CHAPTER 1

INTRODUCTION

1.1 Significance of the problem

Old landfills are significant sources of groundwater and soil contamination. Water percolating through landfills produces leachate, which may contain undesirable or toxic chemicals. This situation poses a serious risk to the environment and to human health, especially when groundwater becomes contamination.

The Mae-Hia landfill site was used as a solid waste disposal site for Chiang Mai municipality from 1958 – 1989. For more than 30 years, the solid waste was dumped here without regard to the environment. In order to evaluate existing groundwater resources, the detection of any contamination is essential.

The Thai-German Research Project "Investigation of Waste Disposal Sites in Thailand" (WADIS) focuses on the protection of groundwater resources that are threatened by the disposal of solid waste. Implementing institutions are the Department of Mineral Resources (DMR, Bangkok) and the Federal Institute for Geosciences and Natural Resources (BGR, Hannover). Associated partners of the project in Thailand are the Ministry of Interior (MOI), the Ministry of Science, Technology and Environment (MOSTE), Chiang Mai University (CMU) and Brandenburg Technical University (BTU) in Cottbus, Germany. The WADIS project is funded by the German Federal Ministry for Education and Research (BMBF).

Within the framework of the joint Thai German project WADIS integrated geophysical investigations were performed to explore and to characterize the geological barrier in the area surrounding the Mae-Hia landfill site. Seismic, gravity, magnetic, two dimension resistivity and electromagnetic resistivity surveys provided detailed information about the geological structure, the distribution of sandy and clayrich sediments, the groundwater table, waste bodies and possible fluid migration paths (Grissemann *et al*., 2004).

From the results of the electromagnetic resistivity survey showing in Figure 1.1 the low resistivity that might be a representative of contaminated plume is trending northward from the landfill site. But according to Grissemann *et al*. (2004), the general direction of groundwater flow is probably from the western to the southeastern part of the area. However, this electromagnetic resistivity map can not confirm a leakage flow from the waste dump because the contaminated path was not correlated with the groundwater flow path.

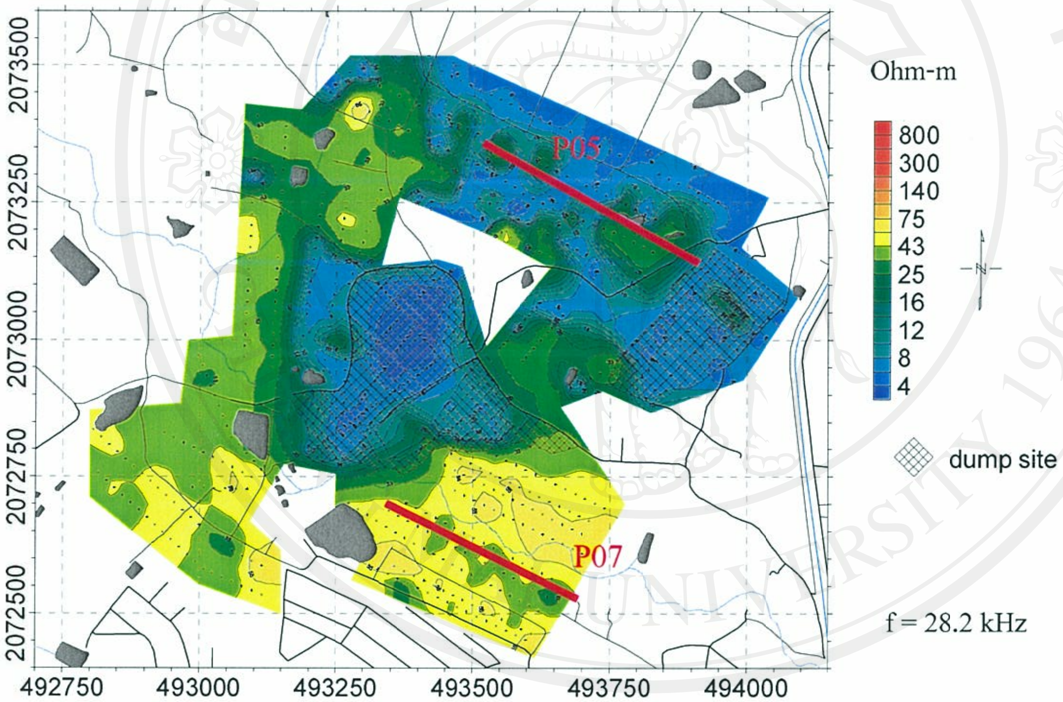

Figure 1.1 Electromagnetic resistivity map of the Mae-Hia landfill, horizontal loop with separation 40 m, frequency = 28.2 kHz (Grissemann *et al*., 2004) (note: enlarge version is shown in Chapter 5).

The heterogeneity, the variation of clay component of the sediment and the electrical properties of pore water, which can be diverse in a very high range through out the area, are the main parameters that affect resistivity. The resistivity value may be reduced in this area because of conductive clay minerals or because of conductive contaminated fluids. The intent of this project was to set up and perform a laboratory experiment to investigate these possibilities.

The goal of this study is to distinguishing the relationship between possible parameters and the variation of resistivity based on Archie's equation. Archie's equation relates electrical resistivity to the physical properties of sediment or soil. The Archie's equation is a simple empirical relationship between bulk resistivity and porosity and the pore fluid resistivity. Archie found that this simple relationship is to be constant for a certain type of material (Archie, 1942).

According to Archie's equation porosity, type of sedimentation, the resistivity value of formation fluid are the most pertinent factors, and these parameters were the focus of this experiment. Four different sediments and leachate collected from Mea-Hia landfill site were mixed to simulate contaminated soil conditions. The electrical resistivity values of all type sediments under different leachate concentration were measured. An electrical resistivity box was fabricated to measure the resistivity valued of geological materials in laboratory.

This experiment evaluates the mathematical relationships between electrical resistivity values with the geologic parameters that effect resistivity. The quantitative distribution of contaminated plume was inspected by correlating the field electrical resistivity data and the laboratory electrical resistivity values.

1.2 Literature review

Lemaitre *et al*. (1988) measured the conductivity of models of porous media made of binary mixtures of insulating spheres, where the pore spaces were filled with conducting fluid. Although the sphere diameter ratios used in the experiment led to two types of packing with very different geometrical structures, their experimental data is in good agreement with Archie's equation with an exponent m = 1.46. They found only a small difference in the conductivities between the two types of packing.

Wildenschild *et al*. (1999) performed a set of laboratory experiments on saturated sand-clay mixtures, with varying quartz sand contents of 0 to 10%. They found that for low fluid conductivities, the sample geometry is greatly effected the magnitude of the surface conductance.

Ahmed and Sulaiman (2001) correlated the resistivity values obtained from laboratory measurements with the electrical resistivity data from a landfill site. They then calculated the true resistivity and true depth of the ground then displayed their interpretation as a 2-D resistivity image of the subsurface along the line of their traverse. However, the relationship between resistivity values and some geological material could not be categorized. Therefore, they also analyzed the groundwater chemistry to further refine their interpretation. They used the combined chemical and laboratory resistivity results to interpret groundwater contamination in their study area.

Fukae *et al.* (2001) developed a cone penetration technique to detect contaminated soil layers that had electrolytes and Non Aqueous Phase Liquids (NAPLs). In their study, laboratory and field experiments were performed to apply the technique. In the laboratory, quantitative changes were made by adding salt or oil to soil samples. They found that the resistivity of sand increased with increasing oil concentration. The effect of oil content was stronger for lower amounts of water in sand.

Yoon *et al.* (2002) investigated the relationship between electrical resistivity and unsaturated subsurface conditions with varying physical properties and varying landfill leachate contaminations. Laboratory test methods for measuring the resistivity of soils include the use of a manufactured resistivity penetration cone. Three different sandy soils and leachates collected from one of the industrial waste landfill sites in Korea were mixed to simulate contaminated soil conditions. They used moisture density as an effective indicator for describing the relationship between electrical resistivity and the physical properties of an unsaturated subsurface. For three different tested soils, the electrical resistivity of the soil decreased exponentially as moisture density increased.

Giao *et al.* (2003) measured the electrical resistivity of 50 Pusan clay core samples in laboratory experiments. They also examined other geotechnical parameters such as salinity, organic content, water content, plasticity, unit weight and sampling depth. These measurements were well correlated with two-dimensional electric images and other parameters. They used their results to map the Pusan clay deposits.

Sreedeep *et al.* (2005) developed a generalized relationship to estimate electrical resistivity of soils corresponding to different saturations. They conducted laboratory experiments soils samples compacted to different saturations. A Perspex cubical electrical resistivity box, which is 100 mm wide and 10 mm thick was fabricated and used to estimate the electrical resistivity (ρ) of the soil sample. Each face of the resistivity box had three brass electrodes spaced at 30 millimeters center-to-center. These electrodes were screwed into the compacted soil sample with embedment length of 2.5 mm. The measured results demonstrate that both electrical resistivity and thermal resistivity strongly depend on the saturation of the soil.

Taylor and Barker (2006) described the limitation of using simple relationships to describe the electrical properties of fully and partially saturated Triassic Wildmoor Sandstone. They concluded that Archie's equation is only valid for high salinity electrolytes while the Hanai-Bruggeman and Waxman and Smits equations are valid at all salinities and provide a more complete description of the rock properties.

The literature about the geology and hydrogeology of this study area were including in Section 1.5 below.

1.3 Research objectives

This study was expected to

a) Determine mathematical relationship between electrical resistivity of Quaternary sediments from Mae-Hia landfill under different parameters.

b) Indicate the quantity distribution of a contaminant plume in groundwater within Mae-Hia landfill by applying the laboratory resistivity measurement data to the interpreted map of resistivity survey data of this area.

1.4 Scope, research plan and methodology

After considering data from Mea Hia landfill site generated by the joint Thai German project WADIS, twenty pilot shallow auguring were taken in additional in the area of approximately 1 km^2 around the Mae-Hia landfill in Mueang District in Chiang Mai (Figure 1.2). The grain size analysis testing was conducted in every certain depth. The representatives of the sediment of this area were validity chosen according to these grain size analysis data.

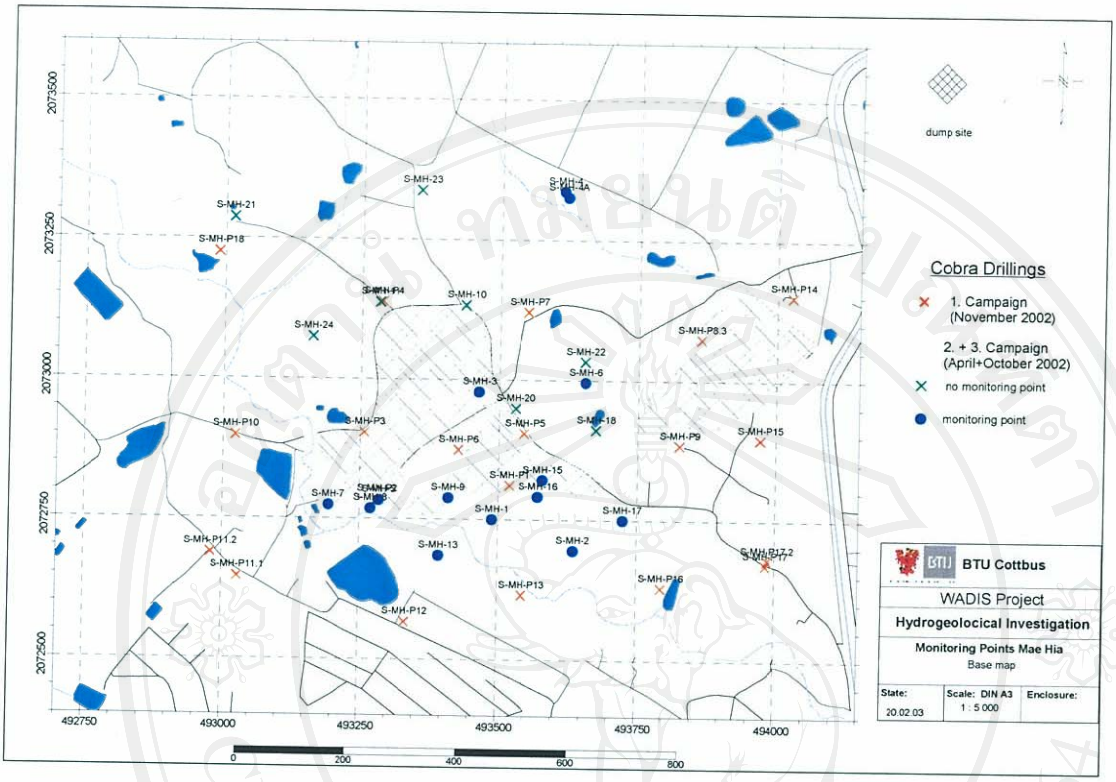

Figure 1.2 Map of Mea-Hia landfill site, showing the position of deep and shallow monitoring wells with available lithology logging data in the study area (modified from Grissemann *et al*., 2004).

Four groups of representative sediment samples are taken from the open pits at the relative depth and position to the logging data. Both chemical and physical analysis of the sediments conducted to delineate the necessary parameters used in Archie's equation and other uncontrolled factors such as the background composite conducting and insulating elements.

A resistivity box was constructed and carefully calibrated to use in this experiment. The box is made of insulating PVC material and can be adjusted using a set of small stainless steel electrodes. After packing the box with the soil to be tested, a 50 Hz AC current is applied to the soil sample and the apparent resistivity is measured.

Sediment was packed into the resistivity box with a compaction similar to its in situ state. The different concentration of leachate taken from the landfill was then allowed to soak into the sediment sample. The samples were soaked to varying degrees from lowest saturation index until they were fully saturated with the leachate. The resistivity value was measured at each step of the saturation index. All the measurement was duplicated. During the experiment leachate concentrations of 0%, 25%, 50%, and 100 % were used. Saturation index varied from the Permanent wilting point index (PWP) of each sediment to 1.0.

The experimental data were plotted and fitted using Archie's law. For each type of sediment a different graph was drawn. The mathematical relationship was obtained by fitting a curve to the experimental data.

1.5 Geology of study area

1.5.1 Geology and hydrogeology of the Chiang Mai basin

The Chiang Mai basin is generally regarded as a Tertiary pull-apart basin. The mountainous areas surrounding the basin consists of the following rock types; gneiss, schist, and calc silicate rocks of Precambrian sandstones, shales, limestone of Lower Paleozoic; Upper Paleozoic quartzite, phyllite, chert and limestones locally intercalated and intruded by Permotriassic intermediate to basic volcanics and by Triassic granites (Baum *et al*., 1982).

These extrabasinal rocks are not significant parts of the aquifer systems, but they provide the source of dritritus that fills the basin. The basin was filled during the Miocene to Quaternary. The mineralogy of the Quaternary alluvium mapped as flood plain, low terrace, and high terrace are similar, having quartz sand and silt as the principle constituents. Organic matter is most common in flood plain deposit as peat and plant remains (Uttamo, 1988; Singharajwaraphan, 1990).

The Miocene to Quaternary deposits is the important shallow aquifer of the Chiang Mai basin (Wongpornchai, 1990). Hydrogeological characters of the three units are summarized in Table 1.1.

Table 1.1 Generalized hydrogeologic units and water-bearing characteristics of Late Tertiary to Quaternary sediment of Chiang Mai basin (modified from Chuamthaisong, 1971).

Hydrogeologic unit	Approximate thickness (m)	Lithology	Water- bearing Characteristics
Flood plain aquifer	100	Clay, silts ,sands and gravel; locally oxidized and limonitic and limonitic; poorly to well sorted	Moderate to high yield with fair to good water quality
High terrace aquifer	300	Gravel and clay; poor to poorly sorted, sub-rounded to rounded; gravel consisted of gneiss, sandstone, quartzite with sandy clay matrix	Low to moderate yield with fair to good quality
Low terrace aquifer	900	Dominantly clays with quartz sands and gravels which are angular to sub-rounded	Moderate to high yield with good quality

The aquifers of the Chiang Mai basin are recharged by rainfall, floods, irrigation runoff and seepage from streams and reservoirs. Effective rainfall is generally confined to August to September. Groundwater occurs under either unconfined or artesian conditions. Water encountered in shallow, hand-dug wells is usually unconfined. Sandy and gravelly aquifers below impermeable clay layers normally exhibit artesian conditions. The static water table generally lies at depths of 3 – 8 m (Intrasutra, 1983).

1.5.2 Geology and hydrogeology of Mae-Hia landfill site

The Mae-Hia landfill site covers an area of approximately 0.12 km^2. The site is located about 10 km southwest of the Chiang Mai municipal area. This sanitary landfill site was used to collected wastes from the Chiang Mai municipality during 1958 -1989. There is a densely populated village near the site. The outskirts of the village are used for agriculture (paddy fields) and pig farming.

Branches of a small stream, which originates in Doi Suthep National Park, flow along the west and south periphery of the landfill site. In the rainy season, runoff from waste pile and seepage from the waste deposit flows down steep terrain into the stream (Yordkhayhun, 2001).

The Mae-Hia landfill site is situated on a sequence of Quaternary colluvial and alluvial deposits that were derived from the high ground on the western side of the Chiang Mai basin. Locally, they rest on preserved remnants of the high terrace deposit. These deposits consist of sand and gravel layers intercalated with clay and silty units (Yordkhayhun, 2001).

The main uppermost aquifer is at 7-30 m depth. Water levels in the shallow wells ranged between 0.5 - 9.55 m below ground level depending on the location and season. The mean hydraulic conductivity value is 1.4 x 10^{-5} m/s. This aquifer is extensive but only a moderately productive aquifer due to its small grain size and poor sorting. This aquifer is overlain by a heterogeneous surficial layer, and consists dominantly of sandy clay, clayey sand, sand and clay. The lower part of the sedimentary sequence is clay. The sandy clay layers have interbeded sand and clay lenses (Iamboon, 2002).

Phatchaiyo (2005) represented a velocity model of the subsurface structure of Mae-Hia landfill. His model was defined using seismic refraction tomography, and showed a three-layer structure. The upper layer was interpreted as topsoil with a thickness of 1.2-9 m. The middle layer was interpreted as waste material and clayey sand with a thickness of 2-13.9 m. The lower layer was interpreted as saturated sand at the base of the landfill site. This layer has a thickness of 1.5 to more than 6.5 m.

Piezometric contours calculated form 1985-1996 data (Margane and Tatong, 1997), show that shallow groundwater passes through the center of the landfill site and flows from the western to the southeastern part of site. The hydrochemical facies of this groundwater is classified as within the Sodium-Calcium-Carbonate facies (Asnachinda, 1997).

From a leachate fluid study (Phromkingkeaw and Pongpipat, 2000), high values of total organic carbon and high concentration of chloride were present in leachate fluids from the landfill because the waste consists of mostly degradable materials. Ground water quality in shallow wells around the Mae-Hia landfill was highly contaminated. Temporal changes in leachate chemistry indicate that flushing from the waste is still occurring in response to rainfall.

Yordkhayhun (2001) used electrical resistivity and a very low frequency electromagnetic survey to delineate the spread of the leachate plume at the Mae-Hia landfill. The interpreted data showing that the contaminant plume extends from a depth of 4 m to 16 m and has spread laterally to a width of between 200 and 400 m.