CHAPTER 1

INTRODUCTION

1.1 Significance of the problem

Mae-Hia landfill was used as a solid waste disposal site of Chiang Mai municipality from 1958 to 1989 (CMU-JICA, 1992). The site lies about 10 kilometers southwest of the city of Chiang Mai and covers an area of approximately 0.12 square kilometers (75 rai). For more than 30 years, the disposal method was open dumping, with no concern for the affect on groundwater quality, odor, and vermin around the site. Furthermore, the villagers point out that there is a small waste disposal site located in the northern part near the first site. Previous methods used to delineate the groundwater contamination at these sites were the analyses of groundwater collected from shallow wells and surface water for physical, chemical, and biological characteristics.

Geophysical techniques have been successfully applied to a wide range of environmental problems, such as locating underground storage tanks, locating and delimiting abandoned landfills, finding buried waste drums, locating and tracking contaminant plumes in groundwater, mapping buried utilities, and monitoring site remediation. In this study, resistivity and very low frequency electromagnetic (VLF) surveys were employed to assess and monitor groundwater contamination caused by leachate at Mae-Hia landfill site.

Abandoned hazardous waste sites or old landfills may contain or emit substances that contaminate the soil, the groundwater, and the biosphere. Resistivity methods reveal conductive zones in the earth caused by electrically conductive contaminated water. These techniques can also be used to determine soil and rock characteristics that control groundwater and contaminant movement. Since most leachates and seepages from landfills and dumps are salty, many plumes carrying soluble contaminants can be detected by this technique.

An important factor of geophysical application is its industrial safety in field work. The protection of working personnel is better than during investigations by mechanical penetration, such as drilling, probing, and trenching, since mechanical penetration may set free harmful gasses or liquids. In addition, geophysics is not destructive, is non-invasive, and can cover the total lateral and spatial expanse of a waste site, whereas boreholes can only provide information about one point or a thin column.

1.2 Literature review

CMU-JICA (1992) sampled 40 shallow water wells (3 to 10 meters in depth) around the Mae-Hia solid waste disposal site in 1989 to 1990 and analysed the samples for physical, chemical, and biological characteristics. Water quality analysis showed that the well water was highly contaminated by total and fecal coliforms in general. Comparison with the World Health Organization (WHO) guidelines for drinking water showed that except for sulphate, hardness, and heavy metals, less than 80 percent of the water samples met these guidelines. Particularly, the percent of samples that met the guidelines for pH, color, and manganese were quite low. The number of samples that meet the World Health Organization guidelines for color, manganese, calcium, and magnesium in the rainy season were more than in the dry season. In contrast, the number of sample in the rainy season that contained total solids, nitrite, nitrate, and iron in amounts that exceed guidelines were less than in the dry season. Using chloride values of shallow well water analyzed in a populated area where contamination source is considered to be only toilet effluent, leachate plumes and wells contaminated by leachate from the waste disposal site were identified. In order to estimate the extent of chloride contamination by leachate, averaged chloride values of shallow well water in the downtown of Chiang Mai City where possible contamination source is considered to be only toilet effluent of residents, are compared to the data obtained in the study. Providing that 71.6 mg/l gives the upper confidence limit value of chloride in the shallow well of which contamination sources are only toilet effluent, it can be preferably said that the wells whose chloride levels are more than 71.6 mg/l throughout the year would be contaminated by the sources other than toilet effluent. According to this prediction, only wells in the village located to the east of the waste disposal site could be polluted by leachate. Major contamination sources of other wells were thought to be toilet effluent or soil constituents including fertilizer. Contamination caused by pig farm effluent seems to be restricted in the vicinity of the pig farms.

Wisuthitarawong and Prawittarawong (1996) studied the water quality in 10 shallow wells in an area near the Mae-Hia landfill site. The samples were collected in 1995. They found that most of the water samples did not meet the drinking water quality standards of the World Health Organization and Ministry of Industry. Hence, the well water around the disposal site is not suitable for direct drinking. Furthermore, comparison with the result of a study conducted during 1989 to 1990 showed that most of the water contamination in the wells sampled in this study was at the same level as in the wells sampled in the 1989 to 1990 study.

Karnchanawong *et al.* (1997) sampled the 40 shallow water wells in 1997 that are the same wells sampled in 1989 to 1990. They also took two samples of leachate from the leachate lagoon at the southeast end of the disposal site. These samples revealed a plume of contaminated groundwater to the east of the site. However, few recognizable organic compounds were identifiable in either the leachate or the contaminated groundwater despite the high total organic carbon values. Temporal changes in leachate chemistry indicate that flushing from the waste is still occurring in response to rainfall. There is a well-delineated contaminant plume that migrates from the site at the rate of 1 to 2 meters per day. There is a lack of evidence for stabilization of the waste or degradation of the contaminant plume after closure.

Greenhouse and Harris (1983) mapped the migration of contaminants and continued to assess the relative usefulness of direct current, very low frequency electromagnetic, and inductive resistivity surveys. They found that where contaminant levels were less than about twice the background level, mapping contaminant distribution with surface geophysics became unreliable.

Mazac *et al.* (1985) discussed the factors influencing relations between electrical and hydraulic properties of aquifers and aquifer materials. A general hydrogeophysical model was shown to depend primarily on two factors: the character of material-level relationship and the mutual relation between the direction of groundwater flow, aquifer layering, and hydrogeophysical conditions in the aquifer.

Mazac *et al.* (1988) attempted to apply methods of vertical electrical sounding and electromagnetic profiling for determination of spatial variability of saturated hydraulic conductivities in the zone of aeration. They concluded that the relation of the saturated hydraulic conductivities to deeper structures of the studied medium was proved. These deeper structures could be easily discovered by applied geophysics. The values of the individual layers of the soil profiles and the type of the soil horizon could be estimated from the resistivity values of the layers.

Benson *et al.* (1997) used electrical resistivity and very low frequency electromagnetic induction surveys in mapping an area of contaminated soil and groundwater at a site of shallow hydrocarbon contamination. Data from the two surveys correlated well. Both geophysical methods identified the contaminant plume by high resistivity values, even though there were higher total dissolved solids concentrations in the contaminated groundwater compared to those in cleaner groundwater.

Kayabali *et al.* (1998) investigated the groundwater contamination caused at a recently closed disposal site using hydrochemical and resistivity methods. The results indicated that total dissolved solids and chloride concentrations decreased horizontally away from the waste site, but increased with depth. Electrical sounding yielded low resistivity values that were obtained from locations near the leachate seepage point.

Stephen (1998) presented inversion of resistivity data to monitor fluid migration in the vadoze zone. Low resistivity zones were inferred to be loci of fluid concentration. The resistivity reductions showed a spatial connection to the plume's source and are suggestive of fluid migration.

Yang *et al.* (1999) combined application of geoelectric and electromagnetic induction methods to help map the lateral and vertical distributions of the freshwater/salt water interface. Based on a modified Archie's law, an empirical relation between pore-water resistivity of the stratum and formation resistivity was obtained. Low resistivity values less than 1.5 ohm-m imply saltwater contamination of groundwater and, thus, can be used to assess groundwater contamination.

Aristodemou and Thomas-Betts (2000) monitored the spread of contamination in underlying aquifers due to a landfill site using direct current resistivity and induced polarization investigations. They found that the type of waste deposited and the influence of the geological environment were the crucial factors investigated. Low porosity may imply reduced fluid content and, therefore, increased bulk resistivities.

Meju (2000) attempted to develop a genetic investigative model for old or abandoned landfill sites based on geoelectrical methods. The attendant geotechnical, hydrogeological, and bio-geochemical constraints at such sites were also incorporated in the model for consistency of practical solutions to landfill problems. The nature of antropogenic deposits and spatial-temporal characteristics of leachate were reviewed in a geoelectrical context.

Slater and Sandberk (2000) demonstrated the use of resistivity and induced polarization in monitoring salt transport under natural hydraulic loads. The results presented the two-dimension of changes in the electrical response at the saltwater-freshwater interface over the duration of a tidal cycle.

1.3 Purpose of the study

(1) To assess the groundwater contamination at the Mae-Hia landfill site, Amphoe Muang, Changwat Chaing Mai, using electrical resistivity and very low frequency electromagnetic surveys.

(2) To determine migration pathways of leachate in order to estimate the possible contaminant plume migration.

1.4 Scope and methodology

1.4.1 Scope

(1) The geophysical investigations were conducted over an area of approximately 1 square kilometer near Mae-Hia landfill site, Amphoe Muang, Changwat Chiang Mai (Figure 1.1).

(2) The geophysical methods used in the study were electrical resistivity and very low frequency electromagnetic methods.

1.4.2 Methodology

(1) Literature review and field survey planning. All available physical and historical data about the target and study area were collected, including information about accessibility, road or electrical installations, geological and hydrogeological surveys, and previous work of the area. Records and reports about geophysical investigations to solve the soil and groundwater contamination were studied.

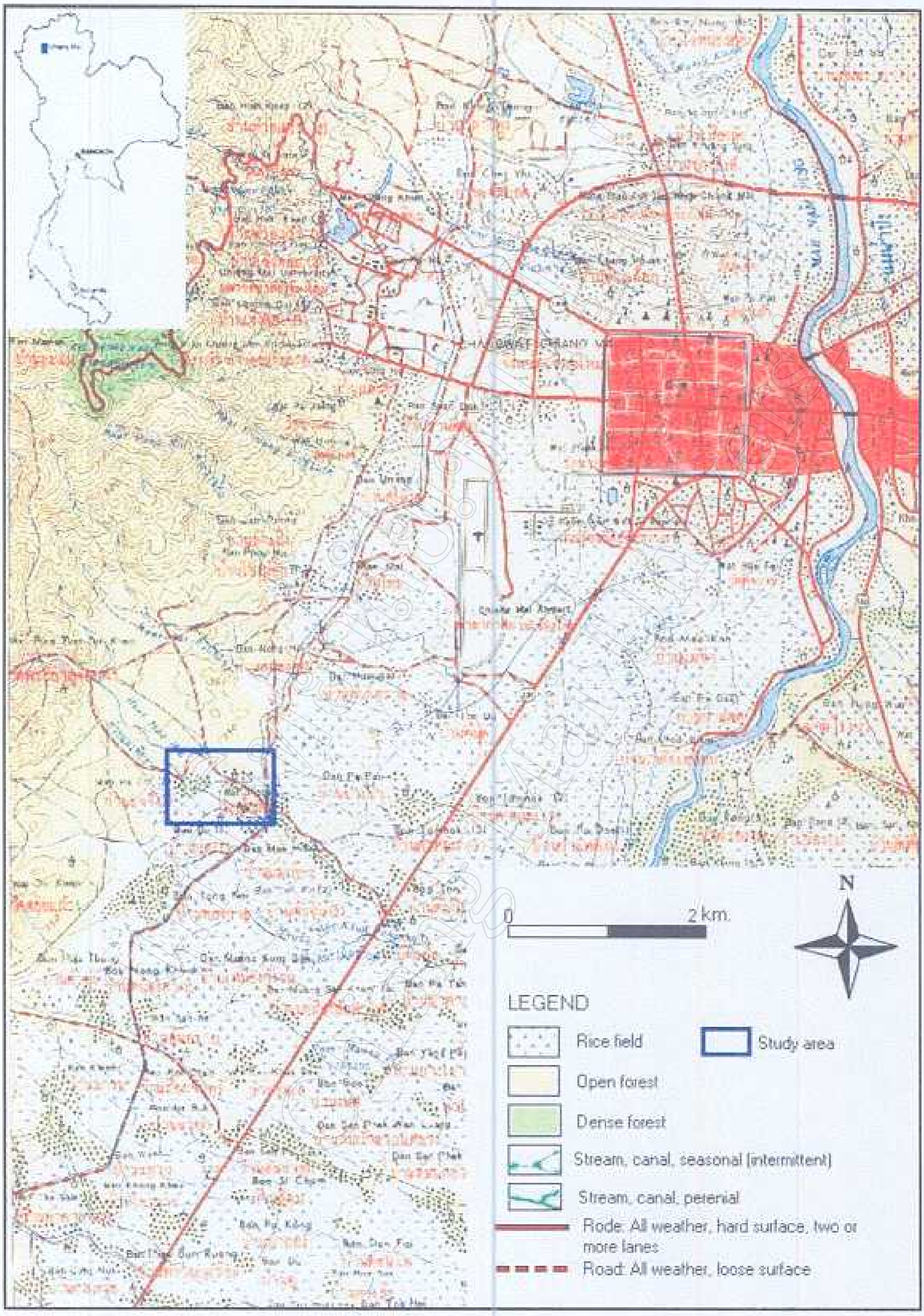

Figure 1.1 Location map of the study area.

(2) Field survey. Since the less possibility to drive or walk into the area, installation of building and plant, survey lines were located in suitable areas around the landfill site. Resistivity measurements were made using ABEM Terrameter SAS 300B instrument. The electrode arrangement used was the Schlumberger array and field operation was depth sounding. Forty-seven sounding stations were located in an area of approximately 1 square kilometer (Figure 1.2). The maximum current electrode separation, AB, was 90 meters. This separation was expected to obtain shallow subsurface information. Very low frequency electromagnetic survey was also run in the study area using an ABEM WADI VLF instrument. Nine survey lines were placed adjacent to the resistivity measurement locations, these having a total length of 1.84 kilometers (Figure 1.2).

(3) Data processing and interpretation. Field data were processed using resistivity modeling software and graphic software. The output were contour maps of resistivity and a pseudosection of very low frequency electromagnetic for each survey line. They were used to investigate the existence of a leachate plume and its dimension. Apparent resistivity values were correlated to those of chemical analyses from shallow wells to determine groundwater quality and spatial variation of the contaminant plume.

1.5 Outline of the study area

The Mae-Hia landfill site, located at about 10 kilometers southwest of the center of Chiang Mai city, had been purchased by the Chiang Mai municipality and was used to dispose of solid waste collected from the municipal area from 1958 to May 1989 (Figure.1.1). The site (site 1) covers an area of approximately 1 square kilometer, of which 0.12 square kilometer (75 rai) was used for waste dumping. The northern part of the site is in Doi Suthep National Park and is adjacent to the farm land of the Faculty of Agriculture, Chiang Mai University which is northwest of the site.

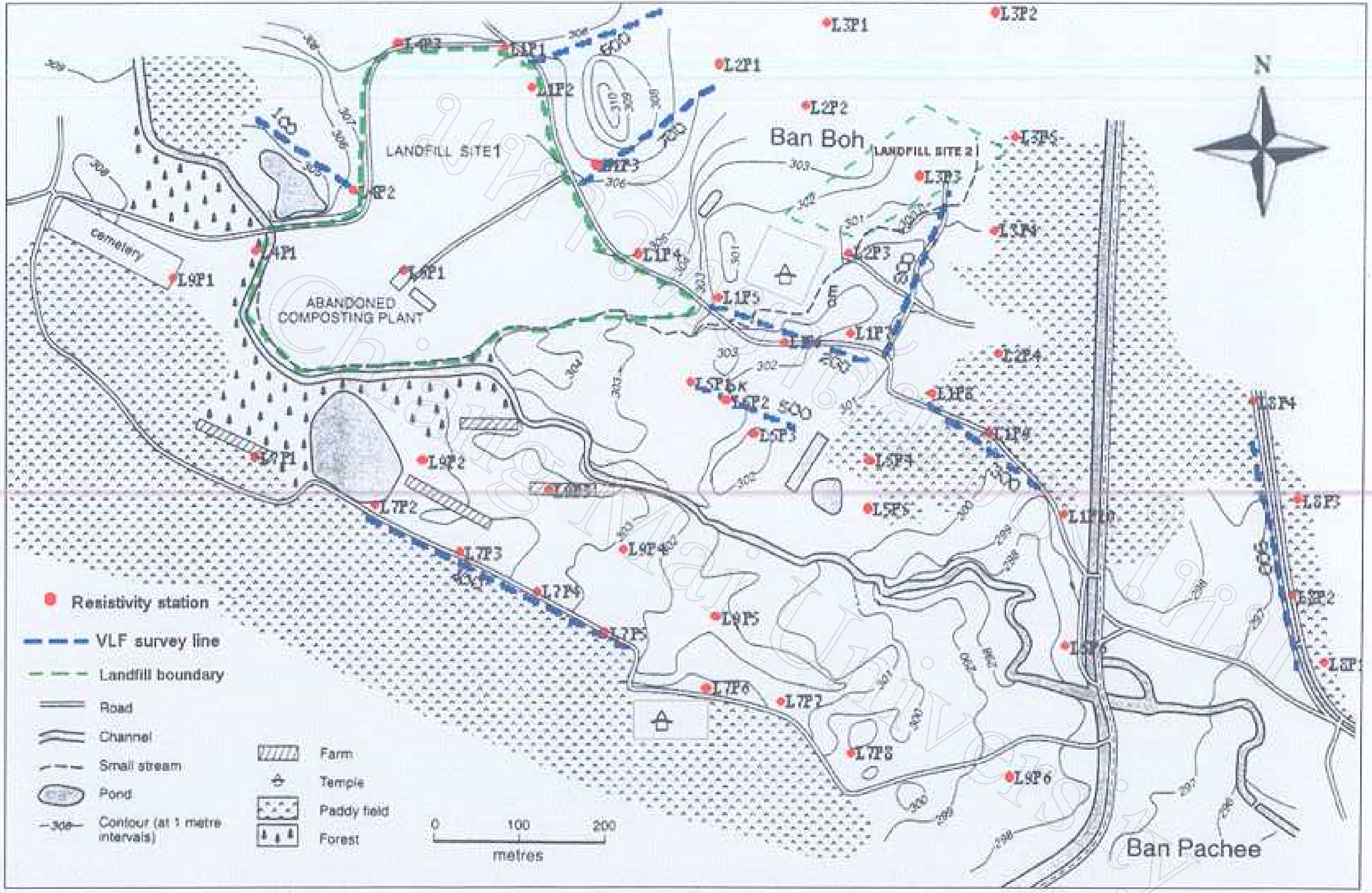

Figure 1.2 Map of study area showing landfill boundaries and geophysical measurement locations (modified from Karnchanawong, 1997).

Figure 1.2 shows the boundaries of waste dumping sites, and geophysical measurement locations. There is a village, located 1 to 2 kilometers in the southeast of the site. Another village is located to the east, only 30 to 200 meters from the center of the site. The outskirts of this village are used for rice fields. To the south of the site, there are several pig farms and orchards where a creek, that originates in Doi Suthep National Park, runs through. A branch of this creek flows along the periphery of the west part of the dumping site. Another small stream, that diverges from this creek, flows along the southern part of the dumping site and runs through the village near the dumping site. In rainy season, runoff water from waste pile and seepage from the waste deposit are suspected to flow into the stream and creek at the western part of the site (CMU-JICA, 1992). Rice fields also exist in the south.

The landfilling method used was initially a sanitary type that used soil cover. A composting plant was constructed on the site and was operated from 1963 to 1973. It was closed due to insufficient market for the products and high operation cost. Since then, waste had been disposed of by both sanitary and open dumping methods. However, since the administration area of the municipality expanded in 1983, the amount of waste to be collected and disposed of by the municipality has increased. Hence, the municipality had to dispose of waste using the open dumping method in order to extend the lifetime of the site. Some deposited wastes caught fire occasionally during dry season.

Another solid waste landfill site (site 2) is located at about 200 meters to the east of the site 1. There is no detailed information about this site. The preliminary information was obtained from villagers who reveal that this waste dumping site covers an area of about 0.02 square kilometer (12 rai). Dumping of solid waste at this site was stopped about 10 years before the closure of site 1. At present there is no evidence of the solid waste dumping in the area except for the site 1 where garbage are still present.

The topography consideration as shown in Figure 1.2 shows that the study area is in an area of steep level terrain, with approximately 10 meters of difference in elevation across the site. High elevation is on the western part and gradually decrease to the east of the study area.

1.6 Geology and Hydrogeology

According to data presented by Wongpornchai (1990), Karnchanawong *et al.* (1997) and Margane and Tatong (1998), the Mae-Hia landfill site is situated on a sequence of Quaternary colluvial deposits that were derived from the high ground on the western side of the Chiang Mai basin (Figure 1.3). These deposits consist of impersistent sand and gravel layers interbedded with clay units. Locally, they rest on preserved remnants of the high terrace deposits, which consist of thick sand and gravel beds. The specific capacity per meter of filter length in the colluvial deposits ranges from less than 0.1 to 3 square meters per day. However, locally, in alluvial channels higher values might be found. Based on a compilation of hydraulic data from tested wells in the colluvial deposits, the hydraulic conductivity is log normally distributed, with a mean value of 1.4 x 10^{-5} meters per second and a maximum value of 2 x 10^{-4} meter per second. This hydraulic conductivity is consistent with that of a sandy gravel aquifer.

Singharajwarapan and Singharajwarapan (1988) studied sedimentary facies in the western part of Chiang Mai basin. Three sedimentary facies were recognized, namely permeable facies, semi-permeable facies, and impermeable facies and were found intercalating with one another. In this regard, permeable facies are considered to be aquifers which can be devided into two levels, upper aquifer (7-30 meters) and lower aquifer (50-140 meters). Based on hydrochemical facies analysis, groundwater is classified as Sodium-Calcium-Bicabonate facies. Wongpornchai (1990) classified the major aquifers of the western part of Chiang Mai basin into 2 units, namely; (a) extensive and productive aquifer and (b) extensive but moderated productive aquifer. The main aquifer of this study area is the extensive but moderate productive aquifer that can be divided into Chiang Rai and Chiang Mai aquifer (Figure 1.4). Chiang Rai aquifer consists of thick sequence of clays with minor or local sand and gravel beds. This aquifer is classified as semipermeable facies. Chiang Mai aquifer consists of terrace deposits of the same characteristics as the extensive and productive Chiang Mai aquifer but yields less quantity of water, principally due to smaller grain sizes and poorer sorting. This aquifer is classified as semipermeable facies.

In the vicinity of the landfill site, water supply is obtained from shallow wells, 3 to 10 meters deep, dug into the colluvial aquifer. Water depth in these wells ranges between 0.5 and 9.55 meters depending on well location and season. In general, water level response to rainfall is fast in most wells. This indicates that infiltration is quite rapid. The groundwater flow direction has been inferred from water level monitoring data. These data generally indicate a flow from west to east as shown in Figure 1.5. In more detail, groundwater under the flat area of rice field flows from the west to the east through the season. On the contrary groundwater in the upper area of the site deviates to the northeast direction from the late dry season (April) until mid-rainy season (August) while it deviates to the southeast direction from the late rainy season (October) until mid-dry season (February). The groundwater that pass through the center of the landfill site seem to flow from western to southeastern part of landfill site as shown in Figure 1.6.

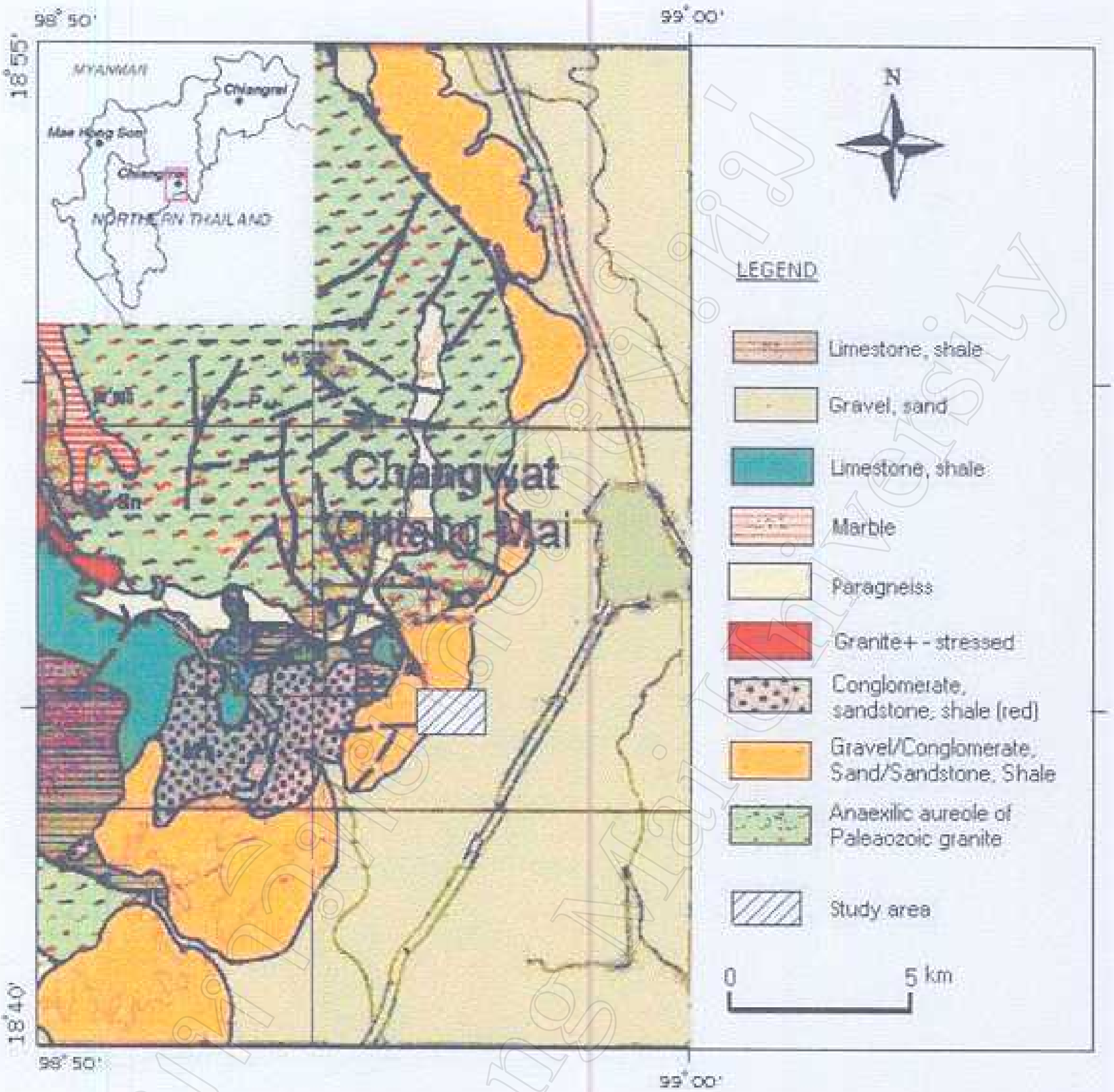

Figure 1.3 Geologic map of the study area (modified from Baum *et al.*, 1981).

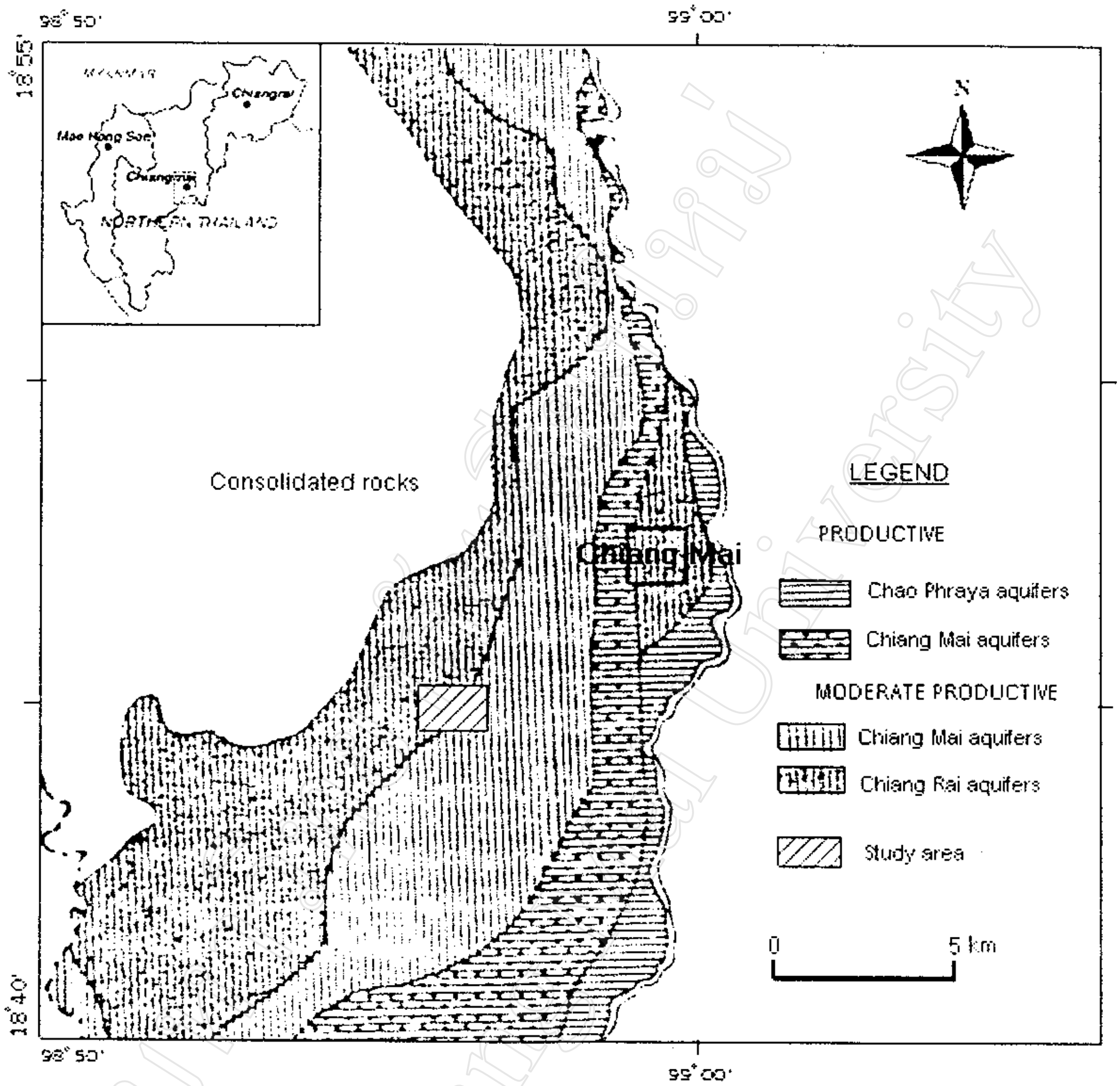

Figure 1.4 Hydrogeological map of the study area (modified from Wongpornchai, 1990).

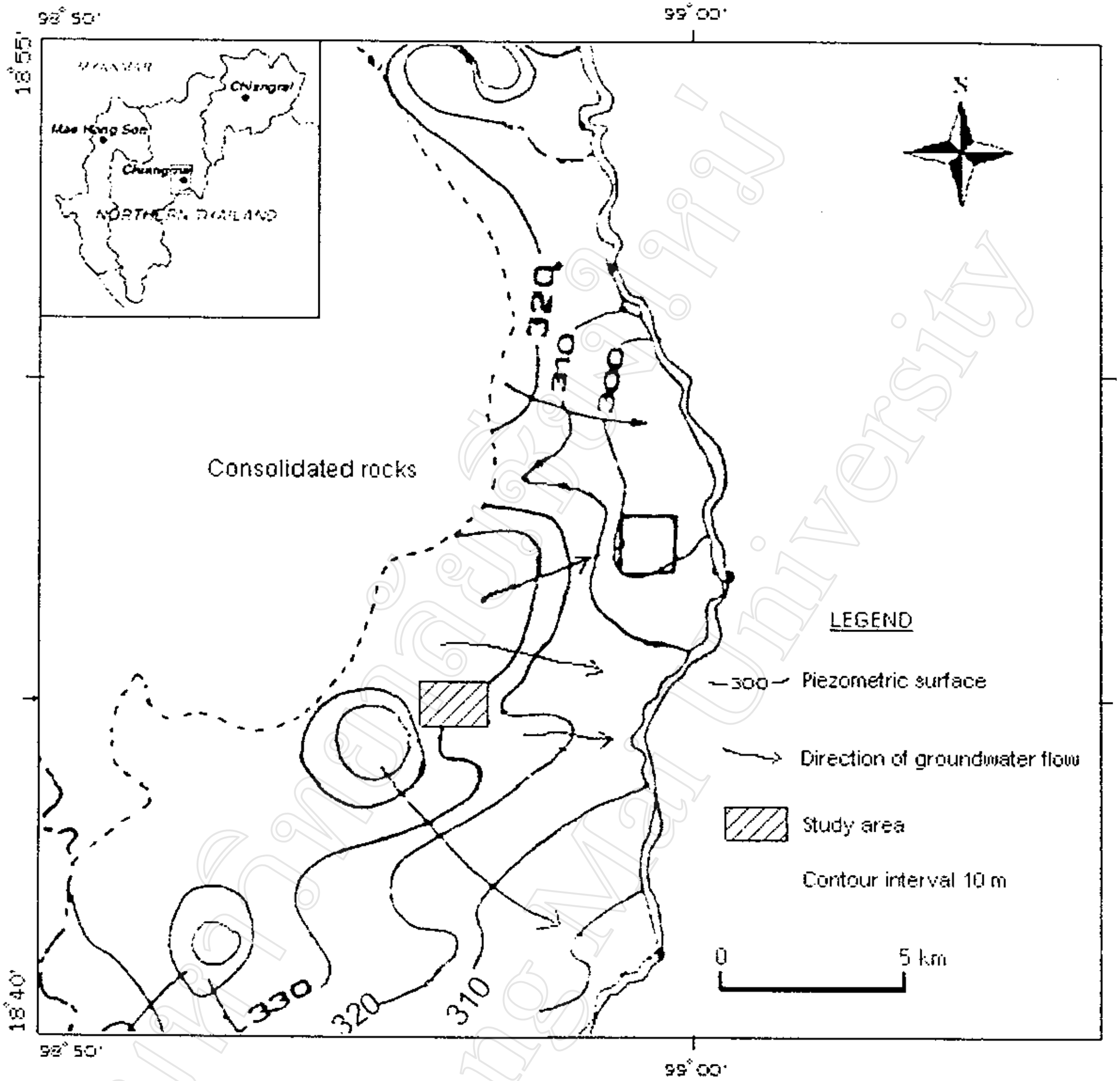

Figure 1.5 Shallow groundwater flow pattern in the study area (modified from Wongpornchai, 1990).

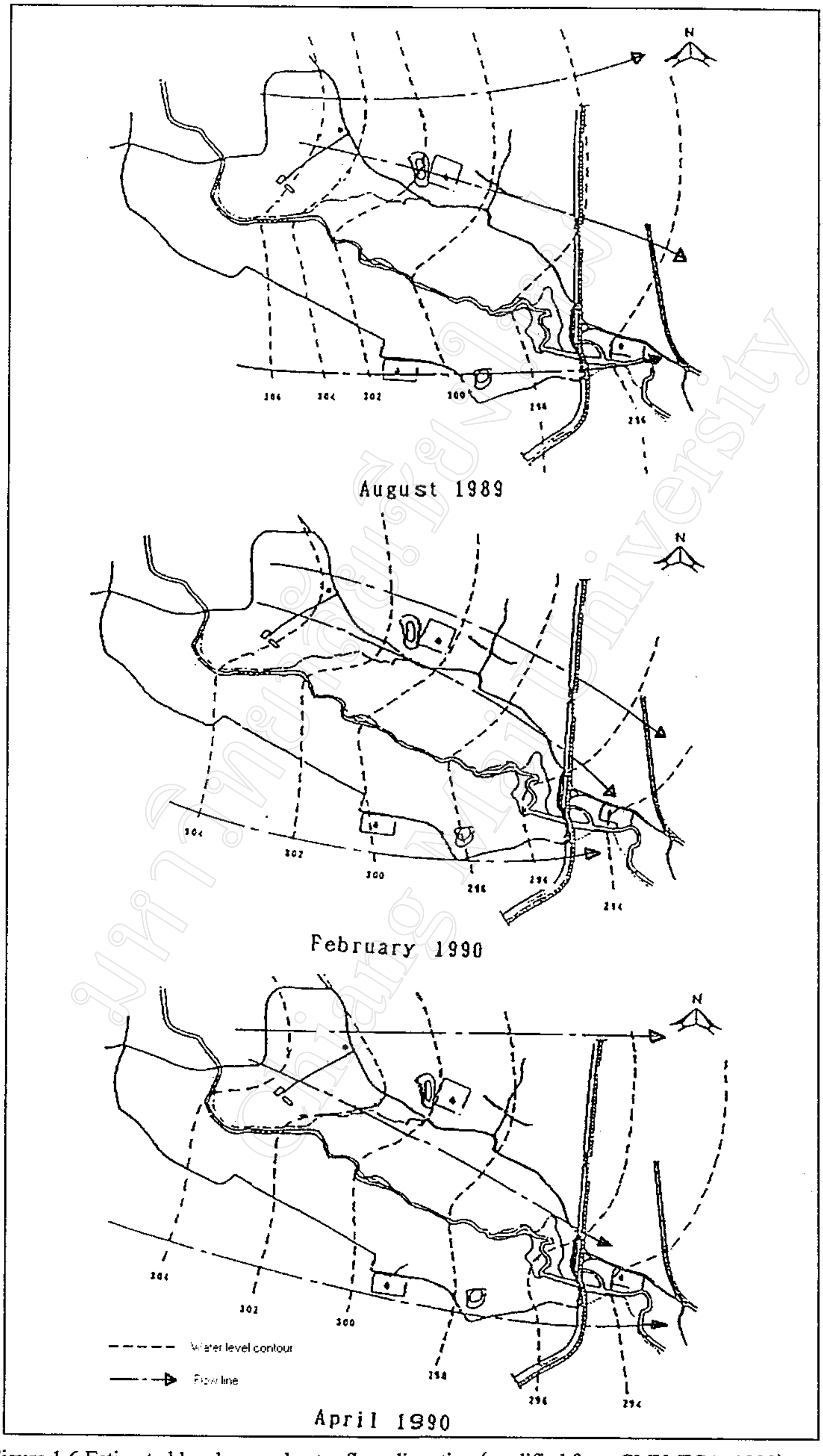

Figure 1.6 Estimated local groundwater flow direction (modified from CMU-JICA, 1992).