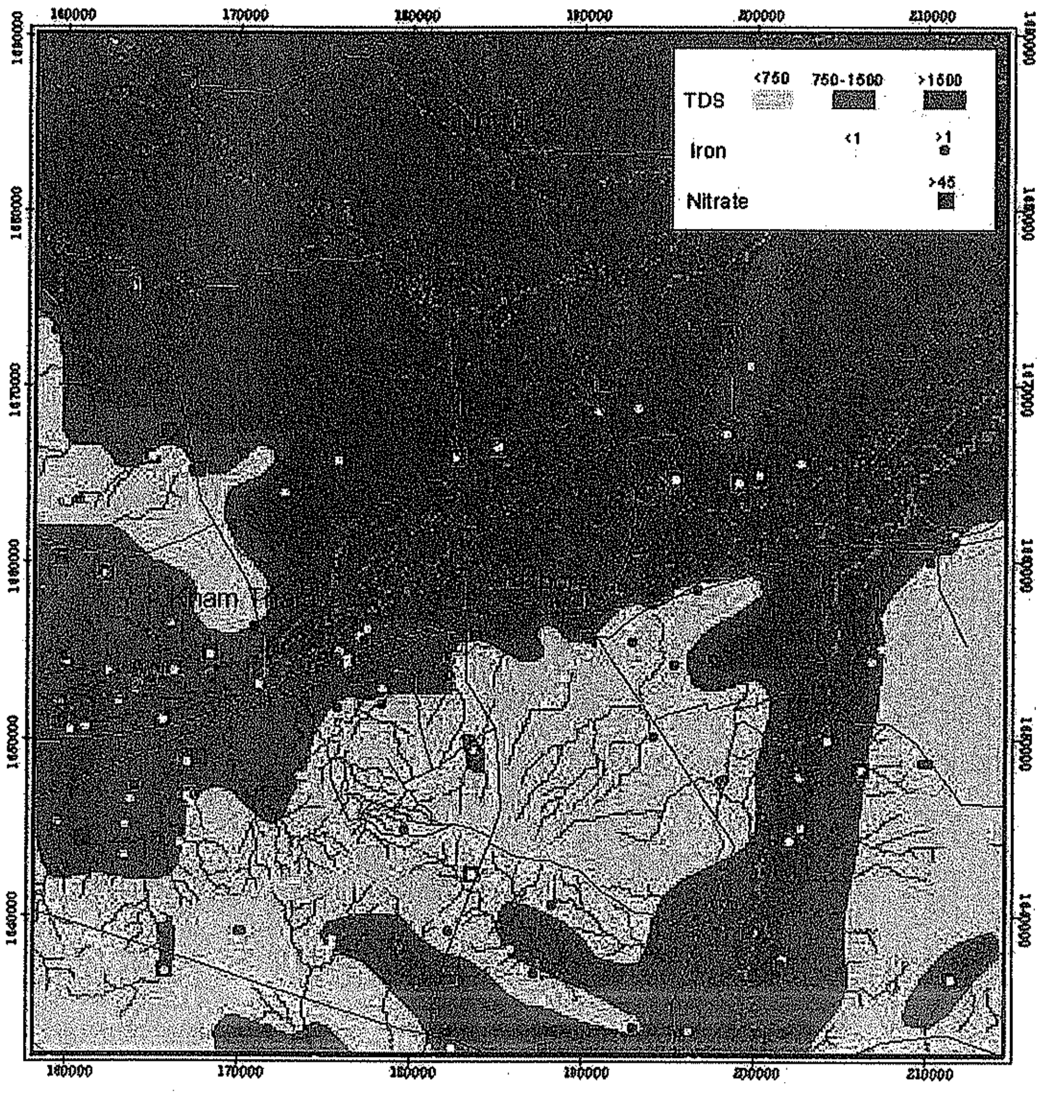

Figure 4.2: Groundwater Quality Map

Iron (Fe): it is a common element in groundwater. It can be found in every aquifer and in every level of TDS in this area. However, high TDS groundwater is often associated with high iron concentrations. Opposite, low iron concentrations are generally found in recharge areas where groundwater has a low TDS. Although iron is not harmful, it causes a lot of problems in using groundwater. It leads to undesirable bad taste, smell and color. Water containing iron over 1.0 mg/l is not suitable for drinking. However, the iron content may be reduced by relatively cheap and easy treatment methods.

4.3 Recommendations for Landuse Planning

Groundwater in this area is important in respect of two issues for landuse planning: availability and quality of water resources. Groundwater is commonly a preferred source for drinking water due to its all-time availability, relatively stable quality and the often low costs for infrastructure when extractable near the place of demand. Therefore, groundwater is the main source for drinking water, wherever possible. Surface water is not available in suitable quality and quantity throughout the year. Other problems are health risks. The residence time of groundwater in the aquifer system is mostly relatively high, exceeding commonly several years. During this time hazardous biological or hydrochemical components are usually degraded, adsorbed or transformed. In surface water, however, these components are quickly moved with water flow and there is therefore not enough time for such attenuation processes. This is the reason why surface water resources have commonly to be thoroughly treated before consumption.

4.3.1 Protected Areas for Groundwater Uses

High and medium exploitation potential areas should be protected against pollution. These freshwater resources can be used for domestic, industrial and agricultural purposes. However, since such groundwater resources are scarce, priority must be given to domestic uses. In all freshwater areas groundwater overuse, i.e. the pumping of groundwater exceeding groundwater recharge, must be avoided in order not to cause saltwater intrusion. Resources must therefore be carefully developed.

Sediments and rocks in these areas do not provide protection against infiltration of wastewater into groundwater. Sediments are predominantly sandy and are underlain by fractured rocks so that wastewater may easily contaminate groundwater or deteriorate its quality. Cleaning a contaminated aquifer, however, is extremely costly. Therefore protection measures are urgently required in these areas. All sources of hazards to groundwater should not be inventoried and the associated contamination risk assessed. Such groundwater hazards include factories, waste disposal sites, waste water treatment plants, etc. In case of existing contaminations, monitoring wells should be installed to monitor water quality.

Freshwater occurrences within brackish and saltwater areas can be found at high elevated areas. These small lenses of fresh groundwater are very important for villagers since they form an alternative source for water during the dry season. Their quality may rapidly deteriorate if groundwater is excessively pumped so that these resources must be carefully developed. They should only be used for domestic purposes.

4.3.2 Relationship between Saline Groundwater and Saline Soil

Salt Production from Saline Groundwater and Its Problems

The occurrence of saline groundwater and soil is known to the people in the northeast since a long time. In former times it was not considered as an important problem. It occurred only in certain areas and carried even the opportunity with it to produce table salt.

In the traditional way of table salt making, the local people collect salt rich soil from the land surface, put it into a wooden container and then dissolve it with water. The salt solution is filtered through sand and becomes clear saltwater. This saltwater is boiled until salt precipitates from the solution. In the new, industrial method, salt is not collected from the land surface but brine water is pumped from deep wells. All of these wells are drilled into the upper part of a rock salt layer. At this level, some part of the rock salt is dissolved where in contact with groundwater. The brine water is either being boiled in large containers or evaporated in large evaporation pans. This method is called salt mining. There are several places of salt mining in the Khorat Greater City Area. The most renowned place is located in the Ban Wang area. In recent years there have been conflicts between the local farmers and the mining companies about the impacts of salt mining. The farmers claim that the salt mines discharge saltwater into the natural surface water drainage system causing groundwater and soil salinization, and the formation of sinkholes. After heavy protests, the area was investigated and delineated as a high-risk area for the formation of sinkholes. Due to this, salt mining was prohibited in this area. However, salt mines in the other areas are still operating. Salt production depends on the market price for table salt. The total number of salt production sites is unknown.

Figure 4.3: Soil salinization in area closing to salt mining at Ban Wang, Non Thai District.

Groundwater and soil salinity problems often occur downstream of salt production facilities. In the industrial production method, saltwater is dried by the sun or by boiling. Salt crystal is started to deposit after some time but salt producers do not wait until the water is evaporated entirely. They collect only salty crystals and flush the remaining water to a wastewater pool. This wastewater sometimes leaks to surrounding areas and flows to downstream areas where it may reach surface water runoff.

Sinkholes resulting from salt dissolution can frequently be found in the area of salt mining by groundwater extraction. When the cave size created by rock salt dissolution becomes too large the overlying sediments and rocks may not be able to support its roof and the roof will collapse, forming a sinkhole.

Salt mining can cause both, saline soils and sinkholes. Therefore this activity should be controlled in term of area and method of mining. Salt production should be restricted to certain areas which are already highly saline and where remedial actions are not possible anymore. Nonetheless, the discharge of wastewater must be reduced to a minimum and these should not be detrimental to the environment. It is recommended to use closed systems where wastewater is injected back into the aquifer. The formation of underground caves and their size must be controlled by suitable techniques in order to avoid catastrophes.

Relationship between groundwater levels and saline soils

Another reason for increased salinity in the Khorat Plateau are the rising groundwater levels. These are resulting from increased groundwater recharge due to deforestation and landuse change.

After infiltration in the recharge areas, groundwater moves downwards and may dissolve rock salt from the Maha Sarakham Formation where it is in contact with the aquifer. This brackish or saltwater is moved with groundwater flow to the discharge area, usually at low topographic levels. In the discharge area groundwater level is close to ground surface. Here groundwater will evaporate due to the capillary force. The depth of this capillary force depends on the grain size and pore space. The smaller the pore space is, the higher is the capillary force. The relationship between sediment type and capillary rise is as follows (Fetter 1994):

Sediment Type	Capillary Rise (m)
Fine silt	7.50
Coarse silt	3.00
Very fine sand	1.00
Fine sand	0.50
Medium sand	0.25
Coarse sand	0.15
Very coarse sand	0.04
Fine gravel	0.02

Table 4.3: The height of capillary rise in sediments

According to table 4.3 the capillary force can act down to approximately 7.5 meter in fine silts. This means that groundwater evaporation will take place if groundwater levels are less than 7.5 meter in fine silts. If the evaporated groundwater is saline salt crusts will accumulated at the land surface. If this process continues for a longer period, large amounts of salt will be accumulated. These may be transported to other areas by wind or be washed out at the beginning of the rainy season.

To get an idea about the actual depth of the capillary force in this area, a silty sand from an area with saline soils was put in a transparent column. Then the column was placed in a water pan and left there for 3 weeks. During the first week, water quickly rose up the column. With time the rate of water rise decreased. The final capillary force measured in the silty sand was 0.8 m. Therefore it is suggested that in areas where groundwater level is less than 1 m groundwater evaporation may occur. In areas covered with vegetation an average rooting depth of around 1 m must be assumed. Hence, in such areas groundwater evaporation will take place if groundwater levels are less than 2 m. All such areas are therefore at a high risk to become affected by groundwater and soil salinization.

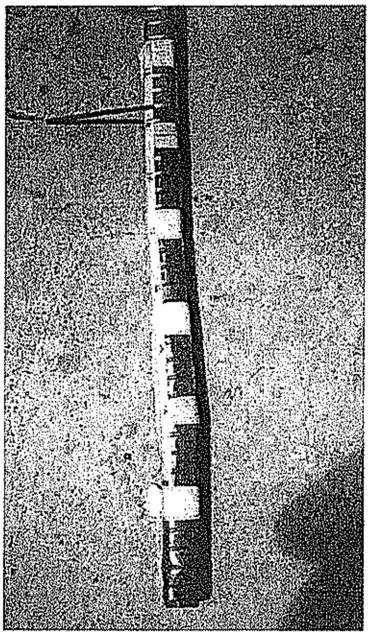

Figure 4.4: The result of capillary rise in a silty sand.

To solve this problem groundwater levels much be lowered. This can be done by decreasing recharge (in the recharge areas) or increasing discharge (in the discharge areas).

The recharge in barren land is much higher than in forest covered areas. To decrease recharge from rainfall one option would be to increase the forest cover. Recharge was increased by deforestation, the construction of irrigation systems and water reservoirs. The construction of irrigation systems and reservoirs is very useful in other areas of Thailand, however, in the study area where the permeability of the rocks and sediments in the underground is very high, the benefits and the disadvantages, especially the environmental effects should be carefully studied for each site. If water seepage to the underground from a reservoir, irrigation system or canal is not reduced to a minimum by suitable means, such as natural (clay), plastic or other liners, water can seep through the bottom or walls and recharge groundwater, causing raised groundwater levels in their surrounding which then may lead to increased groundwater and soil salinity due to groundwater evaporation. This can frequently be observed in the Khorat area. After reservoirs were constructed in the late 1960s and water was distributed through irrigation systems, groundwater levels in this area were raised (Figure 4.5) despite the fact that rainfall decreased by about 6 % in 38 years (Figure 4.6). Saline soil areas have gradually expanded during this time. If groundwater levels do not stop rising, saline soil areas will be more and more expanding so that finally the lowland areas cannot be used for cultivation anymore. To stop this process it is necessary to quantify groundwater recharge, to clarify where the dissolution of rock salt takes place and which amounts are being dissolved, and to investigate the depth of capillary forces in more detail in order to better delineate those areas where evaporation from groundwater takes place. Suitable counter-measures should be formulated for each individual case, depending on the local conditions.

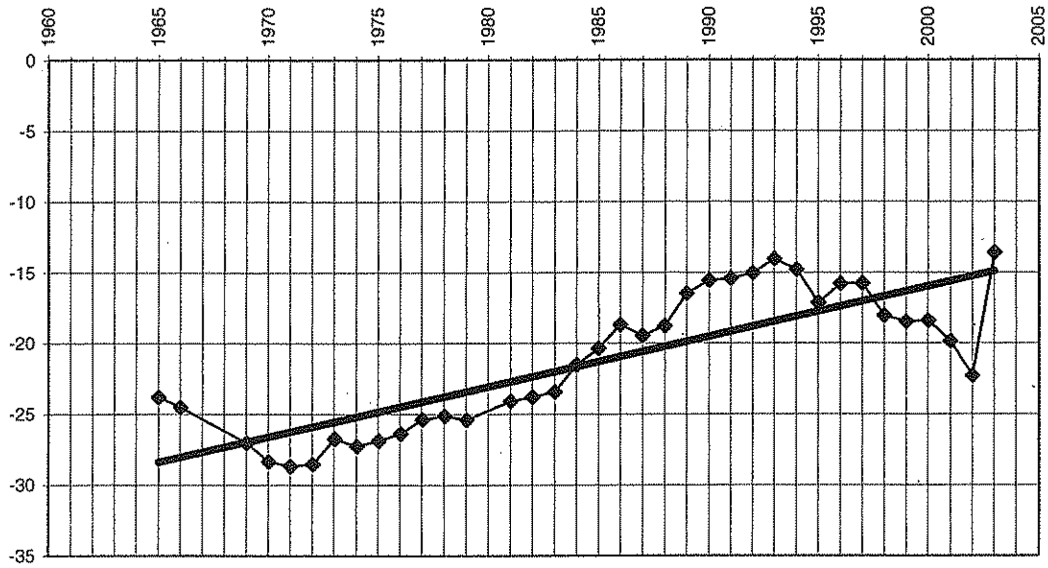

Figure 4.5: The average depth to groundwater of well L0001 and its trend.

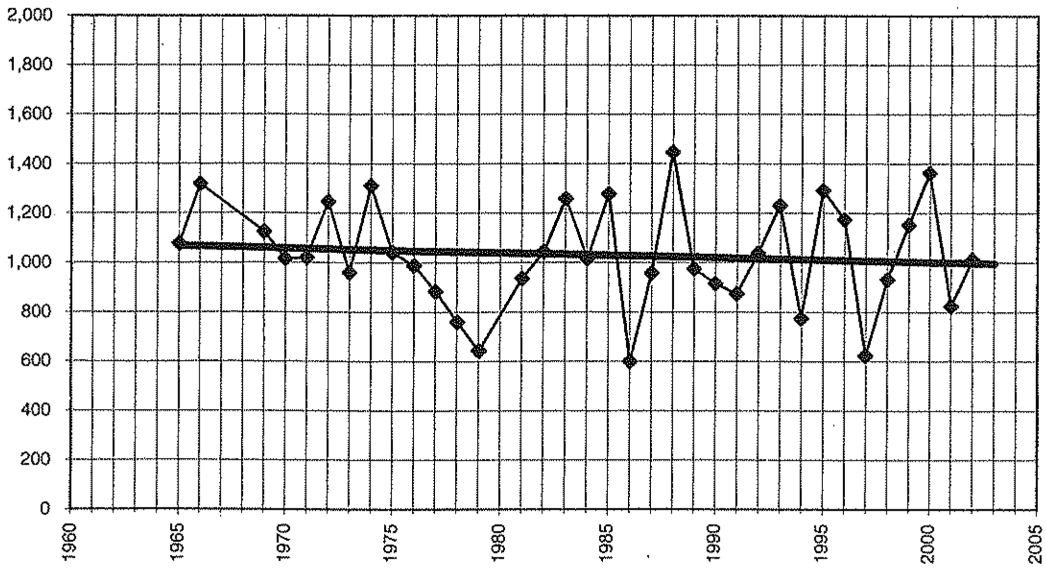

Figure 4.6: The total rainfall of Muang Khorat Station and its trend.

4.3.3 Proposed countermeasures against groundwater and soil salinization

A special problem in this area is groundwater salinization. The dissolution, movement and accumulation of saltwater depends on groundwater recharge and groundwater flow. For landuse planners it is important to know which areas are already strongly affected by groundwater and soil salinization, which measures could be implemented to mitigate the problem and where such measures would be most successful.

All measures to alleviate salinization have to take into account the fact that soil salinity in the Khorat Plateau partly is a natural phenomenon. For instance, the dissolution of rock salt which takes place in the underground cannot be stopped. Also the climatic conditions cannot be changed. Therefore it would be unrealistic to say that the problem of soil and groundwater salinity could be solved entirely in NE-Thailand.

In some areas, especially where salinity has been apparently a long-lasting phenomenon, it will not be possible to overcome salinization at reasonable expenditures. A long-term improvement of the situation can, however, be achieved by the following measures:

- Lowering the groundwater level in discharge areas: this could be reached by growing plants in and in the surrounding of low-lying areas where groundwater levels are now at least during part of the year so high that groundwater is evaporated.
- Decreasing groundwater recharge: this could be reached by reforestation, especially in the main recharge areas, the highlands.

- Reestablishing surface water runoff: most surface water storage facilities in the studied area are neither designed nor managed in a manner which would justify their existence. On the contrary they often are one of the main reasons for the formation of saline soils and groundwater. The impact of each of them should therefore be carefully studied. If the cons outbalance the pros these facilities should be abandoned.
- Surface water drainage systems should be established in areas where the salinization risk is high.
- Irrigation efficiency: irrigation methods should be promoted which consume less water and are more efficient than traditionally practiced methods. To reduce water consumption in agriculture, the growing of less water consuming crops should be encouraged.
- Growing of selected crops: in areas affected by soil salinization certain types of crops should be grown which are resistant to certain levels of mineralization by Na-Cl type water. Growing crops which integrate salt in their cells would also have the effect that the salt content of the soil is decreased when these plants are harvested.
- Banning/restricting salt mining: salt mining by pumping groundwater from greater depths to the surface should be banned while traditional salt mining, i.e. the use of groundwater from shallow depth for salt making commonly has no negative impact. On the contrary, due to the extraction of saltwater the effect of traditional salt making is principally positive due to the fact that salt is being transferred outside of the area.

Taking into account the poor natural productivity of the soils and the farmers' low incomes, any counter-measures against soil and groundwater salinization will have to be conducted through national funds. The alleviation of salinization is only feasible by changing practices of landuse management, such as irrigation methods, choice of cultivated crops, maintaining the natural drainage and cautious industrial salt mining. This needs the active participation of the local population and the support by all involved governmental institutions.

The measures given below are based upon technical aspects. However, it is strongly recommended that all taken actions have to be discussed and coordinated with local demands, which needs to be done specifically for each area in a stepwise approach.

Agricultural Practices

Measure to be Taken in the Uplands: Particularly in the uplands the reduction of groundwater recharge is considered to be the most effective measure for lowering the salinization hazard. Since groundwater flow is directed from the uplands towards the valleys or from the recharge to the discharge areas, high recharge rates in the uplands contribute to rising groundwater levels in the lowlands. This could be achieved by reforestation which increases evapotranspiration because trees take up more water from the soil and perspire it through their leaves, than flat or medium deep rooting cash crops do.

In this respect the non-indigenous species *Eucalyptus camaldulensis* is often proposed since it is a fast growing tree that can be used as firewood already after 5 to 7 years. However, the recommendation to grow Euculyptus is still controversially disputed because it has several ecological drawbacks, such as lowering the soil fertility. Reforestation with indigenous tree species of the dipterocarp forest should commence where land is available. Also planting fruit trees would support to reduce the recharge in the uplands. Therefore it is strongly recommended to grow more trees and to combine growing cash crops and fruit trees. In the beginning, especially the fringes of the medium salt-affected areas should be replanted with trees in order to lower the groundwater level locally.

As most of the upland soils are very sandy, irrigation should be banned, since the loss of irrigation water due to percolation is very high. The practice of growing rice in bunded fields should be discontinued since these fields rarely have a plain topography.

In general irrigation should be reduced in favor of rainfed agriculture.

Measure to be Taken in the Lowlands: Concerning irrigated areas in the lowlands irrigation water efficiency should be improved. A prerequisite to reduce the spending of irrigation water is a good leveling of irrigated fields. On a properly leveled field only a minimum amount of water is needed to keep a field wet. If there are small mounds in the field, either the amount of water has to be raised to the highest elevation or this spot dries up first with salt accumulating around it.

A good water management also means keeping water heights at the same level on neighboring fields. The salinity hazard of fields with little water is increased by lateral seepage of water from better-watered neighboring fields. This situation frequently occurs when non-irrigated fields border irrigated fields.

The salt content of irrigation water should regularly be controlled and water should only be used if salinity is less than 1,000 µS/cm, which is equivalent to a TDS of about 0.7 g/l.

The remediation of soil salinity is possible in many areas affected by soil salinization through the establishment or reestablishment of a drainage system. Usually saltcrusts are dissolved and saltwater is being flushed out at the beginning of the rainy season if a suitable drainage system exists. To this end suitable gradients in this drainage system must be (re-)established. Most important is the exact leveling and careful planning of such systems. Costs may be relatively low if the local workforce and low technology is involved. This would also create awareness among the local population.

Seepage from irrigation channels causes a rise of water levels in the surrounding areas. Reducing channel seepage therefore reduces the salinization hazard in such areas. This could be achieved either using liners, such as concrete liners, synthetic membrane liners and compacted earth liners, or using tubes and pipelines. If economically feasible, irrigation channels should be replaced by pipelines especially in areas with permeable soils and high seepage losses. Open channels may also be covered to reduce evaporation and avoid contamination.

Water spending may also be reduced by introducing tariffs for irrigation water. Many farmers trend to spend excessive amounts of irrigation water as long as it is free.

Another important measure in this respect would be irrigation scheduling. The amount of water applied and the timing of the application have to be in accordance with the water demand of crops. The applied irrigation water mainly depends on crop evapotranspiration and the effective precipitation. The soil moisture status and the plant stress indicators are generally used to determine the time when a crop requires water.

Access water will not only raise the groundwater level, but also the amount of salt in the soil due to evaporation.

In lowland rice systems, puddling is an important soil management practice, conducted with great care for the purpose of destroying the topsoil structure. It is a widely used practice in SE-Asia to minimize percolation losses of irrigation water. By puddling the natural soil structure of the topsoil is destroyed which results in less and finer pores. The process of puddling is accomplished by a series of tillage operations, beginning at soil moisture content above saturation and ending at moisture content closer to field capacity. However, it is only recommended for rice fields that can be irrigated all over the year. This is because of the very hard topsoil of puddled soils once they are dry.

Evaporation rates strongly depend on temperature. Therefore mulching of bare soil is a way to reduce the temperature of the soil surface and hence the evaporation. Besides, mulching can have other positive effects like increasing soil fertility.

In any case farmers have to plant salt tolerant varieties such as the rice varieties Kao Dok Mali 105 and AD6.

Infrastructure dams: As mentioned above, all infrastructure that blocks the natural drainage contributes to the salinity hazard by increasing the infiltration and prolonging the period of flooding.

Therefore attention should be given to maintain the natural drainage pattern and to reestablish runoff. Particularly at the beginning of the rainy season unhindered runoff should be ensured.

The culverts in road and railway dams have to be sufficiently big in order not to reduce the velocity of the natural drainage. Free draining through culverts has to be checked and all materials impeding drainage have to be removed.

Salt mining: Traditional salt mining has been practiced for many centuries at places of high soil salinity which are all located in the lowlands. Mayor damage to the environment is believed to emerge when large-scale salt mining started.

To reduce the negative effects of waste brines salt mining should be restricted to lowlands that are already highly saline and where remedial actions would be too costly. Special attention is to be given to waste brines. They should not be discharged into rivers or streams where they would increase the salt content of the surface water and damage the ecosystem for many kilometers downstream.

Injection of waste brines into the deep salty aquifer could be a feasible disposal method. Though brines derived from evaporation will create specific technical problems such as plugging of pore space and gradual decrease in the permeability, these problems should be overcome by surface treatment to remove organic and inorganic solids, which may otherwise result in well clogging, and by filtering the brine.

5. Conclusions and Recommendations

The project 'Environmental Geology for Regional Planning' in the Khorat Greater City Area has the objective to help mitigating the problem of groundwater and soil salinization and to advise landuse planners in related aspects. The reasons for groundwater and soil salinization are closely related to groundwater recharge and groundwater flow. Therefore the preparation of groundwater maps, which help understanding the groundwater system, was of prime importance. The Khorat Greater City Area was chosen as study area and is around 3,000 km^2 in size.

Hydrogeological data were collected from the Groundwater Department and other involved departments and altogether 520 groundwater well locations were visited to obtain their coordinates and collect water samples and water level data. The groundwater system was divided into 2 aquifer types, aquifers in unconsolidated rocks and aquifers in consolidated rocks. The first type is recognized in Alluvial, High Terrace & Colluvium Deposit. The latter type is found in the Phu Thok, Maha Sarakham and Khok Kruak Formations.

There are 50 piezometer sites in this area whereof 46 belong to the Land Development Department (LDD) and 4 to the Groundwater Department (GWD). Data of groundwater fluctuations with time were plotted as hydrographs. Results of piezometer data interpretation suggest that in topographic high elevations recharge conditions prevail while discharge conditions dominate in the lowlands. Some wells in the transition zone show recharge conditions during the dry season and discharge conditions during the rainy season. With respect to long-term trends the piezometers show increasing groundwater levels since the 1970s, when monitoring started. The depth to groundwater in the northern part, where groundwater levels are commonly less than 5 m, is generally lower than in the southern part.

Recharge results from rainwater and runoff infiltration and infiltration from surface water reservoirs and leaking irrigation systems. The amount of recharge ranges from 15 to 30 % of rainfall, depending on landuse. Under barren land recharge is generally higher than under forest covered areas. There is no estimation of recharge from reservoirs and irrigation systems. However, these losses lead to increased groundwater levels in their surrounding and are therefore seen as the major reason for groundwater and soil salinization in the vicinity of such sites. Groundwater discharge occurs in the form of abstractions through wells and upward leakage from the groundwater to the surface water, along the main rivers. Groundwater abstraction through wells is low, especially in the northern part which is predominantly saline.

Concerning its hydrochemical properties, calcium bicarbonate ($Ca-HCO_3$) type waters are found in high elevated areas of the southern part. Calcium-sodium or sodium-calcium bicarbonate ($Ca-Na-HCO_3$ or $Na-Ca-HCO_3$) type water results from cation exchange processes and is found in the transition zone between recharge and discharge areas. The same counts for sodium bicarbonate ($Na-HCO_3$) type waters which represent the end product of cation exchange. Sodium chloride (Na-Cl) type waters are predominant in the northern part. Groundwater types of minor importance are calcium sulfate (Ca-SO4) and calcium chloride (Ca-Cl) type waters.

For landuse planning purposes, two types of groundwater maps were prepared: a groundwater exploitation potential map and a groundwater quality map.

Groundwater exploitation potential is delineated utilizing the values of normalized specific well capacity. This value depends on the true screen length in correlation to the average screen length and the average drawdown in an area. These values are grouped into 3 classes, high (>20 m^3), medium (10-20 m^3) and low (<10 m^3) representing the expected yield or exploitation potential. Areas of high exploitation potential are recognized in the middle part along the Lam Takhong River. Medium exploitation potential areas are found in the central part close to the main rivers, while low exploitation potential areas are identified in both, southern and northern part.

The groundwater quality map shows the basic quality assessment of the groundwater by means of total dissolved solids (TDS), nitrate and iron contents which could be detrimental to human health. According to the Thai drinking water standards prepared by the Groundwater Department, water is unsuitable for drinking if containing TDS > 1,500 mg/l, nitrate > 45 mg/l or iron > 1 mg/l.

Areas with high TDS content occupy the upper half of the project area. The water in this area is mainly of sodium chloride type. Areas with high nitrate content are found in agricultural areas close to rivers. The nitrate content might result from fertilizer overuse. High iron contents are observed throughout the area and are mostly associated with high TDS values.

For landuse planning purposes, it is important to know details about the availability (quantity), quality and protection of groundwater resources. Areas of high and medium exploitation potential need to be protected against contamination by suitable means, such as the establishment of groundwater protection zones, in order to maintain a sustainable management of the groundwater resources in the long term. Because fresh groundwater resources are scarce, even fresh groundwater resources of low potential should be safeguarded in the project area.

Groundwater and soil salinity are closely related. In areas with saline groundwater, salt crusts can occur at the surface as a result of evapotranspiration from groundwater due to capillary force. This capillary force may act down to a depth of up to 7.5 m, depending on the type of sediment. However, due to the high sand contents the capillary fringe in the project area is only around 1 m. The average rooting depth is 1 m. Consequently in all areas where depth to groundwater level is less than 2 m there is a high risk of soil salinization.

Salt mines in this area pump saline groundwater for the production of table salt. They thereby cause the formation of sinkholes and the degradation of soils in the downstream areas due to the release of highly saline effluents.

From piezometer data it can be observed that groundwater levels in the project area have a rising trend. This means that if this trend cannot be stopped, the problem of groundwater and soil salinization will grow. A rise of groundwater levels occurs e.g. due to increased groundwater recharge. Since rainfall in this area has decreased during the past few decades, the reasons for increasing recharge must be related to landuse changes. The main factors in this respect are: deforestation, the blocking of the natural drainage systems and the construction of surface water reservoirs.

All measures to alleviate salinization have to take into account the fact that soil salinity in the Khorat Plateau partly is a natural phenomenon. For instance, the dissolution of rock salt which takes place in the underground cannot be stopped. Also the climatic conditions cannot be changed. Therefore it would be unrealistic to say that the problem of soil and groundwater salininity could be solved completely in NE-Thailand.

In some areas, especially where salinity has been apparently a long-lasting phenomenon, it will not be possible to overcome salinization at reasonable expenditures. A long-term improvement of the situation can, however, be achieved by the following measures:

- Lowering the groundwater level in discharge areas: this could be reached by growing plants in and in the surrounding of low-lying areas where groundwater levels are now at least during part of the year so high that groundwater is evaporated.
- Decreasing groundwater recharge: this could be reached by reforestation, especially in the main recharge areas, the highlands.
- Reestablishing natural surface water runoff: most surface water storage facilities in the studied area are neither designed nor managed in a manner which would justify their existence. On the contrary they often are one of the main reasons for the formation of saline soils and groundwater. The impact of each of them should therefore be carefully studied. If the cons outbalance the pros these facilities should be abandoned.
- Surface water drainage systems should be established in areas where the salinization risk is high in order to provide better possibilities for the washing out of saline waters.
- Irrigation methods should be promoted which consume less water and are more efficient than traditionally practiced methods. To reduce water consumption in agriculture, the growing of less water consuming crops should be encouraged.
- Growing salt-resistant plants: in areas affected by soil salinization certain types of crops should be grown which are resistant to certain levels of mineralization by Na-Cl type water. Growing crops which integrate salt in their cells would also have the effect that the salt content of the soil is decreased when these plants are harvested.

- Industrial salt mining by pumping groundwater from greater depths to the surface should be banned or at least restricted to areas where land cultivation is no possible anymore due to the advanced soil degradation. Traditional salt mining, i.e. the use of groundwater from shallow depth for salt making commonly has no negative impact. On the contrary, due to the extraction of saltwater the effect of traditional salt making is principally positive due to the fact that salt is being transferred outside of the area. However, it should also only be allowed in already highly saline areas.

Taking into account the poor natural productivity of the soils and the farmers' low incomes, any counter-measures against soil and groundwater salinization will have to be conducted through national funds. The alleviation of salinization is only feasible by changing practices of landuse management, such as irrigation methods, choice of cultivated crops, maintaining the natural drainage and cautious industrial salt mining. This needs the active participation of the local population and the support by all involved governmental institutions.

The measures given above are based upon technical aspects. However, it is strongly recommended that all taken actions have to be discussed and coordinated with the local demands which needs to be done specifically for each area in a stepwise approach.

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