CHAPTER 3

SITE CHARACTERIZATION

In order to design specific remediation scheme for any VOC-contaminated site, detailed site characterization must be conducted to obtain the geology, hydrogeology, and geochemistry information. Site characterization includes hydrostratigraphic data, hydrogeologic parameters, and hydrogeochemistry data including contaminant levels. Data site characterization will subsequently 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 technology for a particular site.

3.1 Background Site Information

Rayong Province is located in the eastern part of Thailand. Its topography consists of mostly undulating terrain, hilly lands and mountains in the northern, flats with little hill from the eastern decreased to the Gulf of Thailand, and coastal plain in the southern part. Rayong Province has two major rivers including Rayong River (sometimes called Klong Yai) and Pra Sae River.

The study area is located in Maptaphut Industrial Estate (MIE), Tambon Maptaphut, Mueang Rayong district, Rayong Province. The topography of Tambon Maptaphut is undulating terrain. Khong Chak Mak is only stream in the study area that flows from the northwest to southeast.

The approximately 84,800 m^2 waste disposal site, operated in the MIE since 1998, approximately 84,800 square meters, consists of a landfill pit, a wastewater treatment unit, fuel storage facilities, and a maintenance shop (Figure 3.1). This site was an abandoned secure landfill, where organic liquid wastes, used metal (catalyst) powder, acids, toxic chemicals, etc., were disposed from factories in the industrial estate. Prior to the completion of the lining construction of this landfill, there was a report indicating that several drums of organic liquid wastes, sitting on a bare ground near well no. 7 (see Figure 3.1), were damaged an leaked resulting in a downward migration of DNAPL to the upper part of unconfined aquifer. Hence groundwater in unconfined aquifer has been contaminated with TCE and PCE (and also their biodegraded daughter products such as *cis*-DCE and vinyl chloride) in the monitoring wells (wells no. 2, 3, and 7) located downstream of the source. The concentrations of these contaminants such as *cis*-DCE were found to be as high as 122 ppb (DEQP, 2010).

3.2 Hydrogeological Characteristics

Twenty-one soil investigation boreholes were drilled and logged. Soil samples were collected and determined their physical and chemical properties. Lithologic and geophysical logs were obtained from field observation, field measurement, and laboratory investigation (mainly, sieve analysis). A 2-D profile of resistivity survey was also conducted nearby the landfill pit to delineate the contaminated zone as well as aquifer thickness.

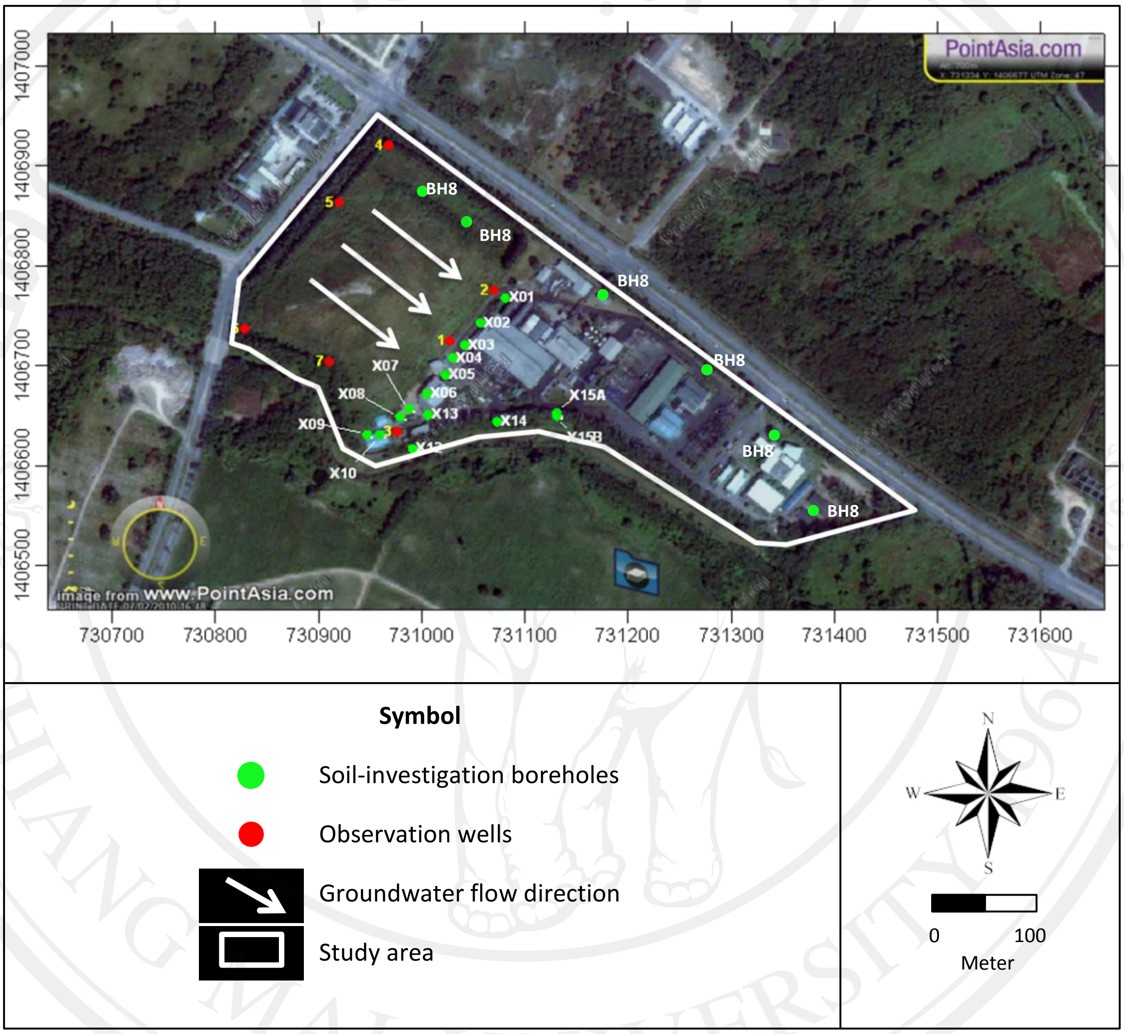

Figure 3.1 Top view picture of the study area and general groundwater flow direction.

3.2.1 Hydrogeologic Settings

Using data from twenty-one boreholes located inside the waste disposal site (Figure 3.2) and eight additional boreholes located outside the waste disposal site (Appendix A), a hydrogeolgic setting of the site can be conceptualized. Based on the available data from the borehole logs in the study area, soil materials can be classified to six hydrogeologic units including: Topsoil, Fine-to-Medium Sand, Medium-to-Coarse Sand, Clay, Weathered Granite, and Fractured Granite.

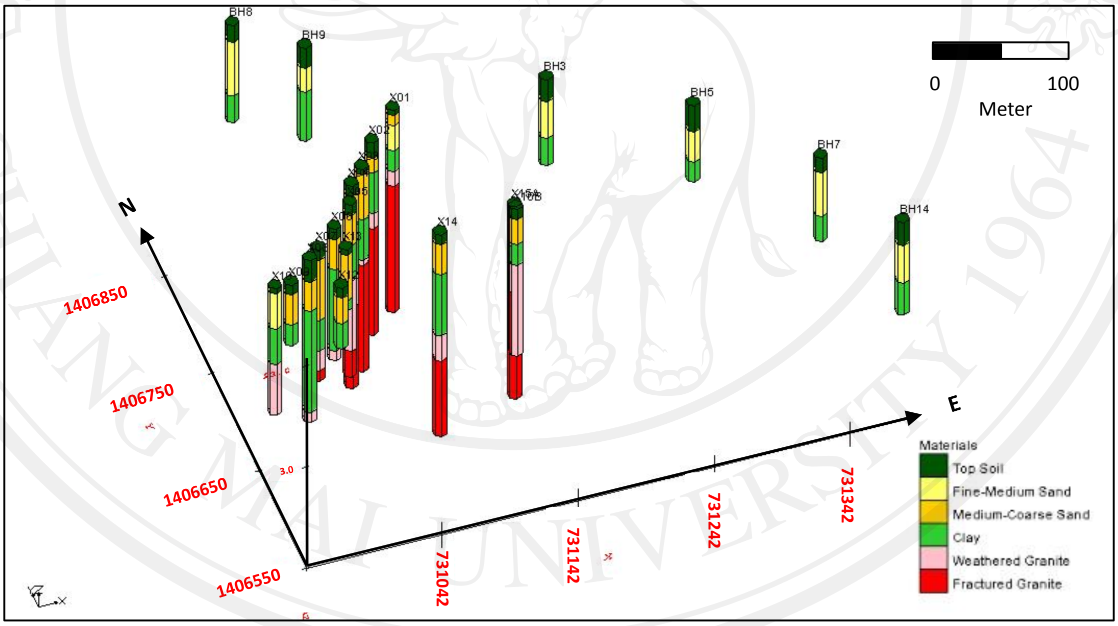

Figure 3.2 Borehole locations and soil structure showing sparse data available for constructing a 3-D solid model.

Topsoil unit is the top of the study area that consists of brown, brownish-yellow, and grayish yellow topsoil. The thickness of the Topsoil unit varies from 1 to 4 meters.

The second unit is Fine-to-Medium Sand unit that consists of fine to medium grain of sand sediment more than clay. Compositions of this sand sediment are quartz and feldspars. In the northern part of the study area, this unit is thicker than the southern part and occurs under the Medium-to-Coarse sand unit in the southern part of the study area.

The next unit is Medium-to-Coarse Sand unit. This unit consists of medium to very coarse grain of sand sediments. Colors of the sediments in this unit are gray, yellowish gray, and grayish yellow. Compositions of the sediment in this unit are quartz and feldspars.

Clay unit is under the entire sand unit. This unit consists of yellowish brown, grayish yellow, yellow, and gray. In some boreholes show some coarse grain of sand in this unit.

In the Weathered Granite, the unit consists of medium to very coarse grain of quartz, feldspars, and micas. Colors of this weathered granite are yellow, yellowish gray, and gray.

The last unit in the study area is the Fractured Granite unit. Granite in this unit is very coarse grain gray highly fractured granite that composed of quartz, feldspars, micas and chlorite. This unit can be found at approximately 15 meters below ground surface.

To obtain a clear picture of the hydrogeologic setting of this site, solid model was constructed. The solid model of this site was conducted from the boreholes investigation data that have six hydrogeologic units. The solid model and fence diagrams of the study area are shown in Figures 3.3 and 3.4. In the solid model and fence diagram show that some units may disappear as they are not continuous indicating that site's heterogeneity is high.

Solid model shows that a shallow aquifer in the study area is an unconfined aquifer consisting of two hydrogeologic units: Fine-to-Medium Sand unit and Medium-to-Coarse Sand unit. The aquitard underneath this shallow unconfined aquifer in the study area is the Clay unit. DEQP (2010) found that the unconfined aquifer in this study area is the aquifer that has been contaminated by VOCs from this waste disposal site. Groundwater in the study area typically flows from northwest to southwest (see Figure 3.5) with the approximate groundwater velocity of 0.1-3 m/year.

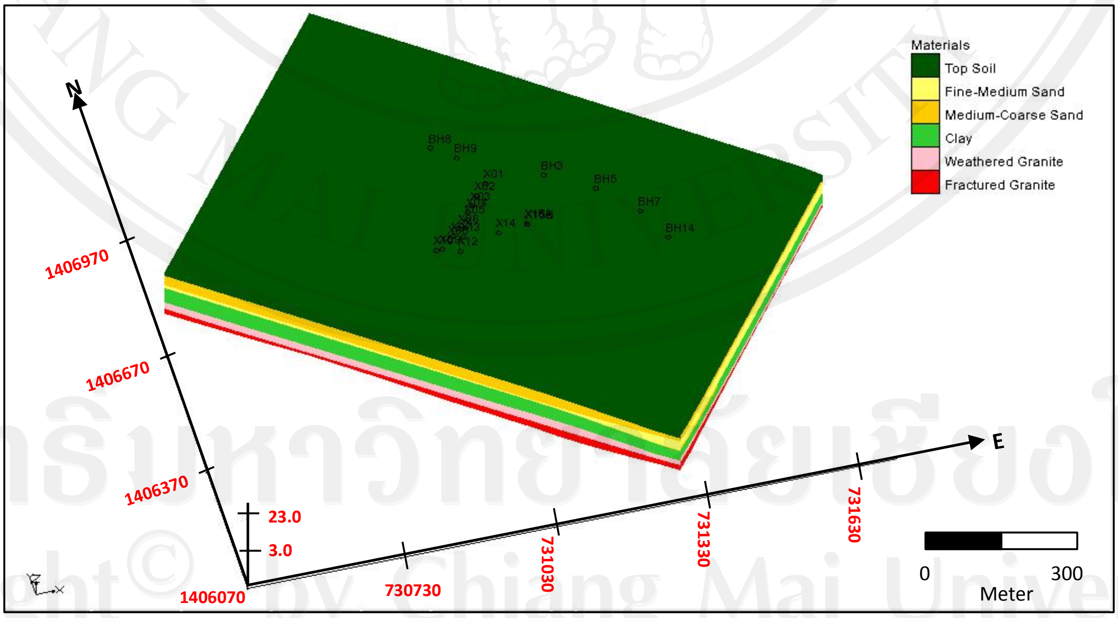

Figure 3.3 Solid model of the study area.

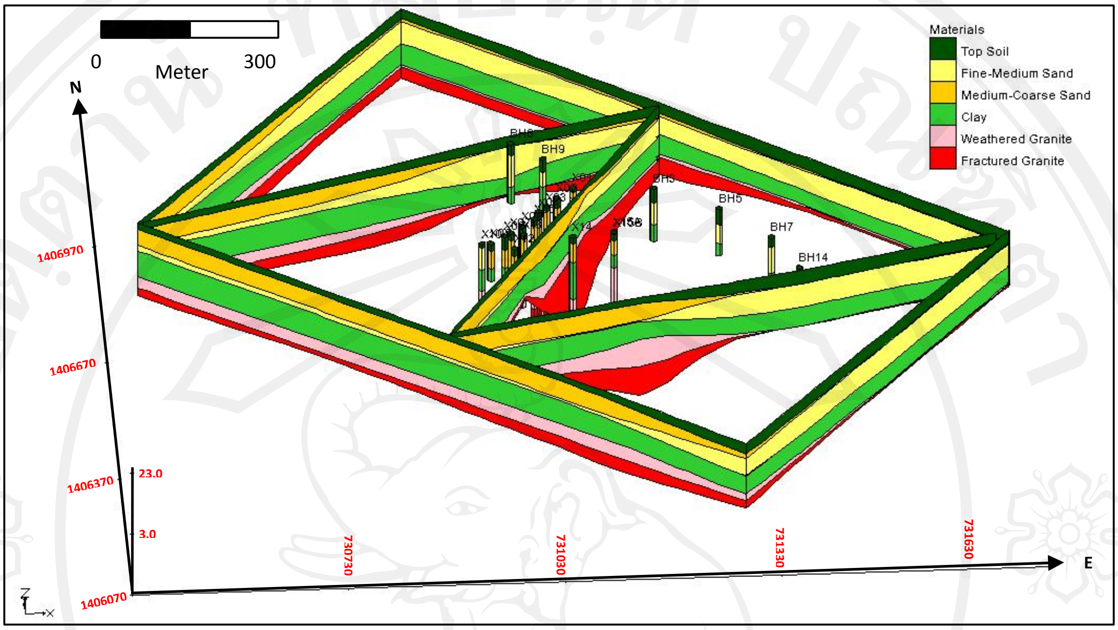

Figure 3.4 Fence diagram of the study area.

3.2.2 Hydraulic Properties

Hydraulic properties of aquifer which are important parameters for the steady-state groundwater flow and contaminant transport simulation include hydraulic conductivity (K), porosity (f), and longitudinal dispersivity (a_L). The values of hydraulic conductivity were obtained mainly from slug test. The porosities of aquifer materials were obtained from field test (gravimetric-volumetric method). And the values of longitudinal dispersivity were obtained from single-well push-pull field tracer test.

Figure 3.5 General groundwater flow direction of the study area (DEQP, 2010).

3.2.2.1 *Hydraulic Conductivity*

Slug test is the method that used to find hydraulic conductivity (K) in the study area. That starts with using the pressure transducer in the groundwater well to record the changing of hydraulic head in the well. After that, the slug is added into the well under the water level then the water level or pressure is monitored and the water level may return to the static water level. To analyze the slug test data, the solution by Bouwer and Rice (1976) was used. The hydraulic conductivity was obtained from equation (3.1);

$$K = \frac{r_c^2 \ln\left[R_e / r_w\right]}{2L} \frac{1}{t} \ln\left[\frac{h_0}{h_t}\right], \tag{3.1}$$

where h_0 is initial head at time zero and h_t is head at time t. The dimensionless ratio $\ln\left[R_e / r_w\right]$ can be obtained from equations (3.2) and (3.3);

$$\ln\left[\frac{R_e}{r_w}\right] = \left\{\frac{1.1}{\ln\left(H / r_w\right)} + \frac{A + B\ln\left[\left(b - H\right)/ r_w\right]}{L / r_w}\right\}^{-1} \tag{3.2}$$

$$\ln\left[\frac{R_e}{r_w}\right] = \left\{\frac{1.1}{\ln\left(H / r_w\right)} + \frac{C}{L / r_w}\right\}^{-1} \tag{3.3}$$

where A, B, and C are dimensionless numbers and they are a function of L_e / r_w (Bouwer, 1979). Appendix B shows the results of the slug test from 5 wells conducted in this study. Average hydraulic conductivity of the aquifer in the study area is in the range of 0.03 to 3.55 m/day.

3.2.2.2 *Porosity*

Soil's porosity is another important parameter that is required for evaluating contaminant quantity as well as for simulating advective transport. It is determined from the field sampling conducted while drilling the soil borehole. Porosity is evaluated based on a simple gravimetric-volumetric method with corrected water content (measured later in the laboratory). The porosity of soil is in the range of 0.19 to 0.42.

3.2.2.3 *Longitudinal Dispersivity*

The dispersivity (a) of an aquifer is useful information that can be used to simulate or predict the spreading of contaminant by dispersive transport. The longitudinal dispersivity of the study area is obtained from single-well push-and-pull tracer test technique (Gelhar and Collins, 1971). To conduct this test, an aqueous solution containing 10-100 mg/L bromide (Br^-) was injected into the test well for 2-3 pore volumes. When the groundwater return to the static water level, water was pumped out of the well for 3-4 pore volumes and bromide concentration were measured at times. Tracer concentration data was analyzed by using the method proposed by Gelhar and Colins (1971) to find longitudinal dispersivity as shown in equation (3.4). Table 3.1 and Figure 3.6 show the results of tracer tests in the study area.

$$\frac{C}{C_0} = \frac{1}{2}\operatorname{erfc}\left\{ \frac{U_p / U_i - 1}{\sqrt{\frac{16}{3}\frac{a}{R_f}\left[2 - \left|1 - U_p / U_i\right|^{0.5}\left(1 - U_p / U_i\right)\right]^{0.5}}} \right\}, \tag{3.4}$$

where U_p is the volume of groundwater pumped from the well, U_i is the volume of the bromide solution recharge into the well, and R_f is the average radius of the Bromide solution recharge that can be calculate from the equation:

$$R_f = \sqrt{\frac{Qt}{pbf}} \tag{3.5}$$

where Q is the recharge rate of the Bromide solution, t is the time to recharge the Bromide solution into the well, b is the distance of the casing, and f is the porosity.

Table 3.1 Locations and results of the single-well tracer test.

No.	Test Code	UTM-E	UTM-N	Well Name	Longitudinal Dispersivity (m)
1	D1	731094	1406764	2	5.01
2	D4	731047	1406719	1	3.64
3	D5	730985	1406623	3	9.92
4	D6	730970	1406689	7	16.1
5	D7	731131	1406653	X15A	1.29
6	D8	730979	1406649	X08	1.78

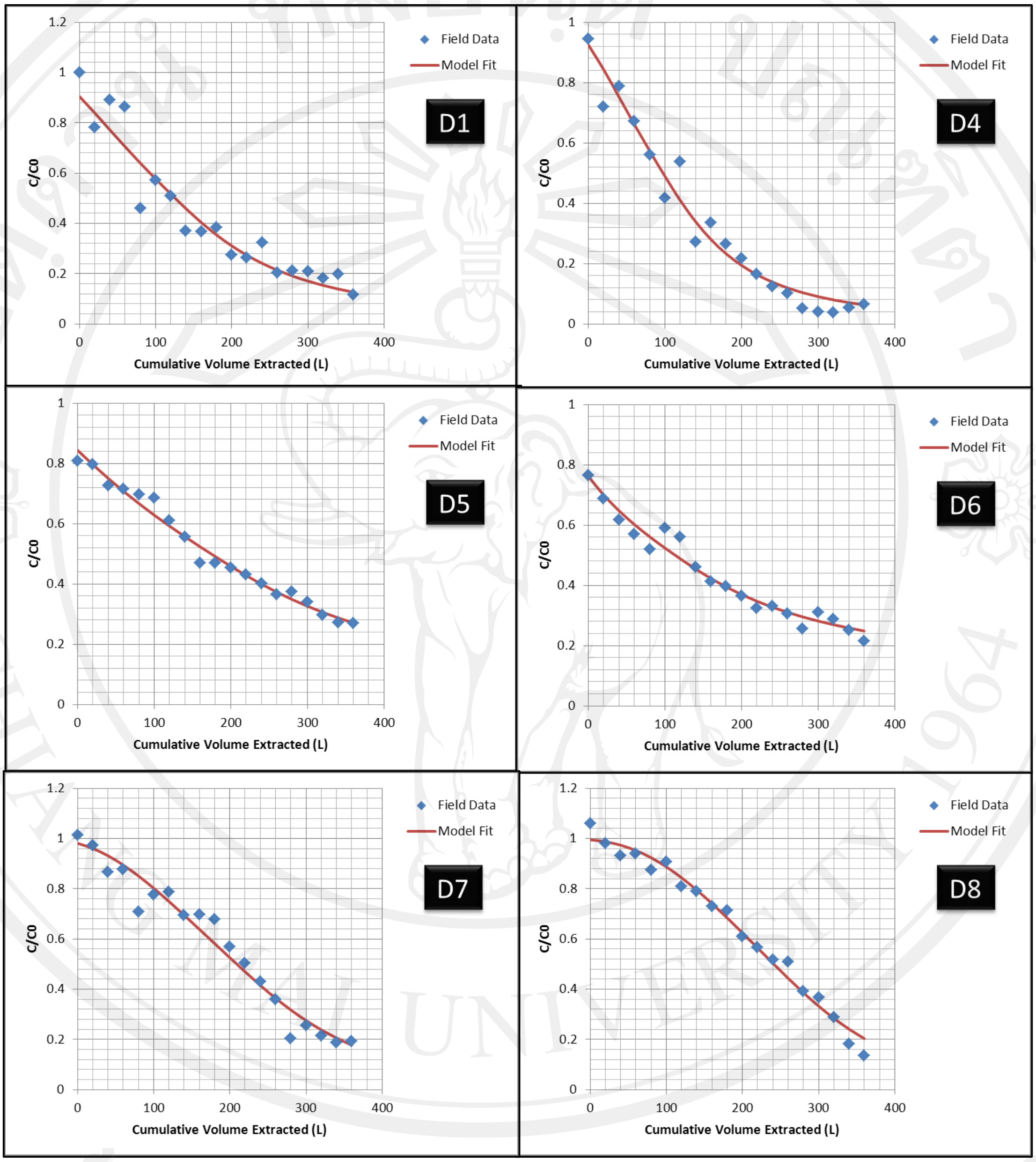

Figure 3.6 The results of the single-well tracer test.

3.3 Hydrogeochemical Characteristics

3.3.1 Hydrochemical Facies

The hydrochemical data in the study area (shown in Appendix C) from DEQP (2010) can be classified on the basis of the dominant ions, using the Piper-trilinear diagram, and defined as hydrochemical facies (Arthur, 1995). The Piper diagrams are plotted by the ion concentration's percentages, with each point representing a chemical analysis. In the study area, the hydrogeochemical facies of the groundwater from seven observation wells over the past five years were found to be Ca-Na and HCO_3-Cl as the dominant cation and anion types, respectively (see Figure 3.7). It should be noted that while groundwater from most wells have consistent facies, the water types of wells no. 3 and 7 have changed significantly with time indicating that there are activities affecting the water quality from additional contamination with time and significant biodegradation.

3.3.2 VOCs Contamination

The Department of Environmental Quality Promotion has monitored VOC content in groundwater in the study area since 2007. Groundwater samples were collected using both low-flow pumping and diffusion-bag methods. Water samples were analyzed using standardized purge-and-trap GC-MS procedure. Sixteen VOCs were analyzed according to the regulated standards published by the Department of Pollution Control. Major contaminants consisted mainly of chlorinated compounds such as tetrachloroethene (PCE), trichloroethene (TCE), *trans*- and *cis*-dichlorothene (DCE), and vinyl chloride (VC). Their concentrations were consistently higher than the regulated standards. Occasionally the BTEX compounds (benzene, toluene, ethyl benzene, and xylenes) were detected but their concentrations were below the regulated standards.

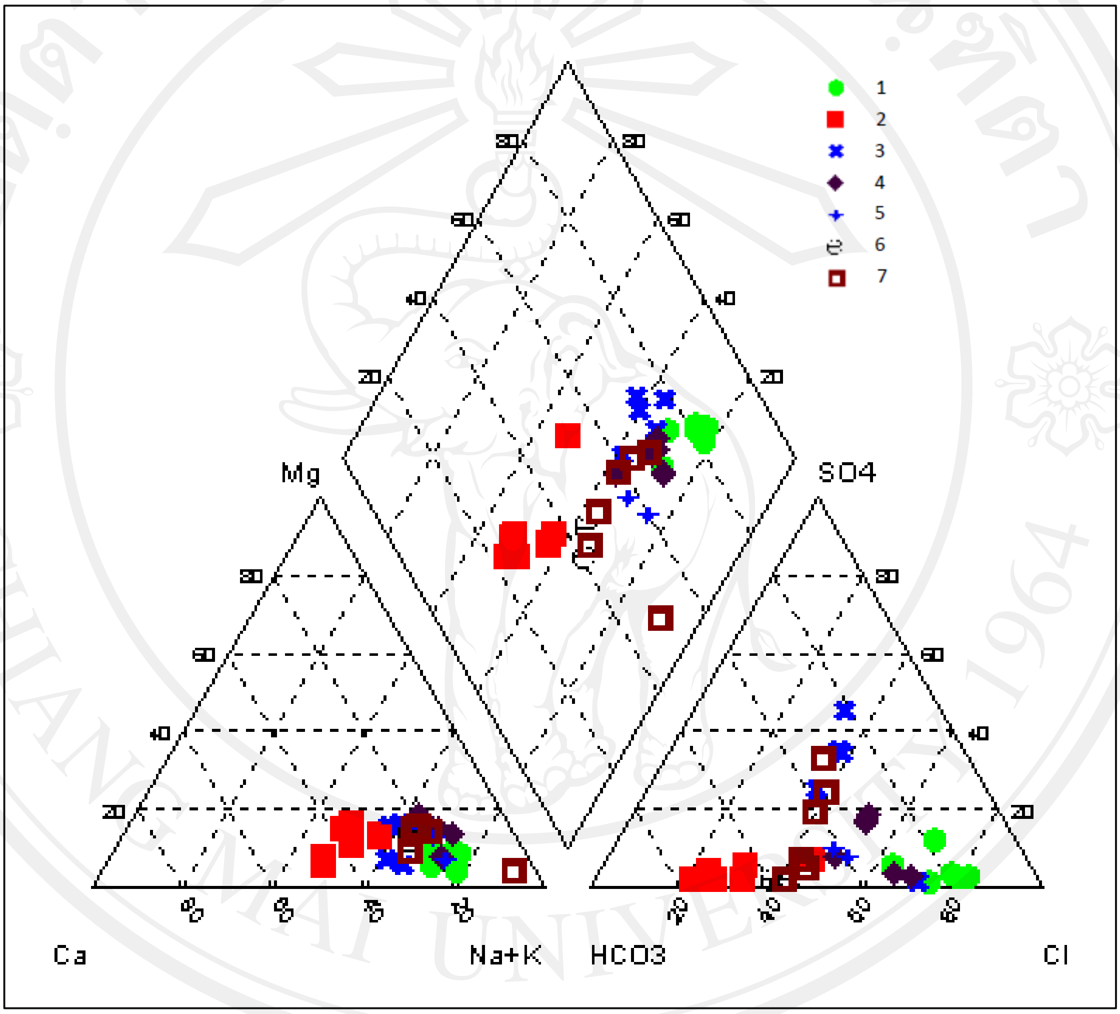

Figure 3.7 Piper diagram showing hydrochemical facies of groundwater samples in monitoring wells.

Figure 3.8 shows plots of concentration of selected chlorinated compounds in monitoring wells. It should be noted that neither *cis*- nor *trans*-DCE is a solvent used industry. Rather, they are the products of chemical and biochemical transformation (from microbes) which can be implied that this site may have a potential for enhancement of natural attenuation of PCE and TCE. An in situ bioremediation of the site has also been planned to implement after site characterization is completed but detailed remediation design is beyond the scope of this work and will not be mentioned.

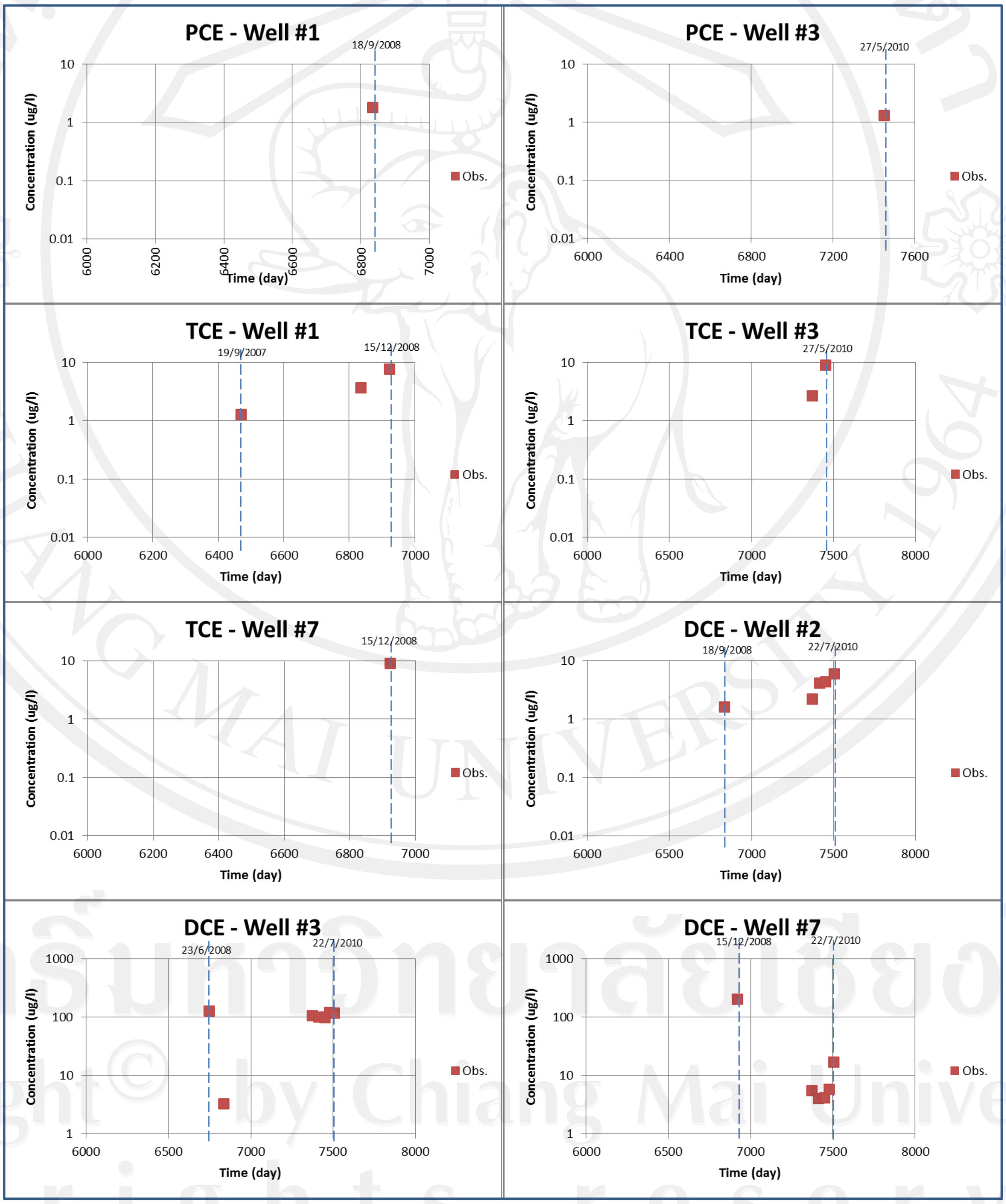

Figure 3.8 Concentrations of selected VOCs in the monitoring wells.

A geophysical investigation using electrical resistivity survey was conducted by DEQP (2010) and the results confirmed the contamination anomaly in this site. Two resistivity survey lines are shown in Figure 3.9. The interpretation showed zones of low resistivity values in the shallow unconfined compared to the surroundings. Figure 3.10 shows the distribution of plume of contaminant in this area. The direction of the plume is from the disposal site toward the south and southeast direction.

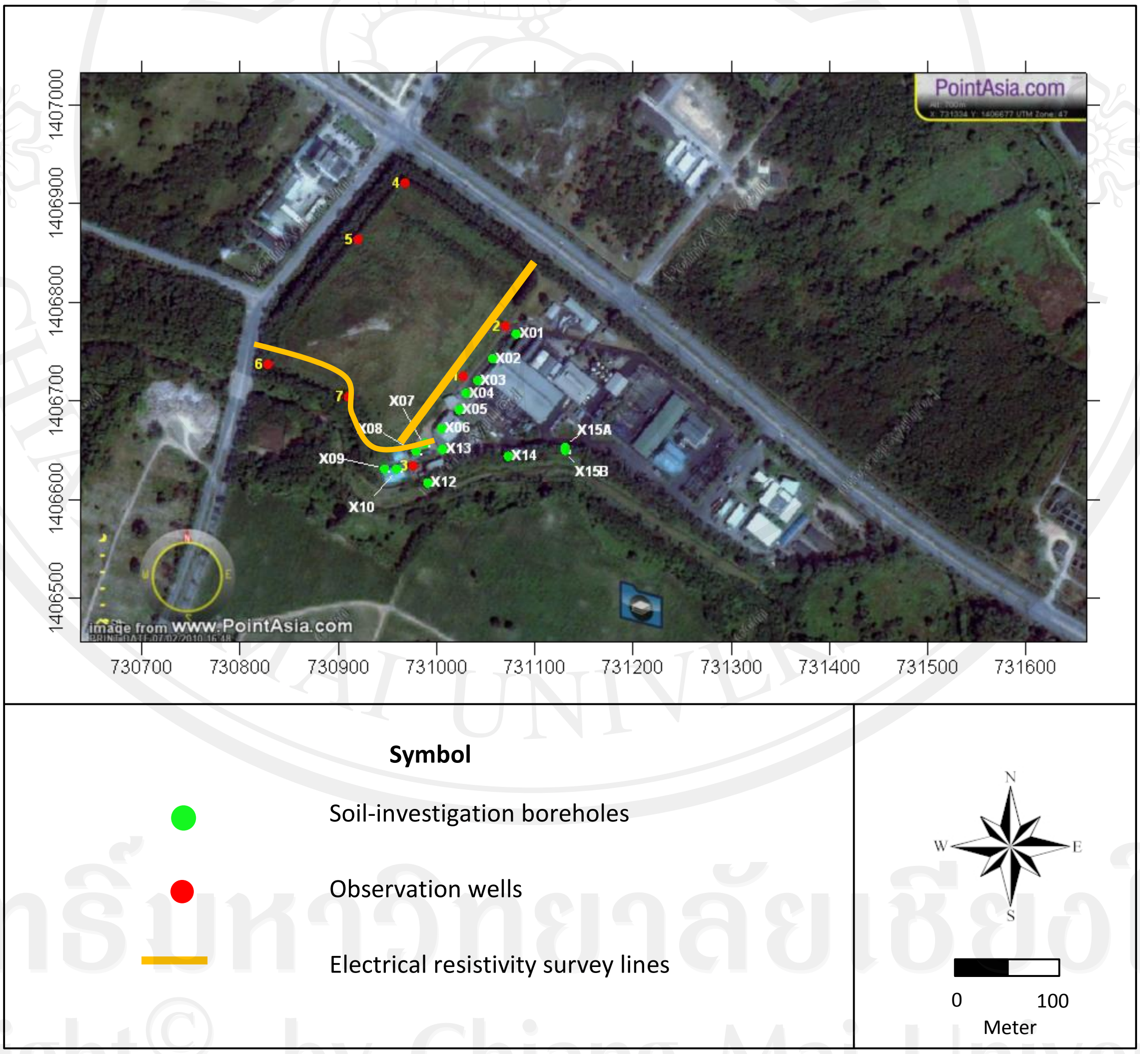

Figure 3.9 Electrical resistivity survey lines in the study area (DEQP, 2010).

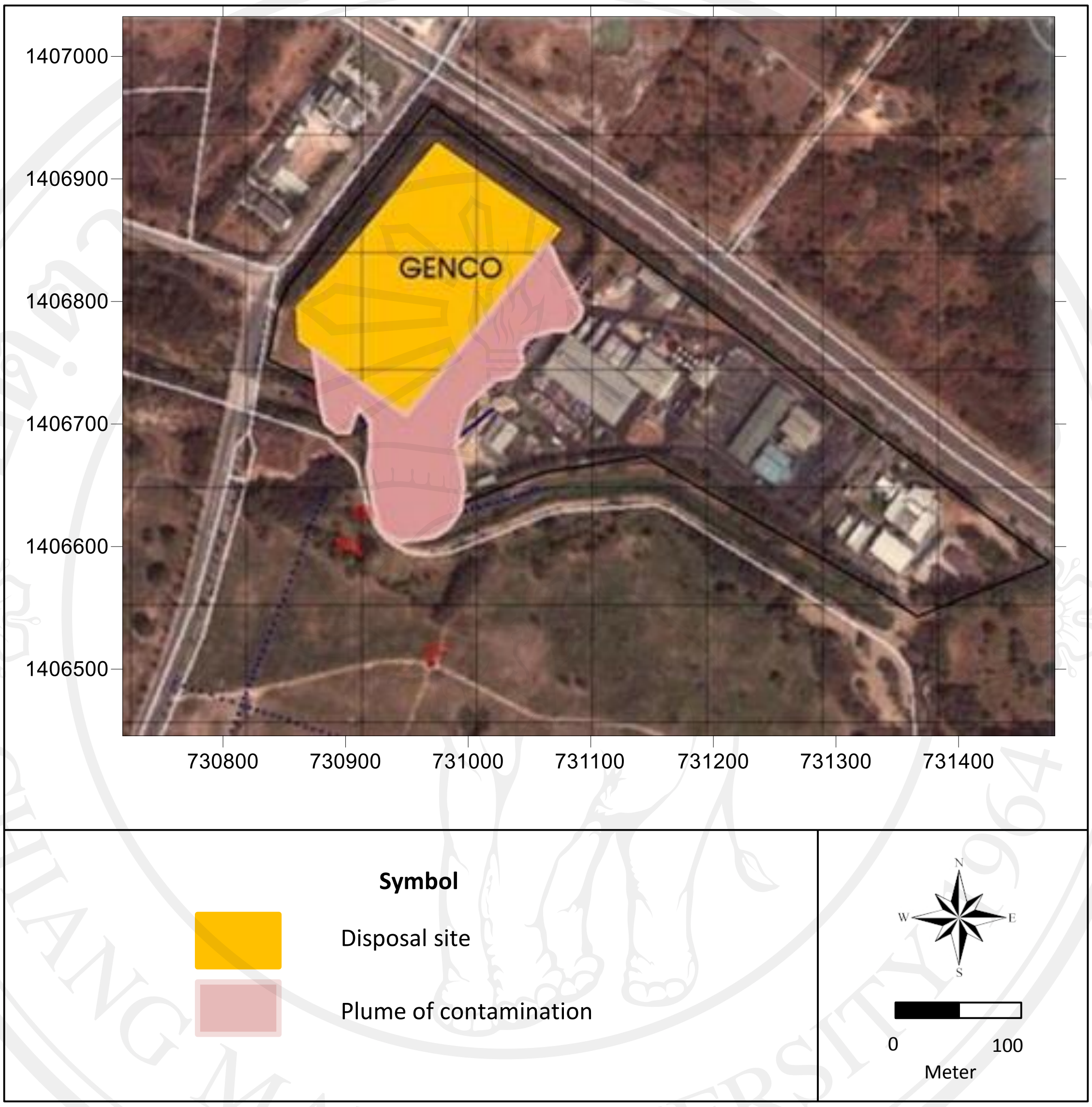

Figure 3.10 Plume of contamination from electrical resistivity survey (DEQP, 2010).

3.3.3 Geomicrobiology

As mentioned in the previous section, the presence of *cis*-DCE in groundwater indicated that there was an evidence of biodegradation of PCE/TCE in contaminated aquifers. It is of our interest to determine what types of microbes are responsible for this degradation processes. This information will be extremely useful when bioremediation is selected and designed. The soil samples collected during drilling investigation were packed and sent to Chiang Mai University's microbiology laboratory (Applied Microbiology Division, Department of Biology, Faculty of Science) for evaluating the microbial communities. It was found that there are several types of bacteria in the aquifer. Mainly, facultative bacteria were found which included *Pseudomonas* sp., *Shewanella* sp., *Burkholderia* sp., and *Rhodococcus* sp. (DEQP, 2010). In addition, a DNA-PCR (Polymerase Chain Reaction) test for detecting remnant bacteria's DNA strand evealed that, *dehalococci* bacteria were present in the aquifer. This type of bacteria is specific to complete degradation of chlorinated compounds such as PCE → TCE → *cis*-DCE → VC → ethene. The presence of natural electron acceptors such as Fe(III) and SO_4 in groundwater system also supported the degradation of PCE and TCE.