Aspects of the Hydrogeology of the Chiang Mai-Lamphun Basin, Thailand that are Important for the Groundwater Management

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Abstract

The aquifer system of the Chiang Mai–Lamphun basin has been studied with the aim to provide information to regional planners on the availability, quality, and natural protection of groundwater resources.

The aquifer system is subdivided into a number of aquifer complexes on the basis of geological and structural criteria. Thematic hydrogeological maps were prepared (piezometric head, groundwater exploitation potential, depth to aquifer, areas of groundwater overexploitation, transmissivity distribution, and hydrochemistry) and groundwater recharge and abstraction were estimated. Groundwater vulnerability and hazards to the groundwater were also mapped.

The highest groundwater exploitation potential is found in the central part of the basin, where mainly sand and gravel were deposited in the area of maximum down-faulting. In some areas, especially in the deeper part of the aquifer system and in low permeability zones, a lowering of the water table of more than 1 m/a are observed. This indicates overexploitation of this part of the aquifer system. Groundwater quality mostly is good to excellent, but in some areas fluoride, iron and manganese contents are well above drinking water standards and water has to be treated or is not suitable for domestic consumption.

The best natural protection of groundwater resources exists in the southeastern part of the project area, where a thick sequence of mainly clay and silt was deposited.

Introduction and Description of the Study Area

Hydrogeological studies of the Chiang Mai–Lamphun basin were conducted between 1996 and 1998 (TATONG et al., 1997, TATONG & NEUMANN-REDLIN 1997, MARGANE et al. 1998) within the framework of the bilateral Technical Cooperation project ‘Environmental Geology for Regional Planning’ of the Department of Mineral Resources (DMR), Bangkok, Thailand, and the Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany. The aim of the study was to provide information to regional planners on the availability, quality, and natural protection of groundwater resources.

The study mainly utilizes information available at DMR and other Thai agencies and was supported by field checks.

The study area covers approximately 2800 km² from 18°30’N to 19°N and from 98°45’ to 99°15’E. The Chiang Mai–Lamphun valley has a kidney shape with mountain ranges on either side which reach a maximum elevation of up to 1685 m to the west and 1025 m to the east of it. The width of this basin reaches more than 25 km in the central part. The basin is relatively flat with elevations between 360 and 280 m.
The hydrography is dominated by the Mae Nam Ping River, which enters the project area at an elevation of about 320 m in the north and leaves it at about 280 m in the south.

Rainfall ranges from less than 800 mm/a in the valley to more than 1500 mm/a in the mountains (Fig. 1). Precipitation is high between May and October. Potential evaporation mostly exceeds rainfall, except between July and October, the main period of groundwater recharge.

The domestic water supply of the cities of Chiang Mai, Mae Rim and Doi Saket is based mainly on surface water. All other cities and villages are supplied from groundwater resources, but only some of the larger municipalities have a central water distribution system. Rising demand and increasing sanitary problems has led to increased drilling of groundwater wells since the early 1980s. Previously, the domestic water supply was from hand-dug wells. More than 21,800 wells have been drilled in the study area by government authorities and private companies. More than 20,500 of these wells are private and are used for agricultural; little data on these wells is available. A database for the 1117 governmental wells drilled in the area was set up by the project team (TATONG et al. 1997) and evaluated for the project.

Geology

The Chiang Mai–Lamphun basin is an intermontane basin that was formed, like similar basins in Thailand, between the late Cretaceous and the early Tertiary during a period of transtensional faulting following the collision of the Indian with the Eurasian plate (BUNOPAS & VELLA 1983, Bunopas & Vella 1992, Polocha n & Saatayarak 1989). The dominant tectonic features are N–S extensional faults, NW–SE dextral shear faults, and NE–SW sinistral shear faults. A sequence of Precambrian to Permian sedimentary rocks is exposed in the area around the basin. West of the basin, these rocks were intruded by granites (Carboniferous and Triassic). East of the basin, there are volcanic rocks.

Evaluation of geological mapping data (CHAIDANEE 1997) and gravity data (WATTANANIKORN et al. 1995), structural interpretation of satellite images, lithological logs, geophysical borehole logs and hydrogeological data reveals that continuous down-faulting since the late Cretaceous has governed the sedimentation pattern. On the basis of geophysical data, the basin fill reaches a thickness of about 2000 m (Wattananikorn et al. 1995). In the areas with high subsidence rates, sand and gravel have been deposited with high accumulation rates during the Quaternary. The more
stable blocks are dominated by the deposition of slope-wash sediments (colluvium) consisting mainly of clay and silt. In some areas almost no down-faulting or even uplift has occurred, as evidenced by the preservation of gravel beds at higher elevations (‘High Terrace’). In the area downstream of the Mae Kuang dam from the foot of the mountains down to the area east of Chiang Mai, sand and gravel beds interfingered with clayey and silty units were deposited in the form of alluvial fans by the Mae Nam Kuang River and its tributaries. Such interfingering units are observed throughout this area, providing evidence of the rapid change of the courses of the streams and rivers. As observed in outcrops and lithological logs, sand and gravel beds can be traced mostly only over short distances.

**Hydrogeology**

**Configuration of the Groundwater System and Aquifer Characteristics**

It is extremely difficult to delineate the sedimentary units in the basin because correlation is mostly not possible. Previous hydrogeological models, which proposed that the aquifer system consists of a number of terraces (CHUAMTHISONG 1971, BUAPENG et al. 1995), could not be confirmed. However, it is possible to delineate areas or blocks with a distinct sedimentation pattern. On the basis of lithological characteristics, the upper part of the Chiang Mai–Lamphun basin down to a depth of around 200 m can be subdivided into the following zones (Fig. 2):

- the ‘Central Alluvial Channel’,
- the ‘Mae Kuang Alluvial Fan’,
- the Nam Wang–Nam Mae Khan sub-basin,
- the ‘Zone of Colluvial Deposits’ and
- the ‘High Terrace’ deposits.

The distinctive lithology of each of these zones results in a very different hydrogeology of the aquifer complexes. However, adjacent aquifer complexes are certainly interconnected hydraulically. The aquifer complexes can be characterized as follows:

**Central Alluvial Channel**

The central part of the Chiang Mai–Lamphun basin is dominated by the deposition of sand and gravel transported under high energy conditions by the Mae Nam Ping River. This is the area where according to the structural interpre-
tation the main down-faulting occurs. Clayey strata are present throughout the sequence but form only a very minor component. Wells in this area are relatively shallow (average depth: about 50 m). In most cases adequate yields with low drawdown (high specific well capacities) have been reached within the top 30 m of the sediments. The Central Alluvial Channel is the area of highest groundwater exploitation potential. Specific well capacities per meter of screen length (i.e., normalized SC) are between 10 and about 100 m/d. Average screen length is around 6 m. Little data is available on hydraulic conductivities from pumping test evaluations; most of the data is from the area around Mae Rim, with hydraulic conductivities between 20 and about 200 m/d.

Groundwater quality is commonly very good, with total dissolved solids (TDS) mostly less than 250 mg/L. The fluoride and iron concentrations are generally low, especially in the upper part of the aquifer, owing to high oxygen concentration and flow velocities.

The future development of groundwater resources for central water supplies should be concentrated in this zone. However, it has to be emphasized that the vulnerability of this aquifer to groundwater pollution is high, due to the lack of a continuous cover of clayey/silty sediments. Therefore, measures leading to protection of these groundwater resources are highly recommended. For example, industrial plants and landfills for waste disposal should be legally banned in these areas, along with other activities hazardous to groundwater quality.

Mae Kuang Alluvial Fan

In the area between the villages of San Sai, Doi Saket and San Kamphaeng, sand and gravel interfinger with silt and clay. Especially in the northern half of this area, sand and gravel prevail. This sedimentation pattern was created by the alluvial fan of the Mae Nam Kuang and the Huai Bon rivers.

The average depth of wells in this area is about 50 m. Specific well capacities per meter screen length vary considerably from one area to the other, from about 1 m/d to about 20 m/d, providing evidence of the rapid lateral changes in lithology. Hydraulic conductivity values range between about 5 and about 100 m/d.

Groundwater quality is mostly good. Only in the southern part have elevated TDS values been observed. The vulnerability of the aquifer to pollution is highly variable. In the area between San Kamphaeng and San Sai, a thick cover of clay silt provides adequate protection against groundwater pollution. This is supported by a geoelectric sounding profile prepared by the Groundwater Division of DMR.

Nam Wang–Nam Mae Khan sub-basin

Evidence for the existence of a down-faulted block has been found from the tectonic interpretation of satellite images and gravity data from the area west of San Pa Tong. Continuous subsidence in this sub-basin has led to the accumulation of predominantly sand and gravel. This interpretation is supported by hydrogeological data that indicate high specific well capacities per meter screen length of as much as about 50 m/d. However, values are quite different from one point to the other and it seems that lower values are confined to the margins and lower parts of this comparably small sub-basin, whereas high values are found in the northwestern part.

Zone of Colluvial Deposits

Clayey and silty colluvial deposits predominate in the area east of the Mae Nam Kuang River from the southern limit of the project area to the Huai Bon River in the north (approximately UTM northing 2080.000). Sand and gravel beds occur only in limited areas as channel deposits of the eastern tributaries of the Mae Nam Kuang River, which have relatively small catchment areas. In a few wells, undated consolidated rocks have been reached (described as limestone and shale), indicating that the bottom of the basin in some areas is quite shallow.

The specific well capacity per meter screen length of wells in this area ranges from less than 0.1 to about 3 m/d. However, higher values may be expected locally – in alluvial channels of the tributaries. Hydraulic conductivity values

### Table 1: Characteristics of the aquifer complexes in the Chiang Mai - Lamphun basin.

<table>
<thead>
<tr>
<th>Aquifer complex</th>
<th>Total depth of wells [m]</th>
<th>SC/screen length [m/d]</th>
<th>Hydraulic conductivity [m/d]</th>
<th>Screen length [m]</th>
<th>Top of the top screen [m bgl]</th>
<th>Average TDS [mg/L]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central alluvial channel</td>
<td>~ 30</td>
<td>10 – &gt; 100</td>
<td>20 – 200</td>
<td>~ 6</td>
<td>~ 20</td>
<td>&lt; 250</td>
</tr>
<tr>
<td>Mae Kuang alluvial fan</td>
<td>~ 50</td>
<td>&lt; 1 – &gt; 20</td>
<td>&lt; 10 – &gt; 100</td>
<td>~ 12</td>
<td>~ 20</td>
<td>mostly &lt; 250</td>
</tr>
<tr>
<td>Nam Wang-Nam Mae Khan sub-basin</td>
<td>~ 50</td>
<td>~ &gt; 50</td>
<td>~</td>
<td>~ 12</td>
<td>~ 15</td>
<td>mostly &lt; 350</td>
</tr>
<tr>
<td>Zone of colluvial deposits</td>
<td>~ 80</td>
<td>&lt; 0.1 – 3</td>
<td>&lt; 1</td>
<td>~ 18</td>
<td>~ 50</td>
<td>&gt; 250 – &lt; 1000</td>
</tr>
<tr>
<td>Zone of High Terrace deposits</td>
<td>~ 80</td>
<td>&lt; 1</td>
<td>~</td>
<td>~ 18</td>
<td>~ 50</td>
<td>&gt; 250 – &lt; 500</td>
</tr>
</tbody>
</table>

### Table 2: Kenndaten der Aqui- fere im Chiang Mai - Lamphun Becken.
are generally less than 1 m/d. Wells are often quite deep (as much as 200 m) and screened at several depth intervals in order to obtain a suitable amount of water. Monitoring of wells shows a relatively large lowering of the water table of up to 1 m/a. This indicates that the recharge rate, especially in deeper parts of the aquifer, is less than the abstraction rate. The high fluoride content in this area of up to 16.5 mg/L provides further proof of low flow velocities (high residence time).

Colluvial deposits have been mapped in several other areas along the foot of the mountain ranges. Very few water wells have been drilled in most of these areas, but in general specific well capacities and hydraulic conductivities are low.

**High Terrace deposits**

Sediments classified as ‘High Terrace’ deposits (Qth) occur along the western margin of the basin. On the eastern margin, such deposits have been mapped only in a very small area (north of UTM northing 2091.500). These deposits consist of sand and gravel beds intercalated with silt and clay, probably deposited during the Late Pliocene to early Quaternary. The sand and gravel beds have a relatively high clay content (mainly kaolinite) and are indurated. The high clay content of ‘High Terrace’ deposits results in a very low specific well capacity, which is clearly reflected on the map of the groundwater exploitation potential (see Fig. 3). Specific well capacity per meter screen length is usually less than 1 m/d. Groundwater monitoring data from this area indicate a rapid lowering of water levels. In the deeper part of this aquifer complex, water levels have in some cases dropped considerably and the difference between the piezometric head in the shallow part of the aquifer and the deeper part is more than 35 m in some places, indicating that the recharge rate of these resources is very low.
Special Aspects of the Groundwater System

**Groundwater flow patterns**

Maps of piezometric head (Fig. 4) have been prepared for the shallow part of the aquifer system (wells screened above 50 m below ground level (b.g.l.)) and for the deeper part (wells screened below 50 m b.g.l.). As few values for the current water level were available, equipotential lines had to be extrapolated to the time of the map. It was observed, however, that water levels in the shallow part of the aquifer system in most areas are relatively uniform and variations lie within the natural annual water level fluctuation of mostly between 1 and 3 m.

The piezometric head in the deeper aquifer system is often considerably lower than the water table in the shallow aquifer system. This difference is more than 15 m in some parts of the San Kamphaeng area and 35 m in some places around San Pa Tong. In both areas specific well capacities are comparably low and the monitoring of wells indicates a lowering of the water table of more than 1 m in some places every year.

**Groundwater Exploitation Potential**

The groundwater exploitation potential in the basin (Fig. 3) was evaluated on the basis of the distribution of specific well capacities (corrected for screen length, i.e., normalized SC). As most water wells in the project area take water from a depth between 10 and 80 m, all other data has been excluded from compilation of the map. The highest exploitation potential is found in the central part of the basin ('Central Alluvial Channel'). Productivity is also elevated in parts of the ‘Mae Kuang Alluvial Fan’ and the ‘Nam Wang–Nam Mae Khan sub-basin’. Yields are less than 20 m³/h in 75 % of the wells in the study area.

**Groundwater Abstraction**

The total amount of groundwater withdrawal in the Chiang Mai–Lamphun basin can only be estimated, as pumping has not been metered in most of the wells. The average domestic water consumption is believed to be in the range of 100–150 L/d per capita, so that the total domestic water consumption would be around 50 Million m³ (MCM)/a. As about 10 MCM/a is provided by surface
water resources from the Mae Nam Ping River and the Mae Nam Kuang reservoir, the annual groundwater abstraction rates for domestic purposes must be around 40 MCM/a. The areas with high groundwater abstraction rates for the domestic water supply are indicated in Fig. 5 (San Sai, San Kamphaeng, and Pa Sang).

The water supply for agricultural (mainly irrigation of rice) and industrial purposes is covered by groundwater abstraction from the more than 20,500 private wells and by surface water resources. Surface water is taken mainly from a number of storage reservoirs and diverted through a system of canals. Amounts of abstraction from private wells is not recorded.

It is estimated that the total groundwater abstraction is higher than 200 MCM/a.

**Groundwater Recharge**

An evaluation of groundwater recharge in the basin is difficult, as many parameters are needed, e.g., amounts of groundwater and surface water abstraction, interflow and waste water input, are not available. Groundwater recharge is estimated to be around 220 – 250 MCM/a. For the shallow part of the aquifer, recharge mostly balances abstraction, since water level monitoring data indicate no or only a slight lowering of the water table.

**Water Level Monitoring**

The water table monitoring network consists of around 30 observation wells. However, only for a few wells has the period of observation been long enough to indicate long-term lowering of the water table. In addition, the project team took around 100 water level measurements. The annual rate of lowering of the water table was calculated using the data from these two sources. The lowering of the water table in many areas reaches more than 1 m/a, especially in areas with low permeability (Zones of Colluvial Deposits and High Terrace deposits). Water level monitoring data together with information obtained from maps of piezometric head, aquifer productivity, and groundwater abstraction were used to delineate areas of possible groundwater overexploitation. Although not monitored adequately, it is probable that overexploitation occurs in all heavily exploited areas, as well as in areas of low permeability.
Hydrochemistry

The hydrochemical characteristics of the aquifer system have been interpreted on the basis of more than 300 analyses (Asnachinda, 1992). The total salinity of the groundwater is generally low (Fig. 6). The groundwater is mostly of Na-HCO₃, Ca-Na-HCO₃, or Ca-HCO₃ type. It was found that Na-HCO₃ water prevails in the area east and northeast of Lamphun. This is attributed to cation exchange, as clay predominates in this area.

Cation exchange also seems to be the reason for the elevated fluoride concentrations in this area, due to the elevated solubility of fluoride in Na-type water (decrease in Ca activity). Elevated ingestion of fluoride is known to cause fluorotoxicosis. According to WHO and Thai drinking water standards, the maximum allowable content should not be higher than 1.5 mg/L F. However, in 35 % of all analyzed groundwater samples this limit was exceeded. Fluoride concentration increases with depth (Table 2).

Table 2: Correlation of screen depth and selected hydrochemical parameters.
TDS = total dissolved solids  Fe = iron compounds  F = Fluoride

<table>
<thead>
<tr>
<th>Depth of well screen (m)</th>
<th>TDS (mg/L)</th>
<th>Average of Fe (mg/L)</th>
<th>F (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 20</td>
<td>257</td>
<td>7.3</td>
<td>1.3</td>
</tr>
<tr>
<td>40 - 80</td>
<td>264</td>
<td>5.8</td>
<td>1.7</td>
</tr>
<tr>
<td>&gt; 80</td>
<td>328</td>
<td>1.1</td>
<td>6.4</td>
</tr>
</tbody>
</table>
Another important hydrochemical parameter, critical especially for groundwater exploitation, is Fe. According to the Thai drinking water guidelines, the maximum allowable content is 1.0 mg/L. This limit is exceeded in 67% of the samples. Although water with elevated iron content is not harmful to health, iron oxyhydroxides may clog the water distribution system and stain clothes and other materials. The spatial distribution of this parameter is highly variable. In general, iron content decreases with depth (Table 2).
Elevated concentrations of manganese are also present in the analyzed groundwater. The allowed maximum of 0.5 mg/L was exceeded in 46% of the samples.

**Groundwater Vulnerability**

The rapid urban development and industrialization which has taken place over the past two decades in the Chiang Mai–Lamphun valley increases the risk of groundwater contamination, so land use planners must take aspects of groundwater protection into account. Therefore, land use planners need information not only on the availability and quality of groundwater resources, but also on the degree of natural protection of aquifers, i.e., the groundwater vulnerability (VRBA & ZAPOROZEC 1994).

Based on the concept developed by the German state Geological Surveys (HÖLTING et al. 1995), a groundwater vulne-
rability map at a scale of 1 : 100,000 was prepared for the project area (Fig. 7). Evaluation of groundwater vulnerability in the Chiang Mai–Lamphun basin is difficult because very few lithological borehole descriptions exist and lithology can change rapidly from place to place, depending on the geological and structural environment. Since effective field capacities of the soils in the Chiang Mai–Lamphun basin were not known, groundwater vulnerability had to be calculated only on the basis of the rock cover.

Four classes of groundwater vulnerability have been differentiated, depending on the overall protective effectiveness (PT), which was calculated using the following formula:

\[ P_T = P_1 + P_2 + Q + HP \]

where

- \( P_1 \) is the protective effectiveness of the soil cover, \( P_1 = S \cdot W \) and \( S \) the effective field capacity of the soil (\( \Phi_{FC} \) in mm down to 1 m depth)
- \( P_2 \) is the protective effectiveness of the rock cover, \( P_2 = W \cdot (R_1 \cdot T_1 + R_2 \cdot T_2 + \ldots + R_n \cdot T_n) \)
- \( W \) : percolation rate factor
- \( R \) : rock type
- \( T \) : soil and rock thickness above aquifer
- \( Q \) is bonus points for perched aquifer systems, and
- \( HP \) is bonus points for hydraulic pressure conditions (artesian)

A protective effectiveness of 7500 points is equivalent to a cover of about 10 m of clay, 4000 points to about 5.3 m of clay. However, for groundwater protection the lateral extent and continuity are more important than the thickness of a low permeability rock cover.

A naturally high protection is found in the area northwest and northnortheast of Chiang Mai, south and west of Lamphun, east and north of San Pa Tong and around Mae Wang. The groundwater vulnerability map also identifies areas where the natural protection of groundwater resources by the overlying soil and rock cover is low, i.e., the risk of groundwater pollution is high. Here, waste disposal and uncontrolled handling of potential contaminants should be avoided at all cost. In contrast, areas of low vulnerability can be seen as potential locations for activities with high pollution risk, e.g., waste disposal sites or industrial plants. The groundwater vulnerability map together with the map of ‘Hazards to Groundwater’, which is being compiled at the present time, can be used to draw up recommendations for better protection of the groundwater resources.

It has to be stressed that the groundwater vulnerability map presented here is based only on available data and that due to uncertainties in the assessment of groundwater vulnerability, a detailed risk assessment is required before final selection of a waste disposal site. A preliminary study for a waste disposal site search in the Chiang Mai–Lamphun basin has been carried out by DORN & TANTIWANT (in prep.).

References


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