# Protection of Water Resources in Landfill Siting in Vietnam

by

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## Abstract

Landfilling is a common method of waste disposal in lower-income countries and many areas practice open dumping. Recently, due to an increase in the awareness of environmental risks from landfills, there has been a movement towards engineered landfills. As one of the major risks from landfills is the contamination of water resources, there has been a focus on landfill liners and leachate management systems in landfill design and operation, and some areas have adopted high-income country standards for landfills. Many areas, however, lack the financial and technical resources required for the installation and operation of sophisticated landfills. In addition, they often lack a process and criteria for landfill siting and design. In order to improve the protection of water resources, a practical landfill siting process and a set of detailed criteria that consider all aspects of water resource protection is required.

Throughout the summer of 2002, research was conducted in Vietnam, as part of a CIDA funded program at the University of Toronto. The purpose of the research was to investigate landfill siting practices and collect information relating to water resources management and technical capabilities within Vietnam. Following this, a landfill siting process, and detailed criteria and data requirements for water resource protection were developed for Vietnam. In addition, a set of recommendations for improvements in landfill siting in Vietnam was outlined. Although the criteria developed were for Vietnam specifically, it is felt that they are general enough to be used in other areas.

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# 1 Introduction

Landfilling is a common solution for the final disposal of wastes in lower-income countries (Diaz and Savage, 2002), and a large majority of communities practice subsistence landfilling or open dumping as their main method of waste disposal (Rushbrook, 1999). Recently, due to the growing urgency of urban environmental problems, solid waste management in lower income countries has attracted much attention (Schubeler, 1996) and there is now a movement toward landfills designed to increase environmental protection. However, many areas do not have a process and criteria or guidelines for landfill siting and design, and in some large areas, there has been a tendency to adopt guidelines or regulations of higher-income countries without modifying or adapting them to local conditions (Diaz and Savage, 2002). This creates a problem because the development of engineered landfills involves complex engineering design and construction techniques. In addition, sophisticated landfills typically have measures to control or use landfill gas, extensive environmental monitoring points, leachate collection and treatment systems, and require a highly trained work force. As such, the adoption of sophisticated engineered landfills can only occur where the local economy can afford the high level of expenditure required for construction and operation of the landfill and where the technical resources to achieve high standards of construction and operation are made available (Rushbrook, 1999). It is therefore important to ensure that when new landfills are sited, the construction and operational capabilities of the local communities are considered in developing siting criteria so that environmental protection objectives can be met. For example, if the material and equipment needed for installing plastic landfill liners is not available within the country, and importing is beyond budget capabilities, an objective of landfill siting should be to find sites with soil suitable for liner material, or sites with borrow material in the proximity.

In addition to available financial and human resources, there are two other reasons why the design and operation of landfills in low-income countries can be different from those in high-income countries: the composition of the waste differs, and the climate of the area differs. In general, domestic waste in low-income countries has a higher proportion of organic, biodegradable waste than waste in high-income countries, resulting in a leachate that has a higher concentration of BOD and COD (Rushbrook and Pugh, 1999). The climates in low-income countries range from tropical to arid, and the potential for leachate production differs greatly in these two regions. In arid areas, there may be little or no leachate generated from waste, and thus site selection criteria and design requirements may be relaxed, and use of high-income country standards would result in unnecessary expenditure for sophisticated leachate collection and treatment systems (Rushbrook and Pugh, 1999).

Johannessen and Boyer (1999) compiled a report of observations made during visits to over 50 landfills in Asia, Africa, and Latin America in 1997-1998. The report identifies emerging features, practices, and necessary improvements in solid waste disposal. One operational issue common to all areas was problematic or inadequate leachate management measures. They indicated that the economic and environmental impacts of poor leachate management practices on groundwater and surface water were not clearly understood. Also, the costs of leachate management for the lifetime of the landfill, and management of leachate until it no longer poses threat to the environment were rarely included in the overall budget for landfill operations. A second concern was the use of low permeability landfill cover, which in some cases attributed to fifty percent of the operating costs. The concern with low permeability cover material is that it limits infiltration of water into the landfill, thus inhibiting the biodegradation of waste. This will result in a longer time for landfill stabilisation, and thus a longer period of leachate generation and longer potential pollution period from the landfill.

A recent review of the design and construction of engineered landfills in Thailand by Ashford and Visvanathan (2000) found that sites selected for landfills were often not ideal areas for locating waste disposal facilities. The sites selected were often those unsuitable for and thus passed over for other development purposes. At most of the sites, groundwater levels were between 1 and 2 meters below the ground surface, and some landfills had experienced major flooding in past years. Two of the ten sites visited had 1.5 mm HDPE over 600 mm clay as a liner, which meets the US EPA guidelines for municipal solid waste landfills; however, both of these sites were located in areas with sandy soil and high water tables, an unfavourable and potentially hazardous condition.

It is evident that there is much room for improvement in environmental protection in landfilling of municipal solid waste in lower-income countries. Although the awareness of potential environmental impacts is increasing, the knowledge of the relationship between landfill siting, design, construction, and operation of landfills and potential environmental impacts is not fully understood. Imposing landfill standards such as those used in high-income countries may be desirable; however, the use of such standards requires a comprehensive knowledge of landfill characteristics, such as leachate and gas generation, and high construction and operating costs. The use of such standards without a complete understanding of the potential environmental impacts of landfills can lead to large expenditures that provide a false sense of environmental protection. The case in Thailand, where the use of sophisticated liner systems may be perceived as providing groundwater protection, but failure of the liner system would result in a potentially hazardous situation, is an example. In addition, high-income countries often have standards for leachate treatment that may not be attainable in low-income countries due to technological and economic constraints. As mentioned above, leachate treatment was one of the most problematic operational issues. As such, it is important that an appropriate landfill site provides environmentally acceptable properties for a long-term leachate management strategy that is feasible, technologically and economically, for the community.

In Vietnam, the government is working to improve waste management practices. Part of this process involves implementing new regulations for landfill siting, design, and construction. Protecting water resources is a key step in improving the environmental aspects of landfills. Water resources are plentiful in Vietnam and crucial to sustaining the urban and rural populations and agricultural activity in the country. The plains and delta regions of the country are underlain by shallow alluvial aquifers, which are a cheap and reliable water source. In the mountain and plateau regions, groundwater sources are much less accessible, but surface water is abundant. A 1993 survey of sources of rural water supply in Vietnam indicated that approximately 60% of water is supplied by wells, 23% by surface water, 13% by rain water, and the remainder by piped schemes (Carl Bro Int. et al., 1998). Despite the relative abundance of water in Vietnam, it is an increasingly vulnerable resource. Population and economic growth compete for water to meet food requirements and other uses. The spatial and temporal variability of rainfall and runoff are high. Vietnam experiences severe flooding at certain times and droughts at others, and watershed degradation has intensified these effects (World Bank, 2001). In addition, groundwater is saline in a large part of the Mekong Delta, in a narrow strip along the central coast, and along the Red River Delta. The people living in these areas generally rely on groundwater from deep aquifers for water supply (Carl Bro Int. et al., 1998). Only a small percentage of exploitable groundwater resources have been tapped due the abundance and low cost of surface water at most times of the year. However, as demands for water and the occurrences of surface water shortages increase, the demand for groundwater development will also increase. Due to the importance and abundance of water resources in Vietnam and the increasing demand for and vulnerability of the resource, a landfill siting process that explicitly considers water resources and construction and operational requirements for protecting water resources is required.

This project was carried out as part of a CIDA funded program at the University of Toronto on waste management in Vietnam, Cambodia, and Laos. The purpose of the project was to develop a process and criteria and identify data needs for landfill siting in Vietnam, specifically for the protection of water resources. Throughout the summer of 2002, research was conducted in Vietnam to investigate landfill siting practices and collect information relating to water resources management and technical capabilities within the country. The criteria have been developed in the context of the Vietnamese regulatory requirements, but they are general enough to be easily adapted for use in other countries. Included in this report are: chapter 2, a methodology for landfill siting process; chapter 3, a summary of the information obtained in Vietnam including regulatory requirement, landfill siting practices, and water resources data sources; chapter 4, a set of water resource related criteria; chapter 5, a case study to illustrate the landfill siting process; and finally, chapter 6, recommendations for changes in Vietnam.

# 2 Literature Review

When seeking to improve solid waste management practices, one of the key issues to be addressed is environmental protection. For landfills in particular, this requires appropriate siting, design, construction and operation of engineered facilities. Perhaps the greatest environmental concern associated with landfilling is the risk of water contamination, which can have adverse effects on both people and the environment. As such, engineered landfills focus on protection of water resources through measures such as control of surface water, installation of landfill liners and removal and treatment of leachate from the landfill. To achieve this requires consideration of necessary site criteria when choosing a landfill location and careful attention to detail in design and construction to avoid or significantly reduce future environmental problems.

In low income countries, affordability of environmental controls may be one of the barriers to engineered landfilling. Through proper site selection, however, the overall cost for environmental controls can be reduced. By choosing sites with natural protection against adverse impacts and sites where the release of contaminants into the environment will have the least impact, the required level of engineering can be decreased, leading to a decrease in construction and operation costs. Thus, in order to protect water resources, it is important to consider site characteristics and their interrelationship with the design and construction of landfills during the site selection process. This chapter provides a literature review of landfill siting processes, and outlines a step by step process, adapted from the literature, that considers design and operational aspects of landfill siting, specifically for water resource protection.

## 2.1 Landfill Site Selection Process

Landfill site selection is an important step in implementing a waste management program. Proper siting can contribute to a reduction in design, construction, and operating costs, as well as help to minimize environmental impacts. From an environmental engineering prospective, an important objective of the process is to select a site that will provide the greatest public health and environmental protection in the event of landfill containment failure by making the best use of the land resources available (Qian, et al., 2002). To ensure that an appropriate site is chosen, a systematic process should be developed and followed (Rushbrook and Pugh, 1999). Unsuccessful landfill siting is typically the result of strong public opposition, and much research has been conducted to explore reasons for siting failures and to recommend changes in siting procedures (Baxter, et al., 1999). As such, it is important that an appropriate method be used so that the process results in the selection of a site that meets social, environmental and economic criteria. Lawrence (1996) identified three major siting approaches: the environmentally suitability approach; the social equity approach; and the community control approach. The basic idea behind each of these three approaches is as follows:

*Environmental Suitability Approach*

This approach follows a rational planning process through which alternatives are identified, screened and compared. The goal of the process is to minimize the negative and maximize the positive environmental effects of the project. There are typically three major stages in the process: area screening and identification; site screening and identification; and finally, site comparison. There are many different qualitative and/or quantitative evaluation methods that can be used for screening and comparing site alternatives. The process and level of detail used can be designed to reflect project types and regional needs and characteristics (Lawrence, 1996).

*Social Equity Approach*

This approach focuses on fairness in the planning process, and a fair distribution of facilities, costs and benefits among stakeholders. Direct involvement of all interested and affected parties is considered essential. Equity concerns have only recently been incorporated into landfill siting processes (Lawrence, 1996).

*Community Control Approach*

This method uses a high degree of process and outcome control by interested and potentially affected parties. Proponents of the landfill and community groups work together to make decisions. There are various ways in which the community can have control over the process: procedural control on the structure and implementation of the siting process; location control, or the freedom to choose whether or not to accept a site; and facility control, the control over the need for, size and operation of a facility (Lawrence, 1996).

Each of these approaches can be applied in a variety of ways, and they can be combined in numerous fashions to suit the needs of the project. The success of landfill siting can be strongly influenced by the choice and application of the siting method (Lawrence, 1996).

When considering protection of water resources in the selection of a landfill site, the potential effects of the site on surrounding groundwater and surface water quality and quantity must be assessed (McBean, et al., 1995). This can be accomplished by applying a series of constraints and criteria in a systematic process, such as the environmental suitability approach mentioned above. A step by step approach offers the advantage of reducing the total amount of data to be handled and restricts the detailed analysis to few sites (Frantzis, 1993). This is extremely important due to the technical and financial requirements for obtaining site-specific data such as geological and hydrogeological conditions. The social equity and community control approaches are not as applicable for site selection based on technical requirements, as they tend to focus on social aspects and community participation. These approaches however, can be used for some aspects of the process, such as deciding on the importance or weighting of criteria or locally suitable constraints. As the focus of this project is on landfill siting and the technical aspects relating to water resources protection, the environmental suitability approach will be used and the other two approaches will not be discussed further.

### *2.1.1 Terminology*

Before engaging in a discussion about landfill siting, it is important to clarify the difference between the terms used. "Objectives" of the landfill siting process describe the goals that are to be achieved. For example, an objective could be to minimize construction costs, or maximize environmental protection. "Criteria" are sub objectives used to compare the suitability of potential sites (Shah, 2000) and measure how well the sites meet the objectives. Criteria should be chosen to minimize or eliminate the negative impacts associated with landfills (Noble, 1992). For example, to minimize construction costs, criteria may include maximizing use of native soil for liner material or maximizing use of existing topography to reduce earth moving requirements. At the start of the process, regional criteria, such as the location of natural features, are used to identify potential sites. As the process continues, the level of detail increases and local, more site-specific criteria are used. "Constraints" are restrictive criteria that screen out areas considered unsuitable for use as landfill sites. They are often a minimum or maximum allowable level of a criterion, They can be a set of regulations enforced by the government, or constraints due to required site size or environmental conditions (Rushbrook and Pugh, 1999). For example, landfills must be located a minimum distance, stipulated by regulations, from residential areas. Data are used as a means of measuring the degree to which a site meets the criteria. For example, the permeability, thickness, and type of soil at the site will provide an indication of how suitable the native soil is for a landfill liner. Finally, the term "area" is used to mean the general location that may be suitable for a landfill during the early stages of landfill siting. The term "site" is used to describe a specific location that could potentially be used for a landfill.

### *2.1.2 Landfill Siting in Lower-Income Countries*

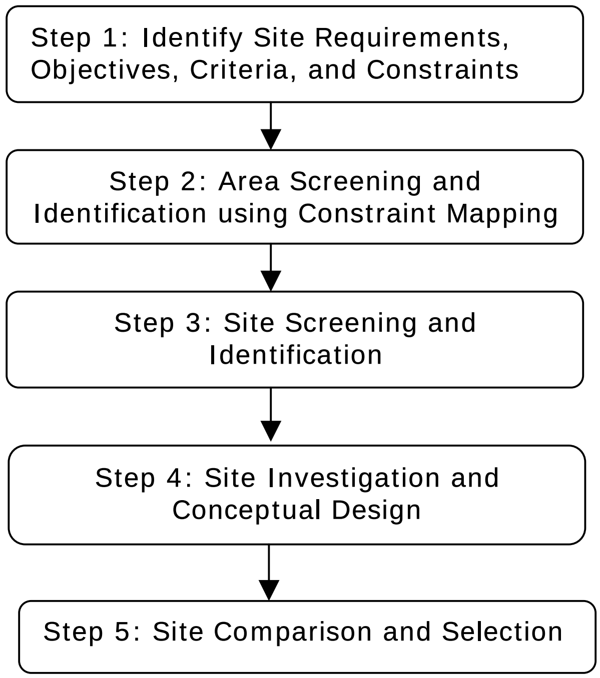
Siting and designing engineered landfills in low-income countries is a difficult task. Often, affordability of environmental control measures is a key issue. Ideally, objectives for landfilling in low-income countries should match corresponding objectives in high-income countries, and objectives for landfills serving large towns and cities should be the same as those for landfills serving small villages (Blight, 1996). However, the communities of small towns and villages in low-income countries usually cannot afford landfill design, construction and operation standards equal to those applied in large cities, and in some cases, large cities cannot afford to apply standards equal to those of high-income countries. Perhaps the first question to be addressed when siting a landfill is: What constitutes an appropriate level of environmental protection for the community? This will differ from community to community, and will depend on the climate in the area and the available resources for construction and operation of the landfill. Often, construction and operation resources are limited, and this must be reflected in the siting process. As was previously mentioned, leachate management is one of the key issues in landfill management in development in low-income countries. Design, construction and operation of a leachate control system often requires the highest development cost, and its failure has the greatest potential to affect human health by contamination of water resources. As such, emphasis should be placed on siting landfills in areas that provide natural protection of water resources in order to reduce the costs and risks associated with landfills.

There is little literature available covering technical aspects of landfill siting in developing countries. Two publications (Diaz and Savage, 2002; Rushbrook and Pugh, 1999) provide general guidance and criteria for a landfill siting process, and a third publication (Blight, 1996) describes an approach for classifying landfills that allows the use of graded standards. Criteria and information relating to the above three publications is summarised in Appendix A. The following landfill siting process has been adapted from a World Bank publication by Rushbrook and Pugh (1999), with additional information from other sources as noted. Water resource related criteria have been highlighted for each section. Following the discussion of the landfill siting process is a description of the application of graded standards for landfilling in lower income countries.

### 2.1.3 Steps in the Landfill Siting Process

The following flow chart provides an overview of the steps in the landfill siting process:

Figure 2-1: Steps in the Landfill Siting Process




Step 1: Identify Site Requirements, Objectives, Criteria and Constraints

The first step in the process is to identify the landfill requirements (site size, etc.) and determine the objectives, constraints and criteria to be used in the process. For example, one objective may be to minimize the risk of groundwater contamination. One of the criteria may be to maximize the depth to the water table, with a constraint that the water table must be, for example, 1.5 m below the base of the landfill. Once the criteria and constraints are established, the data requirements can be determined. The search area must also be defined. This will be influenced by for example, an acceptable travel distance from the city, or administrative boundaries. In some cases, neighbouring communities may wish to work together or be host communities for landfills.

Step 2: Area Screening and Identification using Constraint Mapping

An important element of a successful landfill siting process is evaluating the basic suitability of all available land for landfilling to aid in the selection of a limited number of potential sites for more detailed evaluations. This should be practical, taking into consideration the resources and constraints of the government agencies and consultants involved in the process (McAllister, 1986). As such, it should be based on published data, such as topographic maps, aerial photographs and official development and zoning plans, and not require field work. Constraint mapping is a commonly used technique that involves creating a series of maps to show the areas identified as unsuitable for landfilling based on each of the constraints. When the maps are overlaid, the potential candidate sites can be easily identified (McAllister, 1986). Recently, geographical information system (GIS) have been used to facilitation landfill siting. GIS can be used to convert geo-referenced data into computerized maps and map analysis tools can be used to manipulate maps in an efficient way (Kao et al., 1997). This is especially useful when dealing with large amounts of data, which is typical in landfill siting. The outcome of this step is a long list of potential candidate sites.

Typical constraints relating to water resource protection are:

- Landfills should not be constructed in areas with fractured bedrock, karst topography, etc. to ensure groundwater protection.
- Water bodies (lakes, streams, wetlands, etc.) are not suitable for landfill development.
- Areas with complex geology are not suitable as it will be difficult to monitor and remediate in the event of groundwater contamination.
- Landfills should not be sited in protected areas such as forests, wetlands, and endangered species habitats.
- Landfill should not be constructed in the floodplain of a river or other areas susceptible to frequent flooding.

This step may require iteration, as the constraints may need to be relaxed if too few areas are identified, or further constraints applied if too many or too large of areas are identified. The level of constraints used depends on the minimum level of criteria and will vary depending on local regulations and attitudes. For example, a constraint can be applied that screens out surface water bodies, or, the constraint can screen out areas within a minimum "acceptable" distance from water bodies, for example, 500 m. In addition, this step can be divided into two steps, applying a general set of constraints to the entire search area, and then applying a second, different set of constraints for the remaining area. The purpose of this is to reduce the data required to apply the second set of constraints by reducing the area.

Step 3: Site Screening and Identification

In this step, the areas identified from the constraint analysis are evaluated and compared in order to identify potential sites suitable for landfilling. The objective is to reduce the number of sites to an appropriate number for detailed comparison in the next step. Rushbrook and Pugh (1999) recommend reducing the number of candidate sites to three; however, it may be practical to consider more than three sites. The key issue to keep in mind is that in the next step, each site will require detailed data collection, which is time consuming and costly; thus, given time or budget constraints, comparing many sites may not be feasible.

The data used to compare and evaluate the sites in this step is usually based on published data, and walk over or field surveys if required (IWA, 1992). Walkover surveys may not be required if published sources provide enough data for site comparison. Site investigations can also be used to confirm published information. A consistent approach can be achieved by using a checklist of points, and a suitability matrix to compare various aspects of the site. A checklist for walkover surveys is provided in Appendix A.2.

Ideally, potential sites should be identified based on the full set of criteria established in step 1. This will include the water resource criteria, as well as social, land use, infrastructure, etc. criteria. In reality however, the data required to identify potential sites using all criteria may be general or not available at all. Thus, this step will require judgement by those trained in the areas of geology, hydrogeology, and hydrology, to identify potential sites that meet water resource related criteria based on the data available and site walk over surveys.

If this step results in the identification of many potential sites, they must be compared based how well they meet criteria using the available data in order to reduce sites for further consideration to a reasonable number. This can be accomplished by using a matrix to compare the sites for each criteria and then selecting a few of the most suitable sites for further consideration. Alternatively, there may be further criteria used to identify sites, such as the travel distance from the city. For example, sites within a 20 km travel distance may be preferred, and thus, sites further will be excluded from further consideration, unless a suitable site cannot be identified within the 20 km distance. Finally, if this step fails to identify potential sites, either the constraints used in the first step must be relaxed or the search area must be increased, or both.

Step 4: Site Investigation and Conceptual Design

In this step, detailed data are collected for each candidate site and basic designs are completed. Site investigations should be designed to confirm published data, and collect data required to measure how well each site meets the criteria. To fully understand how each site may affect water resources, subsurface exploration and topographic surveys are carried out at the candidate sites. Appendix A.1 includes a list of suggested hydrogeologic data to be collected during a site investigation. Designs are then completed to the point where approximate cost estimates can be made for comparative purposes. For example, the resources needed to install and operate a leachate control system would be estimated. This requires formulating a leachate control strategy for the site, including leachate treatment and discharge options, monitoring programs requirements, etc. Other aspects to be included are liner design, daily and final cover, requirements for an environmental monitoring program, and site preparation (earth moving, road construction, etc.). The estimate can be used to develop “cost per cubic meter of waste” for each design component considered.

Several design alternatives for a site that result in a range of site suitability based on the criteria may exist. This may also result in a range of construction and operation costs. For example, a site with permeable native material can be designed with or without a liner. A site without a liner will provide less protection against contamination of water resources, but will be less costly to build, as the liner material is not required and construction costs are decreased. However, if groundwater becomes contaminated and has an impact on groundwater use, thus requiring remediation, the operation costs will increase. Conversely, constructing the site with a liner will be more costly, but will decrease the risk of groundwater contamination, and the risk of future remediation requirements. Considering design alternatives for a site will allow the tradeoffs between the level of design and the level of environmental protection to be analysed.

Step 5: Site Comparisons and Selection

This step involves a detailed evaluation and comparison of the candidate sites. This requires comparing the data collected from site investigations and published sources, and conceptual designs to determine which site best meets the criteria. Often, this is achieved by weighting and rating criteria (McAllister, 1986). With this method, the weight of each criterion is determined according to its relative importance and each site is rated for each criterion. The method used for rating does not necessarily need to be the same for all criteria. Numerical ranking such as a scale of 1 to 10, or a qualitative ranking such as high, medium or low can be used. For example, a site with no groundwater resources underlying the landfill may receive a rating of 8, or high acceptability, and a site with groundwater resources less than 5 m below the landfill may receive a rating of 3 or low acceptability. Site are also be compared based on the conceptual design, and more than one design alternative may be considered for a site. A matrix can be used to compare all the sites based on the criteria by filling in the ratings, such as shown below.

Table 2-1: Site Comparison Matrix

| Criteria | Site Suitability | | |
|---|---|---|---|
| | Site A | Site B | Site C |
| Maximize depth to water table | High | High | Low |
| Minimize risk of flooding | Medium | Medium | Low |
| Minimize permeability of underlying geology | High | Medium | Low |
| Cost of liner construction | Low | Medium | High |

In the above example, Site A has soil with low permeability that is suitable for a landfill liner, and therefore the cost for liner construction is low. However, there is a risk of flooding which will need to be addressed in the landfill design, and could lead to increased construction costs. Site C does not have a suitable soil for a liner, increasing the construction costs, and the water table is closer to the ground surface, thus increasing the risk of groundwater contamination. However, the risk of flooding at Site C is low. With respect to water resource protection, Site A would be more suited to minimizing the risk of water contamination, if the risk of flooding can be addressed in the landfill design.

The above process provides an effective, systematic way to assess the suitability of sites for environmental control and cost of implementing the control systems. A more formal approach to dealing with tradeoffs between environmental controls and cost is to apply graded standards or minimum acceptable standards that provide guidance for situations where the level of environmental control can be relaxed. These are discussed in detail in the following section.

## 2.2 Graded Standards for Landfill Siting

In some cases, smaller communities lack the resources available in larger communities for waste management. Smaller communities also generate less waste, and therefore have smaller landfills. Thus, the smaller communities may not be able to meet strict standards. However, environmental risks associated with small landfills are less, and if sited properly, small landfills may not need to meet strict standards in order to provide an acceptable level of environmental protection. Blight (1996) has developed a set of graded standards that are used in South Africa for landfill requirements. Rushbrook and Pugh (1999) have provided guidelines for minimum acceptable standards of design and construction of landfills depending on the level of groundwater protection required. The following is a review of these two methods.

Blight (1996) has identified the following three factors that can be used to determine what level of standards apply in a specific area:

1. Waste Type: Waste composition may be very different – e.g. proportion of biodegradable components may be vastly different, resulting in different leachate characteristics. Waste with a high biodegradable content is likely to produce leachate with higher BOD and COD. The waste type is classified based on amount of biodegradable content, allowing relaxed standards for low-biodegradable waste.

2. Landfill Size: Waste generation rates may be smaller by a factor of 3 or 4, due to differences in climate, diet, culture, and type of fuel. If less waste is produced, landfills of the same age will be smaller, or landfill life will be longer, and therefore have a smaller source of pollution potential. The size of the landfill is classified by considering the maximum rate of deposition (tonnes of waste/year) or by considering the total volume that can be accommodated at the site. The landfill is then classified as communal, small, medium, or large, with higher standards applied to larger landfills.

3. Climate Characteristics: Climates in developing countries may be humid, where the potential for leachate generation is high, or they may be arid, where the potential for leachate generation is low. Climate characteristics are classified based on a climatic water balance to determine whether the site will generate significant amounts of

leachate, and therefore, whether or not a leachate collection system and landfill liner are required.

For details of the classification system, see Appendix A. The application of the system would depend on requirements and conditions in the country in which it is applied. The process tends to be more useful for countries that have a range of climate conditions and waste characteristics. For example, a country may have the same climate throughout, and thus climatic considerations would be omitted. The same country could have the same waste composition throughout, and thus landfills could be classified based on size only. Graded standards could still be based on landfill size, especially in countries where funding for waste management in smaller communities is low. Minimum requirements can be outlined for each phase of a landfill project (siting, site investigation, environmental impact assessment, design, operation, closure, monitoring, etc.) for each combination of landfill type.

The landfill classification method suggested by Blight could easily be adapted and made suitable for different countries. However, there may be resistance from regulatory agencies to allow graded standards, as they may wish to apply the same standards everywhere. In reality, if the standards cannot be met because of financial constraints, they may be ignored, so in fact, graded standards would ensure that some appropriate level of environmental protection is provided.

In another approach, Rushbrook and Pugh (1999) have identified the following three levels of required groundwater protection:

- *Minimum* – where groundwater is already unsuitable for human or agricultural use, where its degradation will not impact on the local ecology, or where the local climate will prevent the generation of leachate from any landfill. Although leachate may not pose a threat to the environment, good management practices should still be implemented. Efforts should still be made to reduce surface water runoff entering the landfill, areas prone to flooding should not be selected, etc.

- *Intermediate* – where attenuate and disperse designs may be sufficient. Ideal conditions for attenuate and disperse sites are:
    - Low local groundwater recharge

    - At least 3 m of unfractured, unsaturated low permeability (i.e clay, silt) material between the base of the landfill and the seasonably high groundwater table
    - High rate of groundwater flow with a high permeability (sandy) aquifer immediately below. This implies either a confined aquifer or relatively steep topography
    - Low importance of groundwater as a resource

  Once again, best management practices should be observed, and groundwater monitoring programs should be in place to monitor leachate migration from the site.

- *Maximum* – where full containment designs are needed to ensure minimal risk of groundwater contamination in areas where groundwater resources are in use or considered valuable. These sites have natural or constructed liners and leachate collection and treatment systems to minimize the risk of groundwater contamination

This approach, which applies on a site-to-site basis, can be very useful in step 4 to do the conceptual designs. Caution should be taken, however, in ensuring that enough data are available to adequately assess a site and determine whether, for example, an intermediate level of protection is sufficient.

Overall, it must be recognised that some areas will not be able to meet high standards and provide adequate protection against groundwater contamination. In these circumstances, every effort should be made to site landfills where the impact of groundwater contamination will be the least.

## 2.3 Criteria and Data Requirements for Water Resource Protection

The step by step process described in section 2.1.3 requires a set of criteria and data collection. Many waste management texts (Rushbrook and Pugh, 1999; McBean et al., 1995; Wood, 1984; Noble, 1992; Shah, 2000; Tchobanoglous, 1993; Bagchi, 1994) provide comprehensive lists of criteria for water resource protection in landfill site selection, and a detailed discussion of each of those criteria is beyond the scope of this paper. The following section highlights key criteria and data that can be used, and discusses the importance of criteria selection in landfill siting.

Criteria should make optimum use of existing data, in order to help minimize the cost and time required for the landfill siting process (LeGrand, 1980). The design of the landfill also influences how well a particular site meets the criteria for site selection. The ability to modify the design of the landfill adds much flexibility to the process, as it allows criteria to be changed to meet the demands of a study. A “price” can be attached to the modification of criteria as it changes the landfill design requirements (Noble, 1992).

Many regulatory agencies tend to specify acceptability of landfill sites based on an index, such as a minimum distance from the landfill to a stream or a well. This, however, is not realistic when faced with a range of hydrogeologic conditions, and may result in some decisions about environmental management being either too conservative, or too liberal. (LeGrand, 1980) It may lead to decisions about site suitability being made by people who are not trained in the field of geology or hydrogeology, and do not fully understand the implications of their decisions, and could result in elimination of a site that may be more suitable than other candidate sites based on a single factor.

When assessing the suitability of a potential landfill site for water resource protection, there are many questions that must be answered, such as: what type of soil is present; is the soil suitable for use as a landfill liner; what are the groundwater conditions, etc. The difficulty in answering these questions lies in the fact that there is a large variety of geologic conditions, materials, and range of flow regimes in these materials that make it difficult, time consuming, and expensive to investigate each actual and potential water contamination problem. In order to ensure that the appropriate data are collected and to avoid collecting unnecessary data that can waste both time and money, a method that enables the strong and weak points of a site to be highlighted is required (LeGrand, 1980). LeGrand (1980) has identified four key hydrogeologic factors that can be used to measure criteria for potential landfill sites. They are as follows:

1. *Distance from landfill to wells, surface water bodies, use of ground and surface water bodies in the area*: When considering movement through material with sorption capacity, the greater the distance the more favourable the site. This is somewhat less significant when the movement is through fractured rock and contamination is likely to extend great distances.

2. *Depth to the water table below base of landfill:* Seasonal fluctuations in groundwater levels are common in many regions. It is the high position of the water table that is of concern when assessing the groundwater contamination potential of a landfill site. The greater the distance from the base of the landfill to the groundwater table, the more favourable the site.

3. *Approximate slope of the water table*: The slope of the water table will indicate the direction of groundwater flow, and thus the area at risk of contamination. It is important to note that if the slope of the water table is very low, or if mounding of the water table occurs, there may be radial flow of contaminated groundwater.

4. *Characteristics of underlying materials, specifically permeability and sorption*: Permeability and sorption of the underlying material provide an indication of the amount of natural protection there is against contamination of underlying groundwater. Permeability provides an indication of the rate at which contaminants can move through the subsurface, and sorption capacity provides an indication of the natural attenuation capacity of the soil. Other important characteristics include: soil types, thickness of geological layers, and depth/thickness of aquifers.

This information is not likely to be available, but can be obtained by field studies. Additional factors and data are typically considered, however, these four factors incorporate indirectly all other pertinent factors, and provide an indication of site suitability. For example, aquifer sensitivity, which is the likelihood of and degree to which groundwater resources may be contaminated at a particular site, can be assessed by considering the permeability of the underlying geology at a site and the depth to the aquifer. Another concern with aquifer sensitivity is the area extent and the use or potential use of the aquifer for water supply. This can be assessed by considering the distance from landfill to wells and the water table gradient.

# 3 Landfill Siting and Water Resources in Vietnam

Throughout the summer of 2002, landfill siting practices and regulations, and water resources data availability in Vietnam were investigated. The purpose of the research was to gather information relating to past and present landfill siting and waste management practices, with a focus on the protection of water resources. The information gathered would help gain an understanding of the strengths and weaknesses of the current system, and allow for recommendations for improvements, as well as development of water resource related criteria that could be used for comparing potential site suitability. In addition, the availability of and capability of collecting data relating to water resources was examined in order to allow criteria to be developed to best suit the situation in Vietnam.

## 3.1 Methodology

Interviews were conducted with government officials involved in waste management in Vietnam in Ha Noi City, Phu Tho Province, and Da Nang City. Ha Noi (population 2.3 million) is the capital of Vietnam, and the location of the national level government agencies. It is located in Red River Delta in the northern part of Vietnam. Phu Tho Province (population 1.3 million) is located north of Ha Noi, and at the time the research was being conducted had just completed a landfill siting project. Finally, Da Nang (population 700,000) is the fourth largest city, located in Central Vietnam, on the coast of the South China Sea. It was selected because they have recently completed a landfill siting process and will be looking for another site soon, and the Environmental Protection and Research Center (EPRC) at Da Nang University is affiliated with the Waste Econ Program.

Approximately 20 interviews were conducted with officials from national and regional level agencies. The interviews followed a semi-structured format, with questions about involvement in landfill siting projects, the process of landfill siting, waste management regulations, criteria used for landfill siting, and landfill design and operation. Officials from agencies responsible for collecting data about water resources and geological and meteorological conditions were also interviewed to determine data collection methods and capabilities. In addition, documents and regulations relating to waste management projects and environmental protection were collected and reviewed. A list of questions and agencies interviewed is included in Appendix B. For confidentiality, interviewees are not identified by name or position.

### 3.2 Overview of Government Agencies

There are numerous agencies involved in waste and water resources management in Vietnam at both the national and regional/local levels. Figure 2 is an organisation chart showing the agencies involved, and a brief description of their roles follows.

*People's Council* – A locally elected body that is the highest government authority at provincial and district levels (UNDP & MPI, 1997).

*People's Committee* – Elected by the People's Council, it is the executive branch of the Council, responsible for government administration at the local level. It is responsible for implementing the constitution, laws passed by the National Assembly, orders of higher State authorities, and resolutions of the People's Council (UNDP & MPI, 1997). The People's Committee must provide the final approval for landfill sites.

*Ministry of Construction (MOC)* – A National government agency with the highest authority in solid waste management (UNDP & MPI, 1997). Its involvement in waste management is through responsibilities for preparing regulations for solid waste management such as landfill design and construction, completing urban plans for class 1 and class 2 cities, and appraising technical design of projects.

*Departments of Construction (DOC)* – Regional level agencies responsible for the administration of solid waste management projects in their areas. They are also involved in local rural and urban planning. Typically, DOC and DOSTE (see below) work together on waste management projects.

*Department of Architecture and Planning* – Under direction of MOC, this department is responsible for preparing land use plans, and controlling land use according to the approved plans and regulations. Potential landfill sites are identified using the official land use plan, either by this department, or by another agency that is responsible for administrating land use.

*National Institute of Urban and Rural Planning (NIURP)* – Under direction of MOC, this agency is responsible for: conducting research on urbanization; development of national urban and rural development strategies; preparing regional, city and detailed plans; and conducting feasibility studies (UNDP & MPI, 1997).

*Center for Research and Planning or Urban and Rural Environment (CRURE)* – Under the direction of NIURP, this agency is responsible for: research and planning for environmental projects; studying and monitoring pollution; conduction environmental impact assessments; providing consulting services (UNDP & MPI, 1997). They are involved in waste management projects through preparation of solid waste management plans for rural and urban areas, undertaking environmental impact assessments (EIAs), and helping local organization undertake landfill siting projects.

*Ministry of Science, Technology and Environment (MOSTE)* – A national government agency which is involved in waste management through its responsibilities for preparing environmental regulations, formulating environmental protection strategies, and appraising EIAs. (As of August 2002, two new ministry were created to replace MOSTE, with the Ministry of Natural Resources and Environment (MNRE) taking over responsibilities relating to environment)

*Departments of Science, Technology and Environment (DOSTE)* – Regional level agency responsible for enforcing environmental regulations and conducting environmental monitoring and environmental engineering projects. Typically, DOSTE and DOC work together on waste management projects. (As of August 2002, these agencies are called DNRE, under the direction of MNRE)

*National Environment Agency (NEA)* – Responsible for aiding MOSTE in management of environmental protection activities throughout the country. Responsibilities include preparing regulations such as those pertaining to solid waste collection, treatment, and technical guidance for landfill siting and design, and appraising EIAs for projects.

*Ministry of Industry (MOI)* – Responsible for preparation of development strategies and plans for the industrial sectors and steering and guiding the implementation of approved plans. They are also responsible for regulation of emissions from industry (UNDP & MPI, 1997).

*Department of Geology and Minerals (DGMV)* – Under the management of the MOI, it is responsible for state management and protection of mineral resources, research, and basic geological surveys for the country. Several specialized divisions, such as the Division of Geological and Mineral Resources Survey, exist throughout the country to undertake research, geological surveys and mapping, and geotechnical and hydrogelogical tigations (DGMV, 2000).

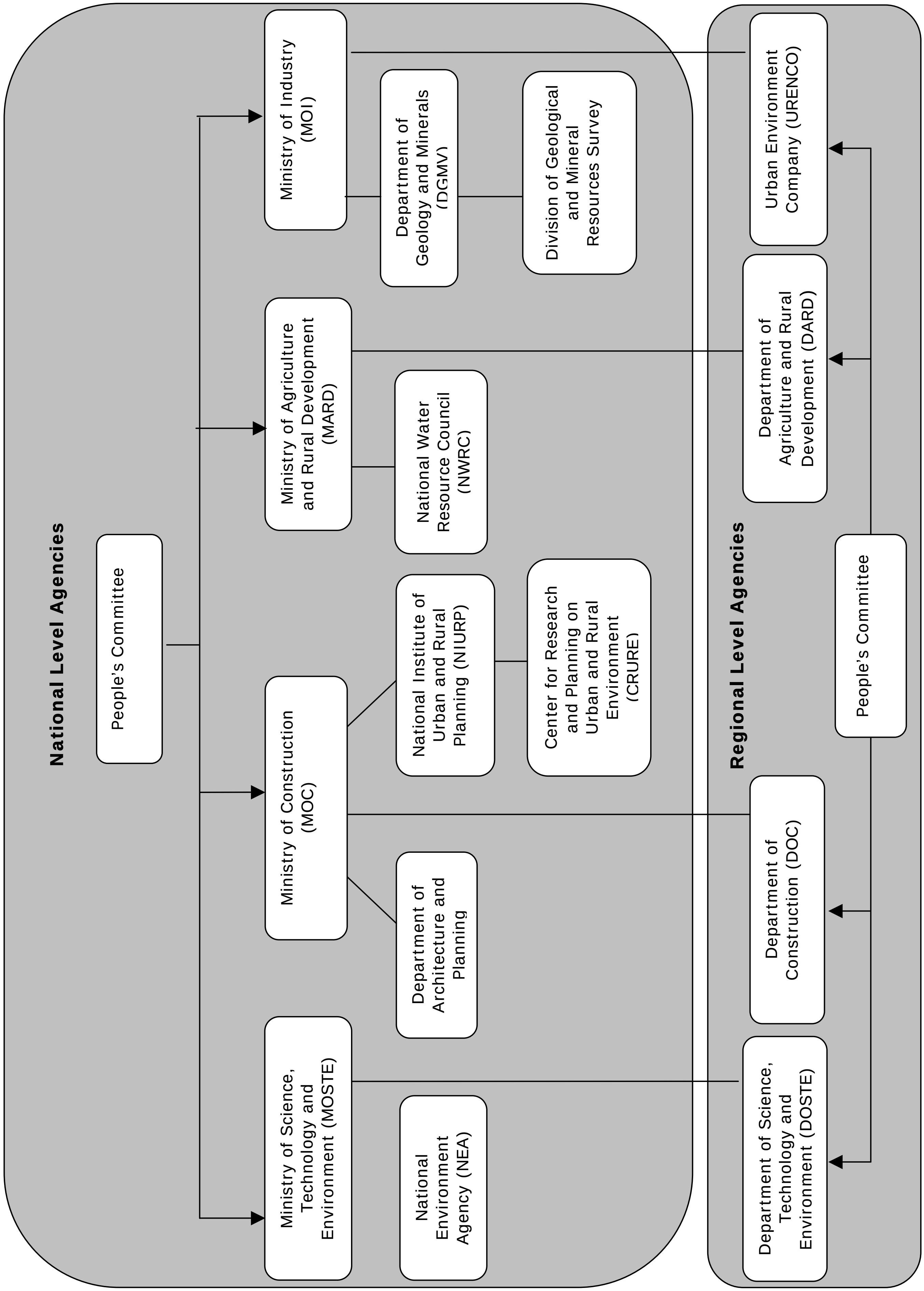



Figure 3-1: Organisation of Government Agencies

*Urban Environment Company (URENCO)* – Owner and operator of most landfills in Vietnam, under direction of MOI.

*Ministry of Agriculture and Rural Development (MARD)* – Responsible for state management of water resources, agriculture, forestry, irrigation, and rural development (MARD, 2002). They prepare regulations for protection of water resources and rural water supply plans.

*Department of Agriculture and Rural Development (DARD)* – Under the direction of MARD, they are responsible for regional level administration of water resources, agriculture, forestry, and rural development. In relation to water resources, they are responsible for construction of water supply facilities (well drilling), undertaking technological studies and water quality analysis, forming and overseeing organisations for rural water supply and environmental sanitation planning, and finally, implementing monitoring projects and services (JICA & MARD, 2000). This department is called the Department of Flooding, Forestry, and Fisheries in Da Nang.

*National Water Resources Council (NRWC)* – Advises the government, through MARD, on important water resource issues and coordinates national water resources planning and management.

The direct involvement of MOSTE and MOC in landfill projects depends on the classification the project. Projects are classified as A, B, or C depending on their size, with A being the largest. Class A projects require the approval of the central government, where as B and C class projects are approved by the local government, and require appraisal by MOC.

## 3.3 Landfill Regulations

Up until 2001, guidelines for landfill siting were very general and the following basic criteria were used for site selection:

1. Sites must be a minimum of 2 km from urban areas
2. Sites must be downwind of the city
3. Sites must be downstream of water supplies
4. Sites must provide measures to protect the environment from pollution

It was indicated during interviews that the distance from urban areas was often the only criterion that was met, and little or no attention was paid to the prevention of environmental problems. Groundwater maps were not used for site selection, as the awareness of environmental problems was low. In some cases, wetlands, lakes and rivers were used for waste disposal, resulting in water contamination. This in now a major problem and there is little funding available to remediate these sites.

In January 2001, MOSTE and the MOC released Joint Circular #01/2001 titled "Guiding the Regulations on Environmental Protection for the Selection of Location for the Construction and Operation of Solid Waste Burial Sites." The circular states that selection of potential landfill sites should be based on approved land use planning of state agencies. It states that the selection of a landfill site must be based on four factors: natural, socioeconomic, and technical infrastructure factors, and appropriate distances. The four factors and their sub factors are as follows:

1. Natural Factors - terrain, climate, hydrology, geology, hydrogeology, natural resources and ecological landscapes
2. Socio-Economic Factors – population distribution, current economic situation, future economic growth, administrative management, historical relics, and security and defence
3. Infrastructure Factors – communication and other services, land use, current and future distribution of industry, water supply systems, and electricity networks
4. Appropriate Distances – distance from urban centers, rural populations, airports, cultural and tourist sites, wells, main roadways (constraints for minimum distances are outlined in Appendix 1 of the circular)

With regards to the landfill site selection process, the circular describes the following four-step process, which is consistent with the land suitability process described in chapter 2:

1. Gather information about the landfill site requirements (volume of waste, projection of waste generation)
2. Locate potential landfill sites based on topographical, geological, hydrogeological, and land use maps and by conducting field surveys.
3. Compare and evaluate landfill sites based on natural, economic and social factors to determine the most appropriate location.
4. Produce a plan for the selected site

In 2001, a new landfill design standard (TCXDVN 261:2001) was also issued. The design standard provides detailed requirements for construction of leachate and gas collection systems, landfill liners, surface drainage and groundwater monitoring, and landfill site layout and design requirements (roads, buildings, etc.).

Leachate from the landfill must be treated to meet the wastewater discharge standards (TCVN 5945:1995). The standard has three levels (A, B, C) for maximum allowable concentration of pollutants, depending on the use of the receiving water. Level A criteria are the most strict, and apply to receiving waters used as a domestic supply. Level B criteria apply to water bodies used for navigation, irrigation purposes, bathing, aquatic breeding, etc. Level C criteria are for specific cases, dictated by government agencies.

Environmental impact assessments are required for the chosen landfill site. The current EIA process follows a general guideline that exists for all types of projects. It was indicated that there has been confusion about what regulations should be followed, and that the EIA process is not consistent throughout the country. MOC is in the process of developing specific EIA guidelines for various types of infrastructure projects, including solid waste management projects. NEA and CRURE indicated these guidelines should be implemented by 2003. This guideline will address the specific environmental concerns associated with landfilling, and help to identify and prevent environmental problems.

### 3.4 Water Resources Regulations

In May 1998, the National Assembly passed the Law on Water Resources (LWR) which describes the responsibilities of government for the management of water resources. It specifies that the Government, through MARD, performs the role of water resource manager. Other ministries are assigned responsibilities in implementing specific functions of water resources management. The People's Committees of the provinces and of cities are responsible for management of water resources in their own jurisdictions. The LWR established the National Water Resource Council (NWRC) whose major role is to advise the government on important water resources issues and to coordinate national water resources planning and management across the various ministries. Other important provisions of the LWR include the introduction of licensing for surface water extraction and a permit system for wastewater discharge. A system for licensing of groundwater exploitation already exists, although it is not widely implemented (World Bank, 2001).

## 3.5 Landfill Siting Practices

Interviewees in Hanoi and Phu Tho Province described the current landfill siting process as follows:

1. Potential landfill sites are identified based on the official plan, which is completed by the Department of Architecture, CRURE, etc. The official plan does not identify specific areas for landfill sites. Sites are selected based on the following general criteria:
    a. The site should be sufficient distance from the urban/residential area, at least 2 km.
    b. The site should be in the downwind direction of the city in order to minimize the nuisance of odours.
    c. The current land at the site should be of low productivity, and construction of a landfill should not interfere with development of the city.
2. Local agencies, such as DOC, DOSTE, URENCO, or consultant companies prepare a report to discuss the advantages and disadvantages of the candidate sites. The factors listed in Appendix 2 of the Joint Circular must be considered. The data used to compare the sites is based on information available from government agencies and field visits; no field studies are conducted. In some cases, if the required data is not available (e.g. aquifer mapping), the agencies base the recommendations on site visit observations. The People's Committee will select the site based on the recommendations from the report. For Class 1 cities, or large projects approval of the Prime Minister is required.
3. A Feasibility Study and Environmental Impact Assessment are completed for the chosen site.
4. The owner of the landfill (e.g. URENCO) will be informed of the site location.
5. The chairman of the province (Prime Minister for special towns) will approve the funding for the project.

Interviewees in Da Nang had not been involved in a landfill siting project since 1998. The local landfill siting process at that time was described as follows:

The Urban and Rural Planning Division of DOC works in coordination with URENCO and DOSTE. URENCO and DOSTE provide DOC with the requirements for the landfill (site area, etc.) and DOC selects candidate sites based on the following criteria:

1. Distance to closest residential area
2. Suitability of or existence of access road to the site
3. Existing infrastructure, e.g. electricity and water supply
4. Economics of using the site for a landfill – cost for transportation and site operation
5. Land use – low productivity land, and land that will not impact future development of the city
6. Maximize use of the existing topography for drainage, minimize earth moving requirements
7. Minimize the environmental impacts – based on the number of rivers in the area, potential impacts of odours and groundwater pollution

Although environmental protection was indicated to be the most important consideration in landfill projects, the level of design and cost required for environmental protection were not considered during the landfill site selection process. It was indicated that environmental protection requirements were considered after the site was chosen. The interviewees were not aware of the Joint Circular #01/2001.

## 3.6 Landfill Siting Criteria

There was a uniform opinion among officials interviewed at the national level agencies that the most important criteria for landfill siting are: protection of the environment (water resources, human health); the use of non-agricultural or low-productivity land; and ensuring appropriate distances from urban areas. It was also indicated that choosing a site with suitable soil for a landfill liner is also a high priority. In recent projects in Hanoi, much attention was paid to environmental criteria, specifically the protection of human health, groundwater, and surface water.

## 3.7 Difficulties and Barriers

Interviewees were asked to describe difficulties with the current landfill practices, and any perceived difficulties in implementing the new regulations. The most common issues that were brought up were related to funding, regulation enforcement, agency involvement, and design, construction and operational aspects. This section summarises the information obtained from interviewees, and in some cases, information was collected from reports and has been included.

### *3.7.1 Project Funding*

Cities and towns in Vietnam are classified by a hierarchy of urban class and by administrative units. Urban areas in Vietnam are divided into five classes, according to population. Class 1 cities have more than 1 million people and class 5 cities have more that 4,000 people. Class 1 cities (Hanoi and Ho Chi Minh City) are under direct control of the central government. Cities are also categorized according to hierarchy of administrative units; for example, provincial capitals are in a higher position when compared to other provincial towns. The hierarchy of administrative units is used to allocate resources within the same level of urban government. Because of this, provincial towns have lagged behind provincial capitals in terms of investment in urban development (UNDP & MPI, 1997). As such, smaller communities may not have the resources and experience in their local offices for landfill siting and construction. In an attempt to overcome this problem, some towns try to build one landfill to serve many small areas; however, this tends to cause a problem with transportation of waste to landfill sites, as there is a lack of funding for waste collection services, especially in small areas.

Recently, there has been much support from foreign governments and development agencies for the siting, construction, and design of engineered landfills. In Ho Chi Minh City, the Dutch government supported construction and operation of the current landfill, and the Asian Development Bank supported construction of the Dong Thanh landfill. In Da Nang, the World Bank is providing funding for the construction of a new landfill, and the landfill siting and design was completed by an Australian Development Agency. In Da Lat, a landfill project is being funded by the Government of Denmark, with the engineering design being completed by Cabro, a Danish consulting firm.

### *3.7.2 Regulation Enforcement*

During interviews, it was indicated that in theory, all new landfills will have to meet the new guidelines; however, due to lack of resources for and difficulties in enforcing regulations, it may take several, if not many years for all offices to follow the regulations. Several reasons were indicated as barriers to meeting the new regulations. Firstly, many areas in Vietnam do not have the technical resources available for landfill siting and construction. Secondly, there is a lack of funding for all aspects of landfill projects. The new regulations require the landfills to have sophisticated liners and leachate collection and treatment systems, which may not be economically feasible in Vietnam. In the past, there have been instances where landfills have been designed to meet high standards, but the design requirements had to be reduced due to lack of resources for construction.

### *3.7.3 Agency Involvement*

In most cases, DOSTE, DOC, and URENCO are the primary agencies involved in landfill siting projects. There are other agencies responsible for geological surveys and water resources, which are great importance when siting landfills; however, they tend not to be directly involved in the siting process. For example, the Department of Geology and Minerals indicated that they have supplied data (maps and reports) to People's Committees and government organizations (DOSTE, DOC, URENCO) for landfill siting projects, but are unsure how the data are used. It was felt that government organizations responsible for landfill siting lacked knowledge of geology, and the data provided was too complicated, or not suitable for their applications. As a result, the data was often overlooked or ignored. A division of the Department of Geology has been involved in past landfill siting projects as a consultant only. Their role was to carry out geological and hydrogeological investigations and provide advice about site suitability. It was indicated that in the past, little attention has been paid to the hydrogeological investigations when finding landfill sites. For example, in 1990 a landfill site was built in Hanoi in an area with 2 significant underlying aquifers. There was an overlying aquitard that would have provided a certain level of protection against groundwater contamination; however, the material was excavated so that the base of the landfill was in the aquifer. As a result, leachate from the landfill is contaminating the groundwater.

It was indicated that the Department of Geology and Minerals would be able to supply geological and hydrogeological data (maps, reports, etc.) for candidate landfill sites if requested by agencies involved in landfill siting. For areas where hydrogeological data is not available, the department would be able to give advice for landfill siting based on geological surveys. It was also indicated that the function of different government organizations is not clear and there are many overlaps. It was felt that the problem of exchange of information could be resolved if the functions of different government organizations were more clearly defined. In addition, a common mechanism for exchange of information between government agencies would help in resolving the problem.

### *3.7.4 Design, Construction and Operational Aspects*

The most common issues that were indicated as barriers to design, construction and operation of landfill were liners, leachate treatment, and landfill odours.

*Landfill Liners*

It was indicated that choosing a site with suitable soil for a liner is a high priority; however, it was also indicated that sites with natural clay are seldom used. If clay is not available at the site, clay from another area could be imported to build a liner. This option, however, is only feasible if there is a source of clay near the landfill. Construction of clay liners is supervised to ensure that it is done properly, but testing methods and specifications were not known, and are not indicated in the current regulations. Installation of HDPE liners is difficult, as the equipment required to install the liner is not available in Vietnam, and thus proper seam welding is difficult to achieve. In addition, HDPE is not available in Vietnam, must be imported, and is therefore costly.

*Leachate Treatment*

Achieving acceptable levels of leachate treatment is a major problem at current landfill sites. At Hanoi's Nam Son landfill site, a local company was selected to treat the leachate at the landfill because the cost was approximately one quarter the cost of using a foreign company. Unfortunately, the biological treatment methods employed at the site have been unsuccessful at treating the leachate to meet regulatory requirements. Many other landfills in Vietnam use flow through ponds or wetlands to treat leachate, and very little sampling and quality control is applied. The failure to treat leachate in many cases was thought to be due to a lack of funding and a lack of technological resources, both skilled personnel to operate the landfill and methods of treatment.

*Landfill Odours*

Odours are a big problem at most landfills, and are generally the largest concern of residents in the area. Many landfills are sprayed with a chemical called "EM" to control the odours. This product is imported from Japan and none of the interviewees in Vietnam knew what is in it, or what it does. Several interviewees expressed concern with using this chemical, and indicated that they thought it might have negative impacts on water quality. At some landfill sites, trees are planted around the site, and daily cover is used to reduce odour. Landfills located far from residential areas seldom use daily cover. At the Nam Son landfill, lime is used as daily cover because it is less expensive than using a chemical or importing soil.

## 3.8 Data Sources Relating to Water Resources

In order to compare potential landfill sites for suitability in protecting water resources, geological, hydrological, and meteorological data must be collected. To determine the availability of data and the data collection capabilities in Vietnam, government officials from agencies involved in collection of this data were interviewed. This section provides the details of the responsibilities of the agencies and the types of data they are responsible for collecting. It should be noted that in most cases, only one branch of each agency was interviewed, thus, the data available from city to city may vary; however, overall the agencies have the same responsibilities.

*Department of Flooding, Forestry and Fisheries (Da Nang)*

This is a regional level agency, under MARD. In most regions, this agency is called the Department of Agriculture and Rural Development. The main responsibilities of this department are flooding, groundwater and surface water management for the city and surrounding area. In the past, they have not been involved in landfill siting projects in Da Nang. The department indicated that no flood plain maps are available for the area, and that flooding predictions are generally based on estimates from monitoring stations. A past investigation by the Hydrogeology Agency of Southern Vietnam (under the Department of Geology and Minerals) was available. The report contains data for approximately 40 boreholes in the Da Nang and Hoi An area, and topographic maps with basic geological characteristics, wetlands, water bodies, large aquifers, etc. Several other site-specific hydrogeologial investigation reports were available for areas where industrial wells had been installed. A Water Resources Plan exists for the area up to the year 2010. It indicates potential use of water for domestic, agricultural, and industrial purposes. Because this agency was not involved in past landfill siting projects, it is not sure whether this plan is considered when finding new landfill sites. According to the Law of Water Resources, the department is responsible for regulating groundwater at a depth 15 m or more. Domestic wells are generally less than 15 m deep, and therefore do not require permits. As such, the location of all domestic wells is not known; however, periodically, the area is surveyed and the location of domestic wells is recorded. Since industrial wells are generally greater than 15 m and require permits, the locations of these wells are known.

*Hydrometeorological Services of Vietnam (Da Nang)*

The hydrometeorological monitoring center for Central Vietnam is located in Da Nang. There are 9 centers located throughout Vietnam. The center in Da Nang has 41 monitoring stations: 26 for hydrology and 15 for meteorology. Since the center was established in 1975, there are 27 years of data on record. Monitoring stations are located on large rivers only, recording temperature, flow rate, and velocity of the rivers. During the dry season, measurements are take every other day. During the rainy season, measurements are taken much more frequently, up to once every hour. This agency works with DOSTE and the Dept. of Flooding, Forestry and Fisheries to produce flood maps, which show flooding based on past records. The meteorological stations record rainfall, temperature, humidity, wind speed and direction, air quality, and rainwater quality. The occurrence of natural hazards (e.g. typhoons, major storms) is recorded, as well as the path of the storm and the areas affected

*Department of Geology and Minerals*

Several divisions of this department throughout Vietnam are responsible for management of mineral resources and basic geological surveys, including groundwater investigation and monitoring. A nationwide program began in 1992 to collect geological data for all urban areas (class 1 to 5 cities and towns). The program is almost complete, and there are now maps available for urban areas. The engineering geology maps indicate soil or rock type and the location of faults and fractures. In a few areas, site specific projects have been carried out and therefore more detailed data, such as engineering soil properties, are available. There are currently no programs to collect data for rural areas; thus, the data available is much less detailed. All completed reports are sent to the People's Committee in the area. Data are not regularly updated; instead, they are collected as part of a program, as mentioned above or for specific projects.

*Division of Geological and Mineral Resources Survey of Northern Vietnam*

This division of the Department of Geology and Minerals is responsible for geological and hydrogeological investigation and monitoring in northern Vietnam. There are two similar divisions to serve Central and South Vietnam. The division has two main functions: to carry out investigation and monitoring projects as directed by the Ministry of Industry; and to act as a consultant and carry out specific surveys for projects such as landfill siting.

In Northern Vietnam, basic mapping is available (1:50,000 or 1:200,000) for approximately 1/2 to 2/3 of the northern area. The data are based on surveys which involve installing temporary wells, doing pump tests, determining location of aquifers, monitoring seasonal fluctuations, and classifying borehole samples (soil type, chemical and organic content). Projects are ongoing, and it is expected that data will be available for the entire area in the future. To date, the information is based on single surveys, and is not updated. There is no single database of information; it is recorded in reports and on maps.

In 1990, a program was established to create a groundwater monitoring network for the Red River delta. It consists of approximately 200 monitoring wells. Water level in aquifers, fluctuations, and groundwater flow direction are monitored on a daily basis. Water quality is also monitored periodically. Two similar monitoring programs exist, one in the central area and one in the south. An annual report is published with the data from all three monitoring networks. Area-specific projects are sometimes conducted, as requested by People's Committees. For example, in Hanoi, a project was established to model the groundwater in the area. Approximately 120 monitoring wells were installed, and the data collected was used to set up a groundwater model in Visual ModFlow.

The following table provides a summary of the types of data available from the agencies discussed above:

Table 3-1: Summary of Data Sources Relating to Water Resources

| Agency | Data |
|---|---|
| Department of Agriculture and Rural Development (DARD) | ▪ Well locations (greater than 15m deep)<br>▪ Future Water Resources Plans<br>▪ Hydrogeological surveys<br>▪ Topographic Maps |
| Hydrometerological Services | ▪ Meteorological Data – rainfall, temperature, wind, air and rain water quality<br>▪ Record of past major storm events<br>▪ Data from river monitoring stations – flow rates, temperature |
| Department of Geology and Minerals & Division of Geological and Mineral Resources Survey | ▪ Geological data – soil and rock type, location of faults and fractures<br>▪ Groundwater data |

# 4 Objectives, Criteria, Constraints, and Data for Water Resource Protection

This chapter discusses the development of criteria and constraints for landfill siting relating to water resources protection. When siting landfills in lower-income countries, data availability and data collection capabilities must be considered in parallel with setting criteria and constraints. In some cases, it may not be possible to obtain information required to measure how well the candidate sites meet a criterion, and thus, either a surrogate measure must be used, the criterion must be adapted so that it may be measured, or the criterion may not be used at all and the decision must be made without the information. The objectives of developing water resource related criteria in this project were: firstly to ensure that the criteria cover all aspects that should be considered for water resource protection; secondly, that the criteria and data requirements reflect the needs and address important issues in Vietnam. Finally, as much as possible, potential data sources in Vietnam and constraints or regulations relating to the criteria are discussed.

## 4.1 Objectives for Water Resource Protection

In the first step of the landfill siting process, the objectives must be determined, and from the objectives, criteria (sub-objectives) will be established. In relation to the protection of water resource, three major objectives have been identified. They are:

1. *Minimize risk of groundwater contamination* - This is critical for protecting groundwater supplies, and thus public health, in areas where there are water supply well. There may also be underlying aquifers that may be a future water supply source. In addition, groundwater may flow into surface water bodies, thus, creating another potential pathway for contamination, and potential hazard for public health.

2. *Minimize effects on surface water and sensitive areas* – In many areas surface water is used as a source of domestic water (drinking, bathing, etc.), and for agricultural purposes (irrigation and livestock). Surface water contamination by landfill leachate can be harmful to human health and agriculture, and can be transported to areas downstream of the immediate landfill area. As such, the potential for surface water contamination should be minimized.

3. *Minimize construction and operation costs related to water resource protection* – Protecting groundwater and surface water from contamination requires use of landfill liners, and leachate collection and treatment systems. These systems can be costly to construct, operate and maintain.

The following table lists the objectives, criteria, constraints, Vietnamese regulatory requirements, data requirements, and potential data sources in Vietnam as discussed in this chapter.

Table 4-1: Objectives, Criteria, Constraints, and Data Requirements

| Objective | Criteria | Constraints | Vietnam Regulation Requirements | Data | Existing Data Sources in Vietnam |
|---|---|---|---|---|---|
| O1.Minimize Risk of Groundwater Contamination | 1.1 Maximize depth to the water table | The seasonable high water table must be below the base of the landfill | | depth to ground water table and seasonal fluctuations | It is unlikely that the Dept of Geology and Minerals or DARD will have records of site specific groundwater levels, unless a previous study was completed at the site. Estimates of groundwater levels and seasonal fluctuations could be obtained through discussions with local residents who have wells |
| | 1.2 Minimize permeability of underlying geology | Landfills should not be constructed in areas with fractured bedrock, karst topography, etc. to ensure groundwater protection | VOR 01/2001, Appendix 1: for sites with limestone bedrock and large underlying aquifers, a minimum of 1 m of low permeability soil ($k < 1 \times 10^{-7}$ cm/s) and a leachate collection and treatment system is required | soil characteristics: soil type, permeability, porosity, density, organic content, vertical profile; presence of and depth to fractured or porous rock | Department of Geology and Minerals - soil and rock type, vertical profile (borehole logs) are available for some areas. Engineering properties are generally not available. |
| | 1.3 Maximize distance to faults and fractures | | | location of faults and fractures | Department of Geology and Minerals |
| | 1.4 Minimize effect on aquifers | | | location of aquifers, soil permeability and sorption capacity, slope of the groundwater table, groundwater quality, areas of salt water intrusion | Division of Geological and Mineral Resources - In area that have been surveyed, the location of significant aquifers, general groundwater levels and fluctuations, areas of salt water intrusion, and soil type classification is available. |

| | | | | | |
|---|---|---|---|---|---|
| O1.Minimize Risk of Groundwater Contamination | 1.5 Maximize distance to water supply sources and minimize the number of sources in the area | Minimum distances are required by local regulation | VOR 01/2001, Appendix 1 Minimum distance to wells from landfill site | location of wells, future use of groundwater in the area | DARD - location of wells at depth greater than 15 m (typically for industrial purposes) will be recorded, however, location of shallower wells (residential) may not be available; therefore, a survey of the surrounding area may be required. A Water Resources plan for the area will indicate sources and future potential water supply in the area |
| O2. Minimize Effects on Surface Water and Sensitive Areas | 2.1 Maximize distance to surface water bodies and protected areas (rivers, lakes, wetlands, protected forests, etc.) | Areas with water bodies (lakes, streams, wetlands, etc.) or protected areas are not suitable for landfill development | National Wetland Inventory - regulates and protects large ecologically sensitive wetlands | location of surface water bodies, wetlands, protected areas | DARD, Dept. of Geology - topographic maps show locations of water bodies, wetlands, etc. |
| | 2.2 Minimize risk of flooding by maximizing the distance from flood plain and avoiding area susceptible to flooding | | | flood plain mapping | Not Available - The local Hydrometerological Services should have a record of past flood events for large rivers in the monitoring area. |
| | 2.3 Maximize distance to downstream water supply souces, and minimize number of sources | | | use of surface water in the area, future water supply sources | |
| O3. Minimize Construction and Operation Costs | 3.1 Maximize suitability of native soil for landfill liner material. If native soil is not suitable, minimize distance to sites with borrow material | Areas with complex geology are not suitable, as it will be difficult to monitor and implement contingency plans | TCXDVN 261:2001 - Solid Waste Landfill Design Standards - Sites that have natural soil with permeability less than $10^{-7}$cm/s with a thickness greater than 1m do not need HDPE liner. Sites that are built at natural holes, such as mines or mountain creek with bottom elevation higher than ground water level and natural soil having permeability less than $1.5x10^{-8}m^3/m^2$/day do not need impermeable liner. | soil type and permeability; location of and distance to potential borrow site | Department of Geology and Minerals - soil type |
| | 3.2 Minimize surface water diversion requirements | | | catchment area, location of surface water bodies, average slope of the site | DARD - topographic maps showing the location of water bodies |

| | | | | | |
|---|---|---|---|---|---|
| O3. Minimize Construction and Operation Costs | 3.3 Maximize use of existing topography to reduce earth moving requirements | | | average slope of the site | DARD - topographic maps |
| | 3.4 Minimize cost and maximize ease of leachate collection, treatment, and discharge | | VOR 01/2001 - Sec III-3 - There must be two monitoring stations for surface water bodies receiving wastewater discharged from the site. One station must be 15 to 20 m upstream of the discharge and the other 15 to 20 m downstream of the discharge point. If there is a reservoir within 1000 m of the discharge, there must be a monitoring station at the reservoir.<br><br>Standard # TCVN 5945:1995 provides wastewater discharge standards. Note that there are three levels for maximum allowable concentration depending on the use of the receiving water. | leachate treatment standards for leachate discharge near the site; underlying geology - soil type, permeability, sorption capacity, location of fractures; monitoring requirements for surface water bodies where leachate is discharged; estimate of the cost of treating leachate at the site (should include the long term cost of leachate treatment - i.e. for the period of landfill operation and post closure) | Geology - see criteria 1.2 and 3.1 |
| | 3.5 Maximize ease of implementing a monitoring system by avoiding areas with complex geology | | VOR 01/2001 - Sec III-3 - There must 4 boreholes (one upstream and three downstream) for monitoring the groundwater around the landfill site, as well as one borehole in each village near the site. | characteristics of underlying geology, sources of groundwater contamination in the area | Geology - see criteria 1.2 and 3.1 |
| | 3.6 Minimize risk of landfill failure due to natural hazards (e.g. floods, typhoons, earthquakes, landslides, etc.) | Landfill should not be constructed in the floodplain of a river or other areas susceptible to frequent flooding, or in unstable areas. | | Flood plain mapping; dates and magnitudes of past natural hazards (hurricanes, typhoons, floods, tornadoes, etc.) locations of faults, past occurrences of earthquakes, seismic risk; topography, past occurrences of landslides, earthquakes, etc. | Hydrometerolgical Services - monitors and records the occurrence of natural hazards; Department of Geology and Minerals - location of faults, topographic maps |

## 4.2 Criteria

Criteria are sub objectives that are used to measure how well each site meets the above objectives. In addition to criteria, constraints can be used to place restrictions so that sites meet specified minimum levels. The criteria discussed in this section include, directly or indirectly, all criteria suggested in the literature discussed in chapter 2 relating to water resource protection, and additional criteria that emphasise the construction and operational aspects of landfills relating to water resources that are important for landfill siting. Selecting criteria should be an iterative process, and should allow for changes as necessary. Also included in this chapter is a discussion of suggested constraints related to the criteria. The criteria and constraints discussed herein should by no means by taken as a requirement for all landfill siting projects, but rather, should be used as a starting point and a reference for projects, and should be adapted to suit local conditions and requirements.

#### *4.2.1 Objective 1 – Minimize Risk of Groundwater Contamination*

When considering the protection of groundwater, several criteria apply and the following must be addressed: geology of the area, groundwater conditions, and groundwater use in the area. Five criteria are suggested to address these, as discussed below.

*1.1* *Maximize the depth to the water table* – In general, as the distance between the water table and the base of the landfill increases, the potential for water contamination decreases. This of course depends of the geological conditions. The elevation of the water table may fluctuate depending on the season, and thus, the seasonal high level of the water table should be the key level considered. Rushbrook and Pugh (1999) recommend that the seasonably high water table (e.g. 10-year high) be below the base of the landfill, and Diaz and Savage (2002) recommend that the 10-year high water table be at least 1.5 m below the base of the landfill. If leachate ponds or lagoons are to be constructed, their impacts on groundwater must also be considered.

*1.2* *Minimize permeability of underlying geology* – Ideally, sites with low permeability soils should be used for landfills in order to slow the movement of leachate from the site. To provide an adequate liner, soil should have a permeability less than $1 \times 10^{-7}$ cm/s when compacted under field conditions, and should not be susceptible to loss in permeability when exposed to waste or leachate (Rushbrook and Pugh, 1999). Well-compacted clay is one of the most commonly used soils for landfill liners. It should be noted that clay can be fractured, and would thus not provide a suitable liner as fractures provide a pathway for leachate migration. Fractures in clay can be caused by a variety of mechanisms, including historical desiccation and stress relief. The vertical profile of the underlying geology is also of concern, as the presence of fractured or porous rock will provide a pathway for leachate and landfill gas migration. Rushbrook and Pugh (1999) recommend that there should be no underlying limestone, carbonate, or other porous rock formations that would be ineffective barriers to leachate and landfill gas migration, where the formations are more than 1.5 m thick and present in the uppermost geological unit.

1.3 *Maximize distance to faults and fractures* – The presence of faults and fractures in the area of the landfill can provide a pathway for leachate and gas migration, and present difficulties in predicting and monitoring contaminant movement. This criterion differs from 1.2 in that it considers faults and fractures in the area, rather than at the specific site. Rushbrook and Pugh (1999) suggest that there should be no faults or significantly fractured geological structures within 500 m of the perimeter of the landfill.

1.4 *Minimize effect on aquifers* – This criterion differs from 1.1 in that it considers aquifers (current or potential water supply sources) in the surrounding area and the effects a landfill may have on water quality and quantity. In areas where landfills are constructed, reduced infiltration and diversion of precipitation may have an impact on aquifer recharge, especially for shallow aquifers. Shallow aquifers may be more susceptible to contamination because they are closer to the surface. The existing quality of groundwater in the area will determine the value of the groundwater as a resource. If the quality is exceptional, it is an extremely valuable resource, where as, if the quality is poor, it may be less valuable. For example, in coastal regions, groundwater may be saline and not acceptable for domestic or industrial use, thus the requirements for groundwater protection may be reduced. In areas where aquifers are or will be used for water supply, the impacts of landfill construction on the aquifer should be thoroughly considered. Rushbrook and Pugh (1999) recommend that landfills should not be located in areas within the 10-year groundwater recharge area for existing or pending water supply development. They also suggest that designated groundwater recharge or sole source aquifer should be excluded from the area of potential landfill sites.

1.5 *Maximize distance to groundwater supply sources, and minimize the number of sources in the area* – Water supply wells down gradient of the landfill should not be affected. This is particularly important if there is no alternative water supply available in the event of contamination. The number or density of wells down gradient of the landfill should also be considered, as the impacts of groundwater contamination will increase as the number of wells increases. The Vietnamese

Joint Circular (01/2001) outlines the minimum distance from the boundary of a landfill to wells of various capacities.

#### *4.2.2 Objective 2 – Minimize Effects on Surface Water and Sensitive Areas*

Three criteria are suggested to assess the suitability of a site for minimizing the risk of surface water contamination and the effects on sensitive areas. They are:

*2.1* *Maximize the distance to surface water bodies and protected areas* – In general, the greater the distance between the landfill and lakes, rivers, wetlands, etc., the lower the risk of contamination. Protected areas may include wetlands, forests, areas with protected species, etc., and may vary locally. Landfills should not be located at water bodies (this can be applied as a constraint) and a safe distance between the water body and the perimeter of the landfill should be established. For example, Diaz and Savage (2002) recommend that waste should not be placed into environmentally important wetlands with significant biodiversity, and the perimeter of a site should not be located within 250 metres of protected forests. The site should be selected so that no known living or breeding areas of environmentally endangered or rare species are present within the site. Diaz and Savage (2002) also recommend the following minimum distances: 200 metres around ponds, marshes and swamps; 250 metres from flowing bodies of water less than 3 metres wide; 300 metres from flowing bodies of water greater than or equal to 3 metres wide. A safe distance may change from site to site depending on topography, use of the water body, etc. and should be adapted to meet local requirements.

*2.2* *Minimize risk of flooding by maximizing the distance from the flood plain and avoiding areas susceptible to flooding* – The potential for flooding at a site is an important consideration as floods can cause water contamination and increase the risk of landfill failure. Rushbrook and Pugh (1999) recommend that sites should not be located in the 10-year floodplain, and sites located within the 100-year floodplain must be amenable to an economic design that eliminates the potential for washout. Diaz and Savage (2002) recommend that landfills should not be located in the 25-year floodplain, with the same suggestion for sites located in the 100-year floodplain. The 10-year, 25-year, or other appropriate floodplain level can be applied as a constraint. In addition, low lying areas that are subject to frequent flooding should be avoided.

2.3 *Maximize distance to downstream water supply sources and minimize the number of water supply sources* – This criterion is similar to the criteria applied for groundwater supply sources. Again, landfills should not be sited upstream of water supply sources especially if there is no other source available in the event of contamination. This is most applicable in cases where leachate will be discharged into rivers or streams, and could have potential impacts downstream.

### *4.2.3 Objective 3 – Minimize Construction and Operation Costs Related to Water Resource Protection*

Six criteria that can be used to indicate site suitability for minimizing construction and operation costs relating to water resources are:

3.1 *Maximize suitability of native soil for landfill liner material. If native soil is not suitable, minimize distance to sites with borrow material* – Selecting a site with native material that is suitable for use as a liner is both convenient and less costly than construction of a liner. If the native material is not suitable, offsite material can be used to construct a liner at the site. Obviously, the cost of transportation of the material to the site is important, and as the distance increases, the cost will increase. A suitable liner material is clay or silty clay of low permeability (e.g. $10^{-7}$ cm/s or less) and must be able to support the weight of overlying material. Artificial liners, such as high-density polyethylene (HDPE), can also be used; however, the availability of material in the area, requirements for installation and cost must be fully considered.

3.2 *Minimize surface water diversion requirements* – Diversion of small surface water bodies increases construction costs, as does the amount of runoff that must be controlled at the site through the construction of ditches. Drainage ditches also require maintenance to control the accumulation of debris and maintain water flow. The position of the site in the watershed, and the size of the area upstream will affect the amount of runoff at the site. Areas with high slopes may have higher runoff potential, and thus require higher runoff management requirements.

3.3 *Maximize the use of existing topography to reduce earth moving requirements* – Since leachate collection systems require a minimum gradient of 2%, gently sloped sites (e.g. 3 to 5%) are preferred. This will reduce the amount of earth moving required during landfill construction, thereby reducing the overall costs.

3.4 *Minimize cost and maximize ease of leachate collection, treatment, and discharge* - Since installing and operating a leachate collection and treatment system can be very costly, a preliminary leachate management strategy should be used to compare the costs for candidate sites. Leachate quantities can be estimated using a climatic water balance (see Appendix A.3 for more details). Regulatory requirements, such as leachate discharge standards and surface water body monitoring requirements must be considered. The type of leachate treatment system to be used and the operation costs, during the operation of the landfill as well as post closure, and technical requirements must be thoroughly considered.

3.5 *Maximize ease of implementing a monitoring system* - Landfill sites need to incorporate a monitoring system to enable failure of environmental controls, and thus contamination, to be detected. The location of the landfill should allow for the construction of a monitoring system to detect pollutants, and for their containment and management in the event of releases. Areas with complex geology and groundwater conditions, such as karst topography (soluble limestone, presence of underground streams, caverns, etc.) may be difficult to monitor, and in the event of contamination, difficult to remediate.

3.6 *Minimize risk of landfill failure* – Since landfill failure can be costly to remediate and can cause significant environmental damage, effects of natural hazards (floods, landslides, earthquakes, storm events, etc.) and the costs associated with constructing landfills to withstand such events should be considered. Areas prone to subsidence (e.g. due to dissolution of limestone and the formation of sinkholes), areas with collapsing soils (loess) and areas with high slopes (high risk of erosion and potential failure) may not be suitable for landfill construction.

### 4.3 Interrelationship between Criteria

Many of the criteria outlined above are interrelated and satisfying one criterion may result in another criterion being satisfied, or may make another criterion less important. For example, if the soil at the site is a low permeability clay, the depth to the water table may become less important in deciding site suitability, provided that the constraints, or minimum criteria (e.g. seasonably high water table is 1.5 m below the base of the landfill) are met. A site with a low permeability clay soil satisfies two criteria – 1.2 and 3.1 - which both relate to permeability of underlying soil; in 1.2 for the protection of groundwater resources, and 3.1 liner construction costs. Another example is the relationship between 2.2 and 3.6, which both consider floods, the former relating to water quality, and the later to landfill stability and construction requirements. Due to overlaps in the criteria, there are also overlaps in data requirements. For example, for criteria 2.2 and 3.6, the location of flood plains is required. Although there is overlap between criteria, the purpose for using all of them is to ensure that all aspects related to water resource protection are considered.

## 4.4 Constraints

Constraints are conditions that make an area unsuitable for landfill construction, due to regulatory requirements (e.g. standards), physical requirements, or to ensure minimum levels of the landfill siting criteria as discussed above. Constraints relating to water resource protection are summarised below.

- The seasonably high water table must be below the base of the landfill.
- Landfills should not be constructed in areas with fractured bedrock, karst topography, etc. to ensure groundwater protection
- Areas with complex geology are not suitable as it will be difficult to monitor and implement contingency plans
- Water bodies and protected areas (lakes, streams, wetlands, etc.) are not suitable for landfill development
- Landfill should not be constructed in the floodplain of a river or other areas susceptible to frequent flooding, or in unstable areas.

This list is by no means exhaustive, and additional local constraints, specific to the region undertaking the landfill siting process and regulatory constraints may be required. Known regulatory constraints for Vietnam are the minimum distances outlined in Joint Circular 01/2001. The minimum required distances from wells is outlined in the following table.

Table 4-2: Minimum distance from wells, as required by Joint Circular 01/2001

| Capacity ($m^3$/day) | Minimum Distance (m) | | |
|---|---|---|---|
| | Small – Medium Landfill Site (10-30 ha) | Large Landfill Site (30-50 ha) | Very Large Landfill Site (≥ 50 ha) |
| < 100 | 50-100 | >100 | >500 |
| <10,000 | >100 | >500 | >1,000 |
| >10,000 | >500 | >1,000 | >5,000 |

It should be noted that ensuring the minimum distance from wells does not ensure that the wells will not be impacted by the landfill, as this is highly dependent on local hydrogeological conditions. As such, minimum distances should be used for constraint mapping purposes, and the further analysis of the potential impacts of a landfill on surrounding wells should be conducted as part of the site investigation.

## 4.5 Data Requirements

Data availability is one of the key requirements for site comparison. The difficulty in comparing sites based on suitability for water resource protection is that there is a large variety of geologic and hydrogeologic conditions and it may be difficult, time consuming, and expensive to investigate all areas. In order to ensure that the appropriate data are collected and to avoid collecting unnecessary data that can waste both time and money, a method that enables the strong and weak points of a site to be highlighted is required. This is in part established by setting criteria that can be measured based on readily available data, obtained from published sources and walkover surveys. This type of data includes the location of surface water bodies, wells, protect areas, site topography, etc. There are however, important criteria, specifically relating to geological and hydrogeological conditions that require site-specific data. As this type of information is typically not readily available in most areas, an effective strategy for site investigation and data collection is required. This subsection outlines data requirements and provides guidance for key data to be collected.

Table 4-1 includes a list of data requirements for each of the criteria outlined above. Some of the data listed, such as location of water bodies and water supply sources do not require further discussion, as this information should be easily obtained. Data such as past storm events will either be recorded and available, or not. In the later case, sites will have to be compared without this information. Other data requirements, however, are critical for indicating site suitability. These may not be available or may be costly or infeasible to obtain, and thus require further discussion. They are:

- *Location of the water table* - Seasonal fluctuations in groundwater levels are common in many regions. It is the high position of the water table that is of concern when assessing the groundwater contamination potential of a landfill site. The greater the distance from the base of the landfill to the groundwater table, the more favourable the site (LeGrand, 1980). Site-specific water table data can be determined from a site investigation; however, as it is not likely that past water table elevations will be available, this information will have to be inferred from other sources. Rainfall records may provide an indication of whether the current and past seasons have been average or above or below average. For example, if the past several years have been drier than average, the current location of the water table may be lower than usual. Local residents who have wells may also be able to provide an indication of seasonal fluctuations in the water table.

- *Characteristics of underlying geology* – Knowledge of the underlying geology at the site is very important; however, site-specific geological data is not typically available, and thus must be found from site surveys. Permeability and sorption of the underlying material provide an indication of the amount of natural protection there is against contamination of underlying groundwater. Permeability provides an indication of the rate at which contaminants can move through the subsurface, and sorption capacity provides an indication of the natural attenuation capacity of the soil (LeGrand, 1980). Other important characteristics include: soil types, thickness of geological layers, and depth/thickness of aquifers. In many areas, general information regarding the type of soil or bedrock present at a site may be available. This information may be sufficient for area screening; however, when potential candidate sites are being compared it is recommended that a site investigation be conducted to confirm the geological characteristics of the site.

- *Approximate slope of the water table*: The slope of the water table will indicate the direction of groundwater flow, and thus the area of potential groundwater contamination. It is important to note that if the slope of the water table is very low, or if mounding of the water table occurs, there may be radial flow of contaminated groundwater (LeGrand, 1980). Again, it is not likely that this information will be available for specific sites. Installation of wells can aid in determining the direction of groundwater flow. The wells can be used for several purposes – to determine the depth to the water table, direction of groundwater flow, obtain samples of underlying material, and obtain water samples to test water quality.

- *Location of floodplains*– Typically, floodplain maps are used to determine the potential for flooding; however, in some areas, floodplain maps may not be available. In this situation, the potential for flooding can inferred from past records of flood events, or from discussions with residents in the area of the landfill.

Further to this list of key hydrogeologic factors are data that are required in order to formulate preliminary leachate management strategies for candidate sites. A leachate management strategy should include options for leachate collection, treatment and discharge. Leachate treatment options will depend on what methods are most feasible for the area. This requires knowledge of methods that have been successfully employed in other areas for leachate treatments, the approximate cost of these methods, etc. Factors that affect leachate treatment requirements, such as the standards that must be met for discharge to a specific water body, must also be considered. The relation of the leachate management strategy to the other criteria will become important when the criteria are weighed in the decision making process. For example, if it is decided that the best leachate management strategy is to "attenuate and disperse" leachate (this may be the best option for a small landfill with limited financial and technical resources) then criteria such as low permeability soil with a high sorption capacity, and maximizing the distance from wells, aquifers, and surface water bodies may be most important.

When the candidate site comparison step of the process is reached, the sites must be compared based on the criteria and data collected. The decision made will be depend on the importance placed on the criteria, and the conceptual designs for the sites. In some cases, there may be data that are not available to measure all criteria, and thus decisions must be made based on the information that are available. Also at this stage, tradeoffs must be made between sites for various criteria. For example, a tradeoffs may occur when one site is located a further distance from the city, and thus has an increased transportation cost, but has native soil suitable for a landfill liner, thus decreasing the construction costs and increasing groundwater protection compared with other sites.

Applying criteria and data and discussing tradeoffs is best shown by examining an illustrative example. The following section presents a landfill siting situation, and discusses the steps involved in the landfill siting process.

## 5 Illustrative Example

This chapter illustrates the landfill siting process described in section 2.1.3 with a hypothetical example. A city in Vietnam with a population of 250,000 people has a landfill that is expected to close in 5 years. It has been decided that the best alternative for waste management is disposal in a landfill site; as such, a new site must be selected.

### 5.1 Step 1: Identify Site Requirements, Objectives, Criteria, and Constraints

To determine the required landfill capacity, the amount of waste generated over the period of operation of the landfill must be determined. This must account for increases in population and waste generation rates over the operating period of the landfill. Based on government regulations, landfills must be designed to accept waste for least 25 years. If the current waste generation rate in the city is 0.4 kg/cap/day, and it is expected that the waste generation rate will increase by 3% per year, and the population by 2% per year, the following formula can be used to determine the amount of waste generated each year:

Total yearly waste generation = $(P_o*(1+i)^n)*(W_o*(1+g)^n)$

where $P_o$ is the initial population, i is the rate of population growth, $W_o$ is the initial waste generation rate (kg/cap/year), g is the rate of increase in waste generation, and n is the year. Summing the amount of waste generated each year will give an estimate of the total amount of waste generated over the operating life of the landfill. Using this method and the above data, the total volume of waste generated over 25 year is estimated to be 1,900,000 tonnes. If the average waste density, after compaction in the landfill is approximately 500 $kg/m^3$, an estimate of the total volume of waste is 3,800,000 $m^3$. The total volume of the landfill is the volume of the waste plus the volume of cover material. If it is assumed that the cover material accounts for 15% of the total volume, then approximately 4,370,000 $m^3$ is required. If it assumed that the average height of waste in the landfill is 20 m, then an area of 22 ha. is required. If instead, the average height of waste is 10 m, then 44 ha is required. In addition, the area of the landfill site must also include space for buildings, access roads, leachate treatment facilities, buffer zones, etc. Thus, in total, approximately 30 – 50 ha are required. According to the Vietnamese landfill guidelines, a medium landfill classification has a current urban population is between 100,000 and 300,000 and a landfill site area is between 10 and 30 ha. A large landfill classification has a current urban population between 300,000 and 1,000,000 people, and a required site area between 30 and 50 ha. The later classification will be used for this case study, as the above described scenario better fits this category.

### *5.1.1 Objectives, Constraints and Criteria*

The local government agencies have limited financial resources for construction of the landfill and a small operating budget. As such, one objective is to minimize the construction and operating costs of the landfill. In addition, the city gets their drinking water from a large underlying aquifer, and is concerned about the potential for groundwater contamination. As such, protection of water resources is a key concern.

Based on the government regulations, selection of a landfill site must consider the environmental, socio-economic and infrastructure factors, as well as minimum distances from urban areas, water supply wells, airports, etc. outlined in the regulation. The three objectives and the criteria identified in chapter 4, with the focus on water resources, are used to guide the landfill siting process. Additional criteria will also be used to provide an indication of how well a site minimizes construction and operating costs. These additional criteria are as follows:

- Minimize travel distance
- Minimize distance from a suitable access road to the site

Although other socio-economic and infrastructure criteria should be considered in detail in a real case, they are not discussed in detail in this example.

Figure 5-1 is a map of the search area, and the location of the city boundaries, water bodies, roads, etc.

## 5.2 Step 2: Site Screening and Identification using Constraint Mapping

To identify suitable areas, the following criteria will be used in constraint mapping:

- Landfills should not be constructed in areas with fractured bedrock, karst topography, etc. to ensure groundwater protection
- Water bodies (lakes, streams, wetlands, etc.) are not suitable for landfill development
- Areas with complex geology are not suitable as it will be difficult to monitor and implement contingency plans
- Landfills should not be sited in protected areas such as forests, wetlands, protect species habitats.
- Landfill should not be constructed in the floodplain of a river or other areas susceptible to frequent flooding.
- Areas that are within the minimum distance as required in regulations are not acceptable (for a large size landfill):
    - 5,000 – 15,000 m from urban regions
    - 2,000 – 3,000 m from airports, industrial zones, seaports
    - At least 1000m from small communities (> 5 households) if they are downwind of the landfill, and at least 300 m if they are not downwind
    - >100 m from wells with a pumping rate < 100 $m^3$/d
    - >500 m from wells with a pumping rate < 10,000 $m^3$/d
    - >1000 m from wells with a pumping rate > 10,000 $m^3$/d
- Areas greater than 3 km from an access road will not be considered

The constraints are used to identify unsuitable areas based on published data, such as topographic maps, geological maps, aerial photographs and official development and zoning plans. Constraint mapping is carried out to create a series of maps that show the areas identified as unsuitable for landfilling based on the constraints. When the maps are overlaid, the potential areas can be easily identified. It should be noted that if the constraint mapping process fails to identify potential areas for landfill sites then search area must be increased, or the constraints must be relaxed, or both. Similarly, if constraint mapping identifies too large of an area that may be difficult to screen and identify potential sites, further constraints can be applied. Figure 5-2 shows a map of the area with the above constraints applied. Areas that are not shaded meet all of the constraints and are therefore considered potentially suitable for landfill sites.

## 5.3 Step 3: Site Screening and Identification

Within these areas there may be many potential sites depending on amount space required for the landfill. The objective of this step is to reduce the number of sites to an appropriate number for detailed comparison in the next step.

From constraint mapping, 8 areas have been identified, as shown in figure 5-2. It can be seen that the potential areas available for landfilling are quite large, and thus, further constraints will be applied to further reduce the search area. Local authorities have decided to limit the search to areas that are within 25 km travel distance by road from edge the city to lessen transport costs, and exclude all highly productive agriculture land. Since areas 1,2 and 6 are greater than 25 km by road from the city boundary, and they will not be considered, unless a suitable site cannot be found in the other areas. Area 9 and parts of area 7 have been identified as a highly productive agriculture area, thus, not suitable for landfill development.

Published data and field walkover surveys were used to identify seven potential sites. General information for these seven sites is summarised in table 5-1. These sites were compared, and three potential sites, A, B, and C were identified as candidate sites to be compared in detail. Site D was removed from further consideration because of the travel distance, and the topography of the area. Site E and G were removed because of the soil conditions at the site, topography, and/or proximity to surface water bodies. Finally, site F was removed because of the proximity to the city boundaries and the potential impacts on future city development.

Table 5-1: Comparison of potential sites

| | Site A | Site B | Site C | Site D | Site E | Site F | Site G |
|---|---|---|---|---|---|---|---|
| Geology | Sand | Clay | Clay | Silt | Sandy Gravel | Clay | Sand |
| Travel Distance | 15 km | 12 km | 13 km | 24 km | 20 km | 7 km | 18 km |
| Land Use | Low productivity agriculture | Unused land | Low productivity agriculture | Unused land | Old quarry | Unused, potential city growth area | Low productivity agriculture |
| Topography | Flat | Flat | Flat | Hilly, high slopes | Valley | Flat | Hilly |
| Distance from access road | 500 m | 1.2 km | 100 m | 1.8 km | 700 m | 1.5 km | 1.2 km |
| Distance from water bodies | 2.5 km to river | 8 km | 1 km | 700 m | 1 km | 1.2 km | 500 m |
| Distance from water supplies | None in the area | 2 km to wells | 10 km to downstream water supply | None in the area | 4 km to downstream water supply | 1 km to city wells | None in the area |

The locations of the three candidate sites, A, B and C are shown in figure 5-3, and a more detailed description of the sites is as follows:

Site A:

- Located 15 km from the city boundary, 500 m from a suitable access road
- Sandy soil
- There is an area approximately 20 km by road with clay soil that would be suitable for a landfill liner
- A major river is located 2.5 km south of the site
- A small stream, which is dry during the part of the year, flows across the site boundary, and eventually into the river
- Located in a low lying area, average slope of the site is 3-4%
- Based on 30 years of flood monitoring, the area has been flooded once
- The site area is approximately 80 ha.

Site B:

- Located 12 km from the city boundary, 1.2 km from a suitable main road
- Clay soil with and underlying sandy aquifer
- 1500 m east of the site is small community
- 2000 m east of the site there are several wells used for domestic water supply for the community
- There is an forested area
- The area is relatively flat, and the average slope at the site is 2-4%
- The site area is approximately 75 ha.

Site C:

- Located 13 km from the city boundary, 100 m from a suitable main road
- Clay soil
- Located 1000 m east of a river that is used for irrigation, livestock watering, and bathing of local residents downstream.
- The average slope at the site is 5- 7%
- The site area is approximately 60 ha.

## 5.4 Step 4: Site Investigation and Conceptual Design

In this step, site investigations are conducted to verify published data, and collect data required to measure criteria and complete conceptual designs. The following table summarises the data collected from site investigations and published sources:

Table 5-2: Data collected from Site Investigation

| Type of Data | Site A | Site B | Site C |
|---|---|---|---|
| Underlying Geology | $1^{st}$ layer – 6 m of sandy gravel<br>$2^{nd}$ layer – 3 m of silt<br>$3^{rd}$ layer – bedrock | $1^{st}$ layer – 6 m of silty clay<br>$2^{nd}$ layer – 6 m sandy aquifer<br>$3^{rd}$ layer – silty clay | $1^{st}$ layer – 3 m of low permeability clay<br>$2^{nd}$ layer – 9 m sandy silt |
| Permeability of soil | Sandy gravel – not tested | Silty clay – $1*10^{-7}$ cm/s | Clay – $1*10^{-9}$ cm/s |
| Location of water table | 4 m below ground surface | 5 m below ground surface | 2 m below ground surface |
| Direction of groundwater flow | South, towards river | East | West toward river |
| Distance from 10-year floodplain (estimated from past flood records) | 1500 m | 5000 m | Unknown – no monitoring stations in this area |
| Groundwater quality at site | Good | Excellent | Excellent |
| Distance to surface water bodies | 2.5 km to river, small stream located at the site | 8 km from river | 1000 m from river<br>1300 m from wetland<br>4000 m from lake |

Conceptual designs are completed for each of the three sites up to the point where they can be used for cost estimate purposes. Design considerations for each of the sites are discussed below.

Site A:

- Construction of the landfill liner will require importing clay from 20 km away. The groundwater table is 4 m below the ground surface, and is likely to have significant seasonal fluctuations, due to the sandy soil with underlying silty clay. As such, the base of the landfill should not be much below the current ground surface elevation.
- A 500m access road will need to be constructed to the site.
- The average slope of the site is 3-5%, thus little earth moving should be required at the site.
- The small stream would have to be diverted away from the site.
- The area has been flooded once in the past 30 years, so the design must ensure that risk of landfill failure due to flooding is minimized.

Site B:

- The native soil is suitable for a landfill liner. Caution should be taken if the base of the landfill is to be below the current ground surface level because there is a shallow, confined sandy aquifer below the clay layer, and the water table is shallow.
- The existing topography is suitable for landfill development; thus, the earth moving requirements at the site should be minor.
- A 1.2 km access road will need to be constructed to the site.
- Since the groundwater flow is toward the wells in the area, they may be at risk of contamination from the landfill, and groundwater sample must be tested often. In addition, another source of water must be made available for the community in the event of contamination.

Site C:

- The native soil is suitable for a landfill liner, the base of the landfill should not be located below the ground surface because of the shallow water table.
- A 100m access road must be constructed to the site.
- There is no information available about flooding at the site; however, it is located within 1000 m of a river.
- Since average slope at the site is 5-7%, site grading will be required in order install a leachate collection system.

## 5.5 Step 5: Site Comparisons and Selection

In the final step, the criteria are used to compare the candidate sites. The data collected and the conceptual designs are used to provide an indication of how well a site meets the criteria, and each site can be rated, in this case as poor, fair, good, excellent, for each criterion.

Table 5-3: Site Comparison Matrix

| Number | Criteria | Site A | Site B | Site C |
|---|---|---|---|---|
| 1.1 | Maximize depth to the water table | Good | Good | Fair |
| 1.2 | Minimize permeability of underlying geology | Poor | Good | Excellent |
| 1.3 | Maximize distance to faults and fractures | Excellent | Excellent | Excellent |
| 1.4 | Minimize effect on aquifers | Good | Poor | Good |

| Number | Criteria | Site A | Site B | Site C |
|---|---|---|---|---|
| 1.5 | Maximize distance to groundwater supply sources and minimize the number of sources in the area | Excellent | Poor | Excellent |
| 2.1 | Maximize distance to surface water bodies and protected areas (rivers, lakes, wetlands, protected forests, etc.) | Good | Excellent | Poor |
| 2.2 | Minimize risk of flooding by maximizing the distance from flood plain and avoiding area susceptible to flooding | Good | Excellent | Unknown – assumed fair because of proximity to river |
| 2.3 | Maximize distance to downstream water supply souces, and minimize number of sources | Excellent | Excellent | Fair |
| 3.1 | Maximize suitability of native soil for landfill liner material. If native soil is not suitable, minimize distance to sites with borrow material | Poor | Good | Excellent |
| 3.2 | Minimize surface water diversion requirements | Fair | Excellent | Excellent |
| 3.3 | Maximize the use of existing topography to reduce earth moving requirements | Excellent | Excellent | Good |
| 3.4 | Minimize cost and maximize ease of leachate collection, treatment, and discharge | Good | Good | Fair |
| 3.5 | Maximize ease of implementing a monitoring system by avoiding areas with complex geology | Excellent | Fair | Excellent |
| 3.6 | Minimize risk of landfill failure due to natural hazards (e.g. floods, typhoons, earthquakes, landslides, etc.) | Fair | Excellent | Unknown – assumed fair because of proximity to river |

The site comparison matrix allows the tradeoffs for each site to be identified. For example, since Site A does not have suitable soil for a liner it requires a liner to be constructed; however, there are no sources of water supply in the area (wells, or surface water supply) that are at risk of contamination. Site B, however, has suitable soil for a landfill liner, but is located in an area with an underlying aquifer that supplies water for a small community. Thus, a tradeoff exists between construction costs for the liner and the potential risk of contamination of a water supply, as shown in Table 5-3 by criteria 1.2, 1.5, and 3.1. Weighing the tradeoffs, and choosing the “best” site will depend on how well the sites meet other criteria (social, land use, etc.) and the priority given to certain criteria, which will differ depending on priorities in the area.

# 6 Conclusion and Recommendations

Siting landfills in low-income countries is a challenging task. Generally, financial, technical, and human resources are limited, thus making it difficult to construct and operation landfills that meet high environmental standards. Water contamination is one of the largest negative environmental impacts from landfills, and the construction and operation of leachate systems is costly and difficult in low-income countries. As such, one of the key aspects of improving landfill practices is the protection of water resources and this must be addressed in the landfill siting process. In Vietnam, new standards and guidelines have been introduced for siting, constructing, and operating landfills to address the environmental impacts associated with landfilling. This has provided a starting point for improvements in landfill practices within the country; however, a detailed, practical process for landfill siting is required in order to ensure that appropriate sites are selected. This project has outlined a landfill siting process and water resource related criteria that are applicable for use in Vietnam and meet the current regulatory requirements.

The following is a set of recommendations for changes or additions to the landfill siting process in Vietnam that will increase the protection of water resources.

1. A step by step process landfill siting process should be adopted and described in detail in the landfill regulations. The process outlined in this report should be used as a starting point, with additional steps, or a parallel process included to address other aspects of landfill siting (e.g. social issues and public participation). The use of a screening process, such as constraint mapping, is highly recommended for identifying potential sites. Finally, considering landfill siting and landfill design in parallel is recommended to allow design tradeoffs to be recognised during the siting process.

2. A detailed set of criteria and constraints should be established. The criteria developed in the report should be used. The additional non-water resource related factors listed in the Joint Circular 01/2001 should be used to develop further criteria and constraints in order to have a complete set of criteria and constraints that can be used for agencies siting landfills.

3. A form of graded standards or minimum acceptable criteria should be considered - It must be recognised that not all areas will be able to meet high design and construction standards; however, this does not mean that they will not be able to meet some level of environmental standards. Graded standards, or minimum

acceptable criteria, along with guidance on criteria for selecting landfill sites that provide natural environmental protection should be considered. In addition, emphasis should be placed on finding sites that provide natural environmental protection during the siting process.

4. Guidelines for developing a leachate management strategy should be included in the landfill regulations. The guidelines should provide local agencies with information about potential contamination problems and appropriate leachate treatment options.

5. Agencies involved in management of water resources and geological surveys should be involved in or consulted throughout the landfill siting process. These agencies have employees knowledgeable in hydrology, hydrogeology, and geology, and are responsible for the administrative management of water resources. As such, they should be consulted and involved in decisions surrounding site suitability for water resource protection. In addition, a mechanism for sharing information and data among agencies should be developed to ease the collection of data for landfill siting.

6. Geological and water resource data collection programs should be reviewed and updated to ensure that sufficient information is being collected and will be available for future use. For example, floodplain mapping is not available but is important for deciding site suitability. Geological data collected through surveys may not be suitable for site comparison purposes (e.g. mineral resources information rather than engineering properties) thus requiring further expenditures for data collection.

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# 8 APPENDICIES

### A.1 Landfill Siting Criteria adapted from Diaz and Savage

Adapted from: Diaz, Luis F. and Savage, George M. "Developing Landfill – Guidelines for Sites in Developing Countries", Waste Management World, July-August 2002.

The following is a list of water resource protection related criteria they suggest:

- The location of the landfill should allow for the construction of a monitoring system to detect pollutants, and for their containment and management in the event of releases.
- Landfills should not be located in areas where there are sinkholes, disappearing streams and caves, as these features threaten containment or monitoring of the leachate, as well as the required level of performance of the leachate control system.
- Landfills should also not be sited on unstable soil or bedrock, as instability may cause the leachate and gas management systems to fail. Ideally, landfills should be sited in areas with clay soils, and in a location where the slope of the natural terrain is greater than 3%.
- The ten-year high level of the groundwater should be at least 1.5 metres below the base of the fill or of any planned excavation
- The existing soils should have relatively low permeability, i.e. $10^{-6}$ cm/sec or lower
- The site should not be within or near the ten-year groundwater recharge area for current or future water supply development
- No type of porous rock formations (such as carbonate and limestone) should be part of the uppermost geologic layer, as these types of rock would not be barriers to gas or leachate migration
- The site should not be located within a flood plain that may be subject to 25-year floods. If the site is located within a 100-year flood plain, it should allow for a financially feasible design that would eliminate washout.
- Landfills should not be sited where there is significant risk of seismic activity; there should be no fault lines or fractured geologic structure within 500 metres of the site's perimeter.
- Public or private water supply wells (whether for drinking, irrigation or animal rearing) should not be located within 500 metre downgradient (hydraulic) from the perimeter of the landfill site. Furthermore, the site should not be located within 30 metre downgradient of a perennial stream unless channels or culverts are used to contain the body of water, and these options prove environmentally and financially acceptable.
- Waste should not be placed into environmentally important wetlands with significant biodiversity, neither should the perimeter of a site be located within 250 metres of protected forests. The site should be selected so that no known living or breeding areas of environmentally endangered or rare species are present within the site boundaries. The following minimum distances are recommended for other types of area:
    - 200 metres around ponds, marshes and swamps
    - 250 metres from flowing bodies of water less than 3 metres wide
    - 300 metres from flowing bodies of water greater than or equal to 3 metres wide.
- The landfill boundary should be at least 150 metres from a marine shoreline.

For data collection, the following is suggested as a minimum for investigation of hydrogeological conditions:

- Conditions beneath the waste fill area and the leachate management system should be defined

- Conditions beyond the waste fill area and within the area that will contain the leachate management system should be defined

- The zone of continuous saturation should be defined

- Any additional aquifers used locally as major sources of water supply.

A first-phase hydrogeologic evaluation should include:

- Description and discussion of existing information, including:
  - soils
  - topography
  - groundwater level
  - vegetation
  - climate
  - maps and photos of the site
  - seismic conditions, including the location of faults near the potential site

- Report should also include (where possible)
  - geologic columns
  - cross-sections
  - direction of groundwater flow
  - inventory of all active and abandoned wells within 2 km of the site.

A second phase hydrogeologic evaluation should include:

- Description of the properties and distribution of the earthen materials underlying the site and groundwater conditions beneath the site

- At least two soil borings should be performed per hectare, to define the site's soil and bedrock conditions, with additional borings performed where necessary.

- The soils and bedrock should be described and classified, and the permeability of the soils of the site determined.

A third phase hydrogeologic evaluation should include:

- Design and installation of the groundwater monitoring system should be designed and installed. The monitoring system should address the hydrogeologic conditions identified in the second phase.

A fourth phase evaluation should include:

- Collection and interpretation of information on water quality from the monitoring system

### A.2 Landfill Siting Criteria adapted from Rushbrook and Pugh

Adapted from: Rushbrook, P. and Pugh, M., "Solid Waste Landfills in Middle- and Lower-Income Countries: A Technical Guide to Planning, Design, and Operation", World Bank Technical Paper No. 426, The World Bank, Washington, D.C., 1999

| **Area Exclusion Criteria Applicable Worldwide** | |
|---|---|
| *Aspect* | *Criteria* |
| Transport | T1. More than 2 km from a suitable main road<br>T2. More than an economic travel distance from points of origin of waste collection vehicles |
| Natural Conditions | N1. Flood plains or other areas liable to flooding<br>N2. Extreme morphology (steep or over-steep slopes liable to landslips or avalanches |
| Land Use | L1. Designated groundwater recharge, sole source aquifer or surface water catchment areas for water supply schemes<br>L2. Incompatible future land use designations on or adjacent to the site, particularly hard (built) development or mineral extraction<br>L3. Within a military exclusion zone |
| Public Acceptability | P1. Within 200 m of existing residential development (this minimum distance may be larger in some places due to political, geological or social requirements) |
| Safety | S1. Within 5 km of an airport run way in the direction of approach and take-off<br>S2. Area of former military activity where buried ordinance may be present<br>S3. Within a microwave transmitter exclusion zone<br>S4. Within a safe buffer distance (say 100 m) from an existing or planned quarry which will undertake blasting with explosives<br>S5. Areas known to contain collapsing soils, such as loess |
| **Area Exclusion Criteria Subject to Local Interpretation** | |
| *Aspect* | *Criteria* |
| Natural Conditions | N3. High or seasonably high water table<br>N4. Karstic or geologically faulted areas, or areas containing mine workings, where leachate may migrate rapidly from the site to a potable aquifer<br>N5. Wetlands (swamps or marshes) or other areas of ecological significance |
| Public Acceptability | P2. Within an acceptable distance (desirable minimum distance 200 m) from historical, religious or other important cultural site heritage |

#### Checklist for Walkover Survey

*Transport Aspects*

- To what point is all weather access presently available?
- How long does it take to travel from the urban area to the nearest accessible point to the site?
- How far (by new or upgraded road) is the site from this point?
- Will vehicles be able to gain access to all parts of the site (via site roads)?
- Will access be unusually expensive to provide (large or long embankments, bridges, cuttings)?

*Natural Features*

- Is the site presently well drained?
- Are there established watercourses within or adjacent to the site?
- Is there evidence of ephemeral streams, springs, or sinkholes?
- Can high water table be inferred from the vegetation anywhere on the site?
- Are surface water diversions likely to be extensive, considering the extent of the catchment?
- From knowledge of the geology of the area, does the morphology of the site suggest significant or minimum depth of soft material (for daily cover and other purposes)?
- Are there areas within a few kilometres of the site that may be suitable for borrow material?
- Is there any evidence of geological features on or near the site?
- Are there any features that will significantly limit the useful area of the site for landfilling?

*Land Use*

- What is the present land use of the site and the route of any access road to it?
- What is the present land use in the immediate vicinity of the site and the access route?
- Are there likely to be any water abstractions (for drinking or livestock watering) downstream of the site (for example, within 1 km)?
- Are there any overhead power lines crossing the site?
- Is there evidence to suggest where the nearest point of a water distribution or electricity distribution network might be to the site?
- Are there any places of historic or cultural significance?
- Is there likely to be a need for resettlement?

*Public Acceptability*

- Are there any significant population centers on the principal route to the site which will be adversely affected by increase traffic volumes?
- Is the site overlooked by, or overlooking, residential or commercial development, or socio-politically sensitive sites?
- Where are the nearest inhabited dwellings (e.g. farms)?

**Water Resource Related Site Selection Criteria**

- The seasonably high groundwater table (i.e. 10-year high) should be below the proposed base of any excavation or site preparation to enable cell development.
- Soils above the groundwater's seasonable high table level are relatively impermeable (preferably, less than $10^{-6}$ cm/s permeability when undisturbed)
- No environmentally significant wetlands of important biodiversity or reproductive value are present within the potential area of the landfill cell development, unless they have adequate capacity to absorb/assimilate the pollution loadings anticipated
- None of the areas within the landfill boundaries is part of the 10-year groundwater recharge area for existing or pending water supply development
- There should be no private or public drinking, irrigation or livestock water supply wells down-gradient of the landfill boundaries if at risk from contamination, unless alternative water supply sources are readily and economically available, and the owner(s) giver written consent to the potential risk of well abandonment
- There are no underlying limestone, carbonate, or other porous rock formations that would be ineffective as barriers to leachate and gas migration, where the formations are more than 1.5 m thickness and present as the uppermost geological unit

- No fault lines of significantly fractured geological structure that would allow unpredictable movement of gas or leachate are within 0.5 km of the perimeter of the proposed cell development
- The site is not within a floodplain subject to 10-year flood. If it is within areas subject to a 100-year flood, it must be amenable to an economic design which would eliminate the potential for washout.

### A.3 Graded Standards for Landfills

Taken from Blight, G. E., "Standards for Landfills in Developing Countries", Waste Management & Research, 14, p. 399-414, 1996

Factors of the Landfill Classification System

1. Waste Type – If the content of biodegradable material exceed 20% by dry mass, the waste is classified as "B" or high-biodegradable waste. If the biodegradable content is less that 20%, it is classified as "b", or low-biodegradable waste. While this is unproved at present, it appears reasonable to relax standards required for "b" refuse, as compared with those required for "B" refuse. The dividing point of 20% of biodegradable material between b and B wastes is tentative at present.

2. Landfill Size – The classification is based on the maximum rate of deposition (MRD) in tonnes of refuse deposited per year. The MRD is the projected rate of deposition at the end of the life of the landfill and is calculated form the initial rate of deposition (IRD) and the estimated annual growth rate or development rate for the community that the landfill is intended to serve. The IRD can be estimated by the amount of refuse entering eh site at present, or in the case o f new site, form the current rate of deposition at the site or sites it is intended to replace. Failing this, a suitable generation rate multiplied by the number of people presently in the community can be used to estimate the IRD. Care should be taken to estimate the IRD for an appropriate working year. This is usually 260 days (52 weeks x 5 days) if the landfill is operated in 5 days of the week.

If D (% $year^{-1}$) is the annual development rate estimated form a landfill interms of the projected increase in the production of waste, the MRD can be calculated from the IRD by:

$$(MRD) = (IRD)(1+D)^T$$

where T is the estimated life of the landfill in years.

$M_T$, the mass of refuse deposited after T years of operation is then:

$$M_T = (IRD)/D * [(1+D)^T-1]$$

In many areas, weigh bridges will not be available to determine the rate of deposition in mass units. In these cases, the calculations can be preformed in terms of a volume. The volume of the refuse can be estimated fairly easily from the dimensions and number of vehicles depositing refuse at a particular site. Equations (1) and (2) can then be used with IRD expressed as cubic meters of refuse per year.

Generally, small landfills are associated with small community and small rates of deposition, whereas large landfills are associated with large rates of deposition. The actual lives of landfills are likely to be similar, regardless of the landfill size, simply because most facilities tend to be designed for a life of 20-25 years.

**Size Classification for Landfills**

| Landfill Size Classification | Maximum rate of deposition (MRD) (tonnes/year) | Typical Population Range |
|---|---|---|
| Communal | < 250 | 1000 – 1500 |
| Small | < 5000 | <30,000 |
| Medium | < 150,000 | >30,000 |
| Large | > 150,000 | >30,000 |

Alternatively, the size classification could be expressed in terms of the total tonnage or volume that can be accommodated by a site.

3. Climate – The effects of climate can be quantified by the water balance for a landfill. The water balance compares the quantities of water entering the landfill as part of the refuse and as infiltrating rain and snow-melt, with the quantity of water stored in the landfilled refuse, and leaving the landfill be evaporation and evapotranspiration. The difference between the net water input and the water stored in the refuse will be available to form leachate. Evaporation from a water surface is measure by recording losses from standard evaporation pans.

In cases where no significant leachate is produced (i.e. in arid climates), it may be possible to relax the standards required for the design of a landfill by omitting the leachate collection system and underliner. However, this will depend on geological and groundwater conditions at the site. If the groundwater exists close to the surface, or if the site is underlain by permeable strata, e.g. sands and gravels or cavernous limestone, it may be prudent to provide a leachate control system regardless of climate.

However, even in arid climates, there are occasional wet years or “wetter-than-normal” wet season. When extreme weather conditions occur, some leachate may be generated. If there is no leachate collection system, this leachate will be available to seep into the soil underlying the landfill. Provided that this does not occur more frequently than (say) once in 5 years, and if the foundation strata are relatively impervious so that the movement of leachate is retarded, the consequences of such escape may not be serious and could be ignored. At sites overlying highly permeable aquifers that are used as sources of drinking water, this approach might be inadequate.

A “climate water balance” is used as a means of deciding whether or not a landfill will generate significant quantities of leachate and, therefore, whether or not a leachate collection system and underliner should be provided. The climatic water balance (W) is expressed as:

$W = R - E$

Where R is the rainfall and E is the evaporation from the landfill cover surface (both in mm water).

E is taken as K*A-pan evaporation or 1.3K*S-pan evaporation, where K is an empirical factor established for the region under consideration. The value of K will depend on local climatic conditions, as well as the characteristics and water content of the incoming waste.

In the expression for W, runoff of precipitation has been ignored. This is not only conservative, but realistic for more landfill is developing countries and developed countries in cases where capping layers are semi-pervious. The lack of runoff occurs because, in many climates, 85% of individual 24-h rainfall events consist of less than 10 mm. A daily quantity of rain as small as this can usually be absorbed completely into a semi-pervious soil layer. Because W is intended to represent a long-term state, the field capacity does not appear in the climatic water balance.

To allow for seasonal influences and variable weather patterns, W is calculated for the wet season of the wettest year on record (the wet season would usually be taken as the wettest 6- month period in a year, based on long-term averages). If the value of W is positive, the indication is that the landfill will generate leachate in a wet year. Vice-versa if W is negative, the indication is that the landfill will not generate leachate, even in a wet year.

As the rainfall and evaporation in any one year do not necessarily correlate, W is recalculated for successively drier years to establish if:

1. W is positive in less than 1 year in 5 for which data is available; or
2. W is positive in more than 1 year in 5.

The value of 1 year in 5 can, of course, be adjusted to 1 year in 10 or more, depending on the local climatic and hydrogeological condition and environmental concerns.

If (1) applies, the site is classified as W-; a leachate collection system and underliner can be omitted from the landfill or its design standard can be reduced. If (2) applies, the site is classified as W+. In this case, regular generation of leachate can be expected so a leachate collection and extraction system and underliner would need to be provided.

**Application of the classification system**

Landfill Classification System

| Waste Type | High biodegradable waste | | | | | | | | Low biodegradable waste | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Landfill size and type | Com-munal | | Small | | Medium | | Large | | Com-munal | | Small | | Medium | | Large | |
| Climatic water balance | W- | W+ | W- | W+ | W- | W+ | W- | W+ | W- | W+ | W- | W+ | W- | W+ | W- | W+ |

The detailed application of the classification system would depend on the requirements and conditions in the country in which it would be applied. For example, the climate in a country may be such that the entire region would be classified as W+. In such as case, the climatic consideration could be omitted, as it would be the same for all sites. A study of the type of water might indicate that all waste would be classified as “high biodegradable” or B. In such as case, the right hand side of the above table could be omitted.

Once the classification has been carried out, the graded requirements can be site under each the headings of:

1. Site selection
2. Site investigation
3. Environmental impact assessment
4. Landfill design (including design of leachate and gas drainage and extractions systems)
5. Site preparation and commissioning
6. Operation and operational monitoring
7. Rehabilitation, closure and end-use
8. Post closure monitoring

### B.1 Interview Questions

- What is the mandate of this Agency?
- What are the responsibilities of this agency with respect of waste management and /or water resources?
- Have you been involved in landfill siting in the past?
- If so, describe past landfill siting practices in Vietnam:
    - What was the role of this agency?
    - What other agencies were involved?
    - What were objectives of landfill siting with respect to the environment?
    - What criteria were used
    - What types of data were collected to measure these objectives?
    - What objectives are used to identify candidate sites?
- Comment of the proposed landfill siting regulations:
    - Do you think there are any constraints that would be appropriate? (i.e depth to the water table must be at least 5 m) Why?
    - Is it feasible to obtain the data required to measure the objectives? If not, what data cannot be obtained and why?
    - Have you seen any examples of barriers to using these objectives in a landfill siting process in Vietnam?
    - Are there any regulations, further to regulation #01/2001, that are constraints
- Discuss the relationship between landfill siting and design:
    - What constitutes an acceptable level of environmental protection in landfill practices in Vietnam?
    - Does the acceptable level change depending on the site conditions or location?
    - Are there resources available to design, construct, and operate a landfill to these standards?
    - How can it be ensured through landfill siting, design, construction, and operation that the acceptable level is not exceeded?
- Discuss recent landfill projects:
    - Describe the design of the landfill: what type of landfill liner is used? Is there a leachate collection system? Is the leachate treated? What type of environmental monitoring program is used? Is the leachate recirculated?
    - How was this project funded?
    - Are there any lessons learned from this project that you would use to improve landfill siting, design, and construction in future projects?
- Data Collection:
    - What types of data are collected by your agency?
    - What area is included in data collection?
    - How often in information updated?
    - How is this information made available to other agencies?

### B.2 List of Agencies Interviewed

MOSTE – Ministry of Science, Technology and Environment
MOC – Ministry of Construction
MARD – Ministry of Agriculture and Rural Development
DOSTE – Department of Science, Technology and Environment
DOC – Department of Construction
DARD – Department of Agriculture and Rural Development
URENCO – Urban Environment Company
DGMV – Department of Geology and Minerals of Vietnam
Hydrometeorological Services of Vietnam
NEA – National Environment Agency
CRURE – Center for Research and Planning on Urban and Rural Environment
Department of Architecture and Planning
Division of Geological and Mineral Resources Survey