CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main objectives of this research are to conduct detailed site characterization of the selected VOCs-contaminated area in the Maptaphut Industrial Estate (MIE) in Rayong province and to construct comprehensive groundwater flow and solute transport models for assessing aquifer contamination. The developed models that can be used to design appropriate remediation system.

The study area is located the waste disposal site that located in MIE, Tambon Maptaphut, Mueang Rayong district, Rayong province. The approximately 84,800 km^2 waste disposal site, operated in the MIE since 1990, 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 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 located downstream of the source.

6.1.1 Site Characterization

Site characterization of the study area includes hydrogeologic and hydrogeochemistry investigations (including VOCs contamination monitoring and geomicrobiology characterization). These data will subsequently be used to visualize geologic conditions and to construct groundwater flow and solute transport models.

Based on the available data from the borehole logs in the study area, soil materials can be classified into six hydrostratigraphic units: Topsoil, Fine-to-Medium Sand, Medium-to-Coarse Sand, Clay, Weathered Granite, and Fractured Granite. Hydrogeologic units appear to be discontinuous and with varying thickness and lithology. Shallow aquifer in the study area is an unconfined aquifer consisting of two hydrostratigraphic units: Fine-to-Medium Sand and Medium-to-Coarse Sand units.

Parameters obtained from the field test are hydraulic conductivity (K), porosity (n), and longitudinal dispersivity (a_L). Average hydraulic conductivity of the aquifer in the study area is in the range of 0.03 to 3.55 meter per day. The porosity of soil is in the range of 0.19 to 0.42. Longitudinal dispersivity is in the range of 1.29 to 16.1 meter.

The hydrogeochemical facies of the groundwater from seven observation wells from the study area over the past five years were found to be Ca-Na and HCO_3-Cl as the dominant cation and anion types, respectively. However, the water types of wells no. 3 and 7 have changed significantly with time indicating that there are additional contaminants or significant biodegradation affecting the water quality. Major contaminants consisted mainly of chlorinated compounds including tetrachloroethene (PCE), trichloroethene (TCE), *trans*- and *cis*-dichlorothene (DCE), and vinyl chloride (VC). Their concentrations were consistently higher than the regulated standards. *cis*- and *trans*-DCE are the products of chemical and biochemical transformation (from microbes) which can be implied that this site have a potential for enhancement of natural attenuation of PCE and TCE. An in-situ bioremediation of the site has also been planned to after site characterization is completed (DEQP, 2010).

The presence of *cis*-DCE in groundwater indicated that there was an evidence of biodegradation of PCE and TCE in contaminated aquifers. From the soil samples collected during drilling investigation, several types of bacteria were found in the aquifer. Mainly, facultative bacteria were found which included *Pseudomonas* sp., *Shewanella* sp., *Burkholderia* sp., and *Rhodococcus* sp..

6.1.2 Groundwater Flow and Solute Transport Models

To assess groundwater contamination in the study area, groundwater flow and solute transport models were constructed using MODFLOW and RT3D, respectively. The model calibration was performed automatically using external parameter estimation software (PEST).

The groundwater flow simulation shows that groundwater in the study area flows generally from northwest to southeast which agrees with the field observation. Khong Chak Mak is a losing stream based on the results of this study and others (DEQP, 2008; 2010). The most sensitive parameter of the model is, not surprisingly, hydraulic conductivity.

The solute transport simulation was setup to simulate the flow and transport of chemical spilled since the construction of the landfill which had started from 1990 and finished in 2010. Results of the simulation show that plumes of PCE, TCE, *cis*-DCE, and VC have different size and shape. These plumes show the effect from the groundwater flow direction and degradation of the chemical. The migration of plumes is not far from the source zones because groundwater velocity is low. The *cis*-DCE plume is the largest in size which could be the contribution from the high degradation rate of TCE and the small degradation rate of *cis*-DCE to VC. The relative sensitivity of the solute transport model shows that all parameters' sensitivity is in the same order of magnitude although the degradation rate of PCE in this area is most sensitive.

6.1.3 Uncertainty Analysis in Groundwater Remediation: Demonstration Simulation

The stochastic simulation was used to evaluate model uncertainty based on the uncertainty in hydrogeologic conditions which is normally not fully characterized. The stochastic simulation of flow and transport was implemented by generating a number of hydraulic conductivity fields (or realizations) based on the horizontal hydraulic conductivity values from site characterization. Ten most realistic realizations were selected based on the consistency of hydraulic conductivities obtained from field tests.

Stochastic simulation indicates that the configuration of hydraulic conductivity field or aquifer materials significantly affect the flow field. In addition, in the solute transport simulations, the plume size and shapes are different according to the difference in hydraulic conductivity field.

The remediation simulation was also conducted using RT3D but slightly differed from regular transport model by adding the bio-permeable reactive barrier (bio-PRB) downstream of the landfill. The model shows that downstream VOC concentration can be reduced because of bio-PRB but the reduction of concentration can vary greatly from one realization to another.

To quantify this uncertainty, total carbon (measured in moles of C from all chlorinated compounds) flowing across the compliance plane was monitored and plotted as a function of time. The model prediction of total mole of carbon released from the source zone for both cases is highly uncertain. In some cases, mass out-flux is very small whereas the others show very high TCE mass in the plume. With implemented bio-PRB, the amount of total mole carbon removed by bioremediation ranges from 10-30%. This removal range indicates there is always uncertainty associated with site characterization, and, hence, subsequent remediation.

6.2 Recommendation

The groundwater flow and solute transport models in this study provide a better understanding of the subsurface system. However the area is found to be highly heterogeneous and the model should inevitably be highly parameterized. However, with the limitation of time and budget of the project, only few observation wells were installed and few pumping and tracer tests were conducted. More boreholes, observation wells, pumping test data, and groundwater sampling points can lead to a better model calibration and prediction. Hence, the uncertainty of the prediction can be reduced.

This research selected the bio-permeable reactive barrier as a potential technique that can be used to remediate the VOC-contaminated groundwater to prevent the contaminated plume from spreading off-site. Although the technique is cheap and the implementation is not complicated, its effectiveness in removing contaminants can vary greatly due to the limited amount of relevant site data. Pilot scale test of this technique should be conducted prior to applying directly to the contaminated site at full scale to ensure its applicability.