CHAPTER 1

INTRODUCTION

1.1 Rationale and Background

The Maptaphut Industrial Estate (MIE) is the largest industrial estate in Thailand, located in Mueang district, Rayong Province (Figure 1.1). The MIE was developed in 1989 by the state enterprise under Industrial Estate Authority of Thailand, Ministry of Industry. Historically, the government considered establishing the industrial complex according to the Fifth National Economic and Social Development Plans in Tambon Maptaphut, Rayong province because of its strategic geography and its vicinity to Bangkok. The complex consisted of petrochemical, chemical and fertilizer, steel, oil refinery, and power plants. Many industries in the estate have widely been using toxic chemicals such as Volatile Organic Compounds (VOCs) and heavy metals in the manufacturing systems. Therefore waste and wastewater generated from these industries, if improperly handled and leaked, can be harmful contaminants to environments and human health.

The Environmental Research and Training Center (ERTC) of the Department of Environmental Quality Promotion (DEQP) had monitored contamination of VOCs in soils and groundwater of the MIE from 2006-2007 (DEQP, 2008). VOCs in groundwater in the MIE area consisted of chlorinated solvents such as trichloroethylene (TCE) and tetrachloroethylene (PCE) and BTEX compounds.

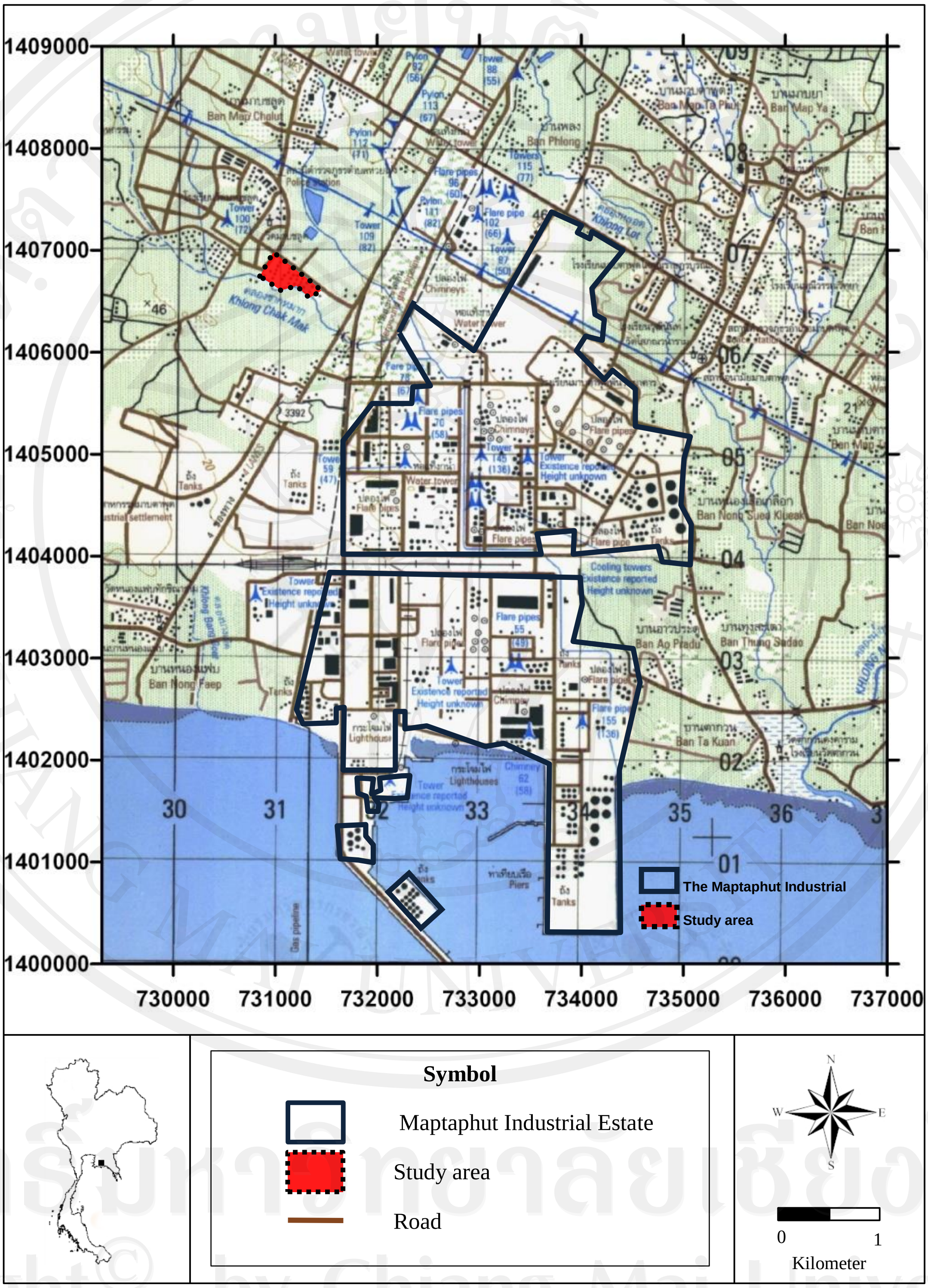

Figure 1.1 The location of study area (modified from Royal Thai Survey Department, 1992).

Their concentrations exceeded regulated standards in a number of deep and shallow groundwater wells. Once groundwater have been contaminated by VOCs, it is possible that VOCs can migrate downward as a free-phase or dissolve into the flowing groundwater and move downstream away from the source zone, and spread or disperse to form a large contaminant plume. In addition VOCs in groundwater can volatilize to atmosphere and become another source of air pollution. Hence there is the need for corrective actions to be taken and implemented immediately in order to control or contain the contaminant plume, and perhaps remediate the source zone.

Several remedial techniques are available for treatment of VOCs-contaminated soil and groundwater such as soil vapor extraction (U.S. Environment Protection Agency, 1997), pump-and-treat technique (U.S. Environment Protection Agency, 1990), in-situ bioremediation (Interstate Technology Regulatory Council, 2005a), and in-situ chemical treatment (Interstate Technology Regulatory Council, 2005b). Before the design of specific remediation scheme for any site, detailed site characterization must be conducted in order to obtain the geology, hydrogeology, and geochemistry information of the site. Data from the site characterization can then be used to visualize geologic conditions and to construct groundwater flow and solute transport models, which are essential tools for selecting and designing the most-suitable remediation technique for a particular site.

This research's aims are divided into two folds which consist of (1) characterization of the VOCs-contaminated soils and groundwater and (2) development of a comprehensive set of groundwater flow and solute transport models for designing proper remedial scheme. Site characterization includes borehole investigations, hydraulic head measurements, VOCs distribution determination, and field-measurement of hydrogeologic parameters such as hydraulic conductivity, storage coefficient, and dispersivity. Models for simulation remediation scheme are based on MODFLOW (Harbaugh et al., 2000) and RT3D (Clement, 1997) programs.

1.2 Literature Review

1.2.1 Hydrogeology of the MIE Area

The Department of Groundwater Resources or DGR (2007) conducted comprehensive hydrogeological investigations and produced a map of groundwater aquifers of the Maptaphut (Figure 1.2). The study area consists of seven hydrogeologic units, which can be categorized into two main aquifers: consolidated and unconsolidated sediment aquifers. The unconsolidated sediment aquifer can be divided to beach sand aquifer, alluvial aquifer, and colluvial aquifer. Most of groundwater quality in Rayong Province meets the Thailand Groundwater Drinking Standards, although there is an evidence of saltwater intrusion problem in the beach sand aquifer area.

1.2.2 VOCs Contamination in MIE

The Environmental Research and Training Center (ERTC) of the Department of Environmental Quality Promotion (2008) has conducted a comprehensive groundwater sampling program to assess VOCs contamination in subsurface water in the MIE. Groundwater samples were analyzed for 15 regulated volatile organic compounds, following Thailand Groundwater Quality Standards, using purge and trap technique with gas chromatography mass spectrometry (GC-MS). The result indicated the presence of several VOCs hotspots (i.e., high concentration). These locations are mainly within the petrochemical, and petroleum refinery, and steel manufacturing factories. The level of contamination occasionally exceeds the regulated standards and it could potentially pose a health threat to exposures. Interestingly, the presence of VOCs in groundwater wells of some factories, which do not use organic compound precursor, suggests that groundwater flow may assist VOCs transport and disperse from one location to another.

1.2.3 Groundwater Flow and Solute Transport Models of MIE

Industrial Estate Authority of Thailand or IEAT (2008) and Department of Environmental Quality Promotion (2009) constructed the sub-regional groundwater flow models of Maptaphut area. These models show the general trend of groundwater flow direction from northwest to southeast. Recharge rate and hydraulic conductivity are found to be the most sensitive parameters for flow conditions. Shallow groundwater is vulnerable to contamination from VOCs and could discharge to surface water bodies such as streams and coastal areas.

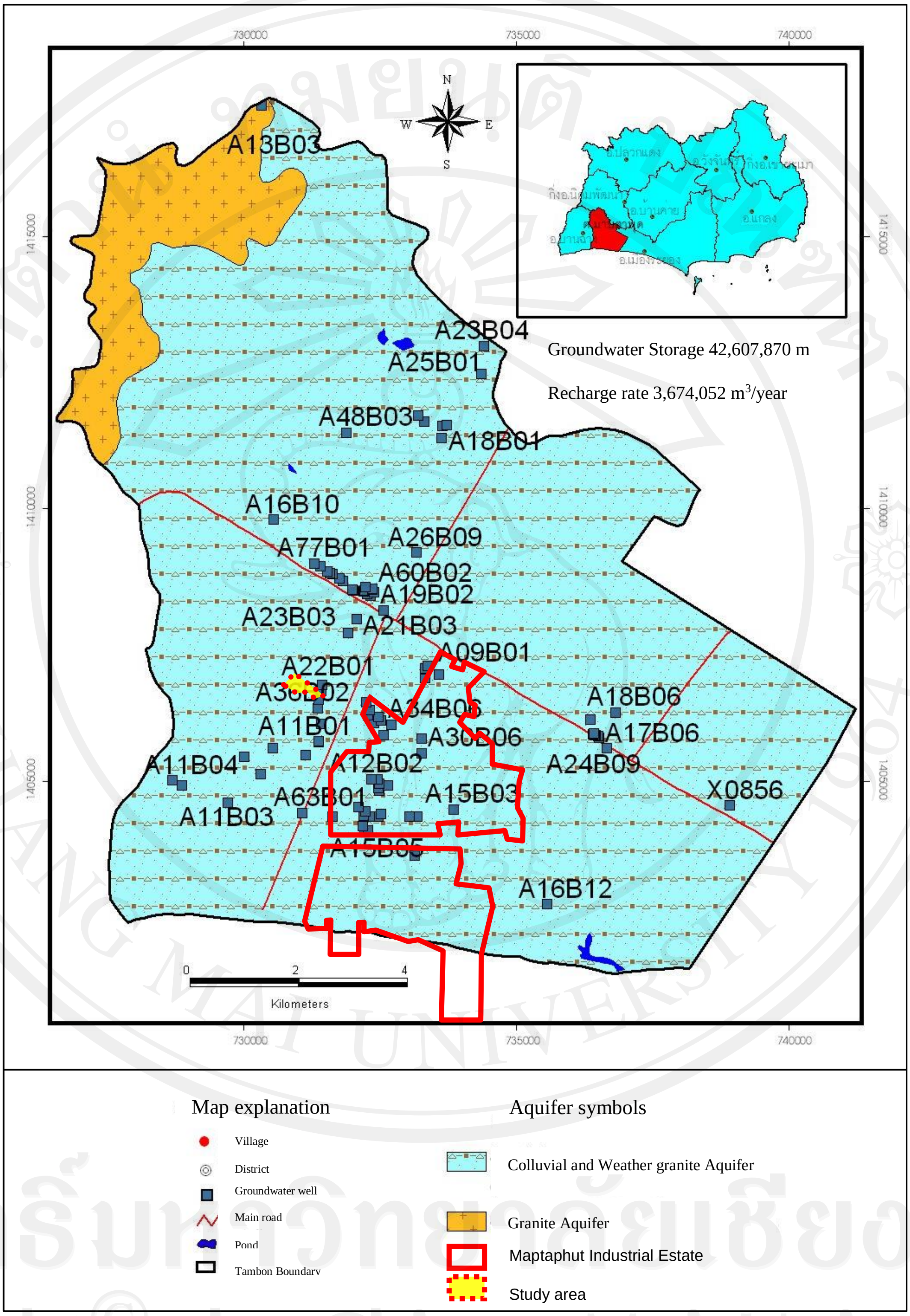

Figure 1.2 Hydrogeologic map of the Maptaphut area (DGR, 2007).

1.2.4 Groundwater Remediation of VOCs-Contaminated Site in MIE

In 2010-2011, the Department of Environmental Quality Promotion or DEQP (2011), under the collaboration with Chiang Mai University, has implemented an in-situ bioremediation technology to remediate shallow groundwater (depth < 30 m) at a site in MIE which has been contaminated with PCE, TCE, and BTEX compounds. Although the selected remedial technology is not new, their work represented the very first attempt of a pilot-scale testing of the in-situ groundwater bioremediation. After a year of treatment and comprehensive monitoring, it was found that the contamination level, measured in terms of concentration and mass fluxes emanating from the source zone, were significantly reduced. There was however a problem with numerical modeling for predicting downstream concentrations which could not be exactly simulated contaminant behavior. One of the possible reasons for such discrepancies between model-simulated and observed downstream concentrations is an inability to fully characterize the hydraulic conductivity field (i.e., lithology) of the source zone due to its inaccessibility. Hence, the interpolated hydraulic conductivity field from few boreholes surrounding the source may lead to errors in numerical modeling. The author suggested that model uncertainties (i.e., in terms of minimum-maximum envelop of downstream concentrations) should be evaluated so that model applicability can be assessed.

1.3 Objectives and Scope

The main objectives of this research are:

1) To conduct detailed site characterization of the selected VOCs-contaminated area in MIE.

2) To construct comprehensive groundwater flow and solute transport models for assessing aquifer contamination.

This research focuses on characterizing (hydrogeology, geochemistry, and contamination) the VOCs-contaminated site in MIE area and constructing the groundwater flow and solute transport models that can be used to design appropriate remediation system.

1.4 Methodology

The methods used in this study include field work, data compilation, numerical modeling, and design the best scenario for the selected remedial technique. Flowchart in Figure 1.3 shows the groundwater modeling process.

1) Collecting and reinterpreting previous geologic and hydrogeologic data of the study area and constructing hydrogeologic cross-sections from previously collected and interpreted data such as geologic map, topographic map, drilling logs, resistivity surveys, etc.

2) Conducting hydrogeological surveys. This survey includes measuring water level at boreholes and observation wells in the study area, compiling aquifer test and groundwater contamination data, and assessing the degree of contamination.

3) Setting up a groundwater flow model using MODFLOW program (Harbaugh et al., 2000) and performing model calibration using PEST program (Doherty, 1994).

4) Setting up a solute transport model based on the calibrated flow model using RT3D program (Clement, 1997) and calibrating the model using PEST program (Doherty, 1994).

5) Use models developed in 3) and 4) to design the best scenario for each of the selected remedial technology. In this case, pump-and-treat, in-situ bioremediation, and permeable reactive barrier based on in-situ chemical oxidation will be selected.

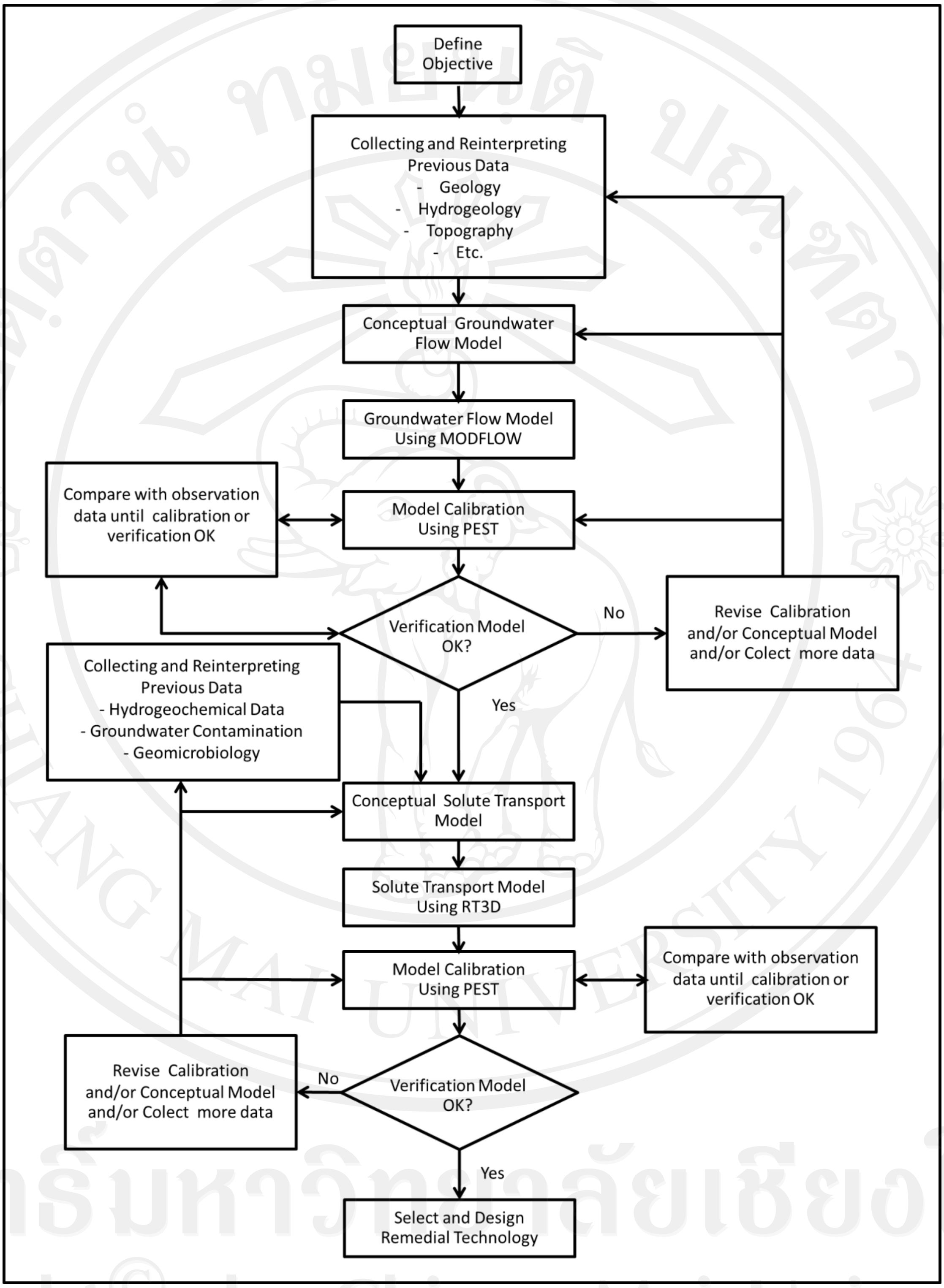

Figure 1.3 Steps involved in groundwater flow and contaminant transport modeling in this study (modified from Anderson and Woessner, 1992).