JAPAN INTERNATIONAL COOPERATION AGENCY

MINISTRY OF HOUSING AND LOCAL GOVERNMENT, MALAYSIA

THE STUDY ON THE SAFE CLOSURE AND REHABILITATION OF LANDFILL SITES IN MALAYSIA

FINAL REPORT

Volume 5

The Technical Guideline for Sanitary Landfill, Design and Operation (Revised Draft, 2004)

NOVEMBER 2004

YACHIYO ENGINEERING CO., LTD.

EX CORPORATION

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The Final Report of "The Study on The Safe Closure and Rehabilitation of Landfill Sites in Malaysia" is composed of seven Volumes as shown below:

Volume 1	**Summary**
Volume 2	**Main Report**
Volume 3	**Guideline for Safe Closure and Rehabilitation of MSW Landfill Sites**
Volume 4	**Pilot Projects on Safe Closure and Rehabilitation of Landfill Sites**
Volume 5	**Technical Guideline for Sanitary Landfill, Design and Operation (Revised Draft, 2004)**
Volume 6	**User Manual of LACMIS (Landfill Closure Management Information System)**
Volume 7	**Data Book**

This Report is "**Volume 5 Technical Guideline for Sanitary Landfill, Design and Operation (Revised Draft, 2004)**".

THE TECHNICAL GUIDELINE FOR SANITARY LANDFILL, DESIGN AND OPERATION

(Revised Draft, 2004)

November 2004

Ministry of Housing and Local Government
MALAYSIA

STRUCTURE AND CHARACTERISTICS OF THE TECHNICAL GUIDELINE FOR SANITARY LANDFILL, DESIGN AND OPERATION (Revised Draft, 2004)

The Technical Guideline for Sanitary Landfill comprises of four (4) parts, they are:

i.	Part I	:	Introduction and Basic Design of Sanitary Landfill
ii.	Part II	:	Technical Guideline on Sanitary Landfill System
iii.	Part III	:	Management of Sanitary Landfill
iv.	Part IV	:	Appendices

1. Background for the Preparation of the Technical Guideline in 1990

This Technical Guideline was originally prepared as general guidelines taking into account issues raised from the answers and replies from the two questionnaire surveys, namely, "Questionnaire survey of Final Disposal" and "Survey on Present Condition of Landfills" conducted by the Ministry of Housing and Local Government during 1989 to 1990.

The results and findings of the "Survey on Present Condition of Landfills" highlighted a number of recommended countermeasures and required facilities necessary for the improvement of existing landfills in Malaysia. These are as follows:

(1) Construction of an all weather road for access purposes.

(2) Installation of gate, notice board, bund, fences, ditches, etc. for a clearer demarcation of the landfill site boundary

(3) Clearer demarcation of all working cells/phases and control expansion of the phases.

(4) Better control of procurement of cover material and use of heavy machinery to ensure proper completion of daily covering activities and better understanding of covering technologies.

(5) To adopt semi-aerobic sanitary landfill methods as a measure to prevent pollution caused by leachate and to achieve a faster stabilisation period for the landfill.

(6) Installation of gas venting facilities as countermeasures for gas production and to achieve a faster stabilisation period for the landfill.

(7) Installation of surface trenches for the closed landfill sections.

(8) To adopt suitable landfilling methods such as the area method, area depression method, trench method, etc.

(9) Implementation of separate landfill method based on control of landfill site and post closure land use plan.

(10) Installation and utilisation of weighbridge to record the arrival and loads of the transport vehicles, and to monitor the vehicle usage.

Based on the surveys, during the past years, several Local Authorities have begun to improve their landfill sites by following the abovementioned recommended countermeasures.

It must be appreciated that Malaysia's "sanitary landfill" technology is still in its infancy and hence it is still necessary to refer to other foreign technologies as basis for further improvements. Besides the inclusion of existing guidelines, other basic technologies that have been adopted and implemented by some Local Authorities have been summarised and included in the Technical Guidelines. Such also included the technical advices given by the Ministry of Housing and Local Government. Emphasis is given to new regulations and technologies that can be applied and used in the future.

The sanitary landfill technology is still an evolving technology and requires regular reviews and updating Sanitary landfill operators and related personnel must endeavour through their gained experiences to develop and to formulate the guidelines that are more concrete and applicable.

2. Review of the Technical Guideline in 2004

The primary purpose of the landfill site is to implement final disposal of the wastes by sanitary methods and with minimum environmental impact. However in Malaysia which is rapidly developing economically, it is also very important to introduce advanced concepts into landfill design and operation, such as the effective utilization of landfill sites where the filling works is already completed, measures to attain a recycle-based sustainable society, and so on.

However, the technical guideline has not been reviewed for more than 10 years after being published in 1990, and the content of the guideline does not entirely comply with the actual present circumstances in Malaysia. Therefore, the technical guideline has been reviewed, and up-dated.

The items to be reviewed of the Technical Guideline are as follows.

(1) Recommendation of Semi-aerobic Landfill System

To prevent the various problems caused by the landfill site, it is effective to make the structure of landfill site appropriate so as not to influence the surrounding environment. In addition it is effective to reduce the potential environment risks of landfill operations by accelerating the stabilization of landfilled waste.

Moreover, acceleration of the stabilization of landfilled waste is important for the safe closure of landfill site. Environmental risk on the closed landfill site is reduced, and effective utilization of the land resources becomes possible

In order to minimize the environmental impact caused by the landfill site, introduction of the semi-aerobic system and constructing and operating the landfill accordingly is necessary.

This concept of semi-aerobic system, which is landfill standard in Japan, has been recommended to the Malaysian government by Prof. Matsufuji based on research and practical experiences related to this system. Therefore the emphasis of the review of technical guideline is laid on the recommendation of semi-aerobic landfill system.

(2) Level of Sanitary Landfill

Actual site visits by the JICA study team in the year 2003 to prepare the landfill inventory and data collection from local authorities showed that there is difference in the interpretation of the sanitary landfill level by each of the team and the local authorities.

Therefore, in order to develop a unified understanding of the facility/operation levels of sanitary landfill, level 1-4, more detailed description of the concept of each level was prepared, and recommendations to develop the landfill with the higher possible level was also included.

Concretely, the additional descriptions on the concept of each sanitary landfill level are as follows.

<Primitive level>

Level 1 Primitive Landfill required for basic urban sanitation*(*waste removal from the living environment.)

<Minimum level>

Level 2 Maintain a healthy sanitary environment in and around the landfill at a minimum level

<Basic level>

Level 3 Alleviate the environmental impact of leachate by collecting and circulating the leachate, and accelerate the stabilization of the landfill by maintaining a semi aerobic state

<Advanced level>

Level 4 Control the impact of leachate to the ground water system by treating the leachate and constructing a seepage control works.

Table Concept of Levels 1-4 of Sanitary Landfill

Item	*Level 1*	*Level 2*	*Level 3*	*Level 4*
Urban sanitation	+++	+++	+++	+++
Maintain a healthy sanitary environment in and around the landfill		++	+++	+++
Alleviate the environmental impact			++	+++
Acceleration of stabilization by leachate		+	+++	+++
Reduction of the effect to the underground water system by leachate			++	+++

Note + magnitude of effect (+ low, ++ medium, +++ high)

(3) Function of Landfill Site

The functions of the landfill site were reviewed, and three functions were clearly identified, "storage and treatment function", "environmental protection function", and "land development function". Especially, the land development function is an important subject for the landfill site in Malaysia, and hence aspects on the land development were added.

(4) Necessity of the Cover Soil

Majority of landfill sites in Malaysia have inadequate cover soil, and that is the major factor which makes the sanitary condition of the landfill inferior. The main cause of inadequacy of cover soil is that the acquisition of cover soil isn't stipulated in the development plan of the landfill site. Therefore, in order to stipulate the acquisition of the cover soil from the planning stage of landfill site, significance and technical requirement for cover soil were added to the technical guideline.

Further, regarding the calculation method for the design capacity of the landfill, the description of the method for calculating the cover soil volume was modified so as to be able to calculate the design capacity inclusive of the volume of cover soil, by adding the method for calculation of cover soil volume requirements.

(5) Environmental Monitoring

When developing a landfill site, the preliminary procedure of environment impact assessment is important, and in addition, it is important to implement the appropriate monitoring throughout from

the operation stage to post-closure stage. Thus, from the planning stage of landfill site, it is necessary to consider the monitoring of leachate, discharged water, groundwater, landfill gas, etc. from the point of view of protection of living conditions and environmental pollution control Therefore, the description about monitoring was added.

(6) Counter-measures for Squall

In Malaysia, there is rainfall throughout the year and a high intensity of rainfall within a short period is observed. Therefore, it is necessary to plan for the stormwater drainage system, leachate collection system, leachate treatment system, etc. so as to have enough capacity. Moreover, in order to minimize the leachate amount and introduce proper capacity of the facilities, it is important to drain stormwater quickly by introduction of sectional landfilling and the appropriate intermediate cover soil.

Also, as the heavy rain in short time causes the erosion of the slope, access road, etc., therefore, countermeasures were also added.

(7) Compartmental Landfilling

When landfilling for a long period in a relatively large landfill site, introduction of compartmental landfilling is effective to reduce the amount of leachate and to minimise O/M cost. Especially for short but strong rainfalls, compartmental landfilling has the benefit of a leachate reduction by fast drainage. Hence, comments on compartmental landfilling have also been added.

(8) Design Capacity of Leachate Control Systems

Based on the landfill inventory survey carried out by the JICA study, landfill sites with no control systems for leachate, or with insufficient capacity of the system are very common. Therefore design method of the capacity of leachate control system and planning inflow volume of leachate has been added.

(9) Treatment Method of Leachate

The waste composition of Malaysia used to be mainly organic matters, but recently chemical products such as plastics have been increasing. This trend is further projected to increase. For regions where incinerators will be introduced, an increase of ash can also be predicted. In accordance with the change of waste characteristics in coming to the landfill site, measures for Dioxins, heavy metals, pops etc. will be required. Hence, the need for the leachate treatment is becoming more important. Landfills corresponding to levels 3 and 4 are expected to be introduced mainly in Malaysia.

Hence, comments on pre-treatment, leachate circulation, biological treatment, physical treatment and natural treatment have been added As leachate treatment facility is necessary, especially for level 4 landfills, comments on leachate treatment have been extensively added.

(10) Occupational Safety and Health

The landfill site has some potential elements for the unsanitary and dangerous conditions of the working environment. So, it is necessary to consider the occupational safety of the landfill worker and the sanitation of working environment from the planning stage of landfill site. Therefore, cautionary items on working conditions were added.

(11) Landfill Operation and Maintenance Control

Recently, in some cases, landfill operation has been commissioned to private contractors, and this trend will be more widely introduced in the near future in Malaysia Under this condition, government side will have the responsibility for monitoring of landfill operation under certain contract conditions. Based on this understanding, in order to carry out the proper monitoring of landfill operation, performance indicators have been added. The main indicators are as follows.

Incoming waste record
Landfill works
Facility and equipment
Environmental protection and monitoring
Social consideration

Moreover, "Part III Management of Sanitary Landfill" was newly created in this guideline

Items for operation and management of landfill will be summarized based on the landfill operation manual in the making by Japan Waste Research Foundation (JWRF).

(12) Rehabilitation of Existing Landfill Site

Based on the landfill inventory survey carried out by the JICA study, it was found that more than 90% of landfill sites in Peninsula Malaysia are open dumping or level 1, and are therefore sources of environmental risks. Therefore, the necessity of the rehabilitation of existing landfill sites in accordance with this guideline was stated.

(13) Cost for Landfill Construction and Operation

Information on the cost for landfill site construction has been added, just for reference. It should be noted that cost is very site specific matter and therefore it depends very much on the site location, site condition, design concept etc.

(14) Explanation of Intermediate Treatment

To refine the waste management plan comprehensively by introduction of the appropriate intermediate treatment, such as recycling, incineration system, etc. is important for the effective utilization of resources and construction of a recycle-based sustainable society. It is also important for the reduction of environmental load to the landfill site, and for the early stabilization of landfill site.

Therefore, introduction on the related intermediate treatment systems such as recycling, incineration system, were added

(15) Updating Data

Data was updated to collect the present SWM condition in Malaysia

(16) Revision of the Contents

In addition to the comments mentioned above, the overall contents of the guideline have been modified to make it more reader friendly. Also, focused points of each article of the guideline have been put at the heading, followed by explanation.

ABBREVIATIONS

AD	Anaerobic Digestion
ADCMW	Annual Designed Cover Material Weight
ADLV	Annual Designed Landfill Volume
ADLW	Annual Designed Landfill Weight
BOD	Biochemical Oxygen Demand
CAPEX	Capital Expenditure
CHP	Combined Heat and Power
CMV	Cover Material Volume
COD	Chemical Oxygen Demand
DLC	Designed Landfill Capacity
DO	Dissolved Oxygen
DOE	Department of Environment
EfW	Energy-from-Waste
EIA	Environmental Impact Assessment
FRP	Fibreglass Reinforced Plastic
GOM	Government of Malaysia
JICA	Japan International Cooperation Agency
JWRF	Japan Waste Research Foundation
LAs	Local Authorities
MSW	Municipal Solid Waste
MLSS	Mixed Liquor Suspended Solid
MRF	Material Recycling Facility
O & M	Operation and Maintenance
RDF	Refuse Derived Fuel
SS	Suspended Solids
SVI	Sludge Volume Index
SWCM	Specific Weight of Cover Material
SWM	Solid Waste Management
SWW	Specific Weight of Solid Waste
VHV	Vehicle Haulage Volume

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Part I

Introduction and Basic Design of Sanitary Landfill

Part I Introduction and Basic Design of Sanitary Landfill

Chapter 1 Landfill Disposal Concept

1.1 Landfill Disposal Concept

The aim of solid waste disposal is to immediately remove discarded waste from the community by reducing its volume and rendering them stable and hygienic.

In selecting the proper treatment and disposal process, consideration must be given to the geographical area, the financial situation and the level of technology to be used. Generally, such solid waste management (SWM) process can be divided into three activities such as collection/transport, intermediate treatment and final disposal. Disposal by landfilling is the only final disposal method that treats and restores the organic portions of the waste back to nature.

It is important to have a practical method of disposal that takes into account of the type, form and composition of wastes, the location of disposal site, the local environment, geology, ecology, hydrology and climatic conditions.

In planning the final disposal site, it is necessary to determine and establish the types and volume of waste for landfilling in order to formulate an effective master plan for solid waste management based on the actual needs of the region. This final disposal plan should take into account and be integrated with the other collection or haulage plans and intermediate treatment plan.

Solid waste management (SWM) can be defined as the systematic interaction between various activities of waste generation, storage, collection, transfer and transport, intermediate treatment and final disposal. Newer concepts such as resource recovery, volume reductions, solid wastes stabilisation or sanitation have been incorporated in the SWM processes. Although more advanced and sophisticated intermediate treatment methods have been developed, the sanitary landfilling method is still considered to be one of the most important and ideal final disposal process.

The primary aim of ideal final disposal method is to adopt the sanitary and environmental friendly landfilling method. Other advanced concept of technology may also be integrated, such as effective post closure utilisation, adoption of resource recovery and recycling philosophies, etc.

For effective post closure utilisation of the landfill site, it is essential to adopt the more advanced landfill management methods with semi-aerobic structure and equipped with higher level treatment facilities so that earlier stabilization of wastes may be achieved.

Final disposal sites such as sanitary landfills must be utilized with consideration towards a sustainable environment and with regards to effective utilization of available resources. In providing such landfills, the use of recycled construction material such as those reclaimed from construction and demolition wastes like concrete debris or spent activated carbon, or biomass material should be encouraged.

1.2 Classification of Landfill Types

The landfills can be generally classified into five major types and they are as follows:

- Anaerobic Landfill
- Anaerobic Sanitary Landfill with Daily Cover
- Improved Anaerobic Sanitary Landfill with Buried Leachate Collection Pipes
- Semi-aerobic Landfill with Natural Ventilation and Leachate Collection Facilities
- Aerobic Landfill with Forced Aeration

Examples of the different types of landfills are shown in **Figure I-1(b).**

The aerobic and semi-aerobic landfill types are considered the most ideal due to the leachate and ventilation treatment systems that reduces the quantity and improves the quality of leachate and gaseous emissions.

The semi-anaerobic landfill will be provided with a leachate collection system to collect the leachate for further treatment. Leachate drainage pump may be provided to transfer the leachate to the treatment facility. However, due to the higher costs, pumps may not be provided and the leachate transfer will be by gravity flow. Recent development has introduced the "Recirculatory Semi-Aerobic Landfill" system that pumps and recirculate the leachate back to the landfill layers for further treatment and to provide more ventilation in order to enhance and promote earlier stabilisation of the landfill (**see Figure I-1(a)**).

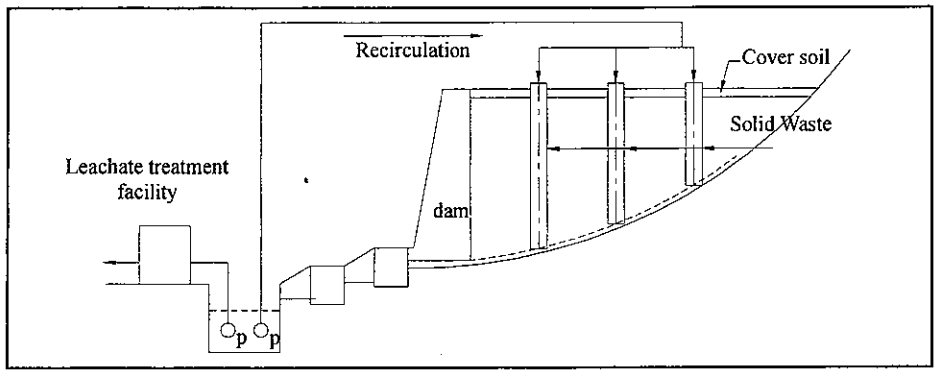
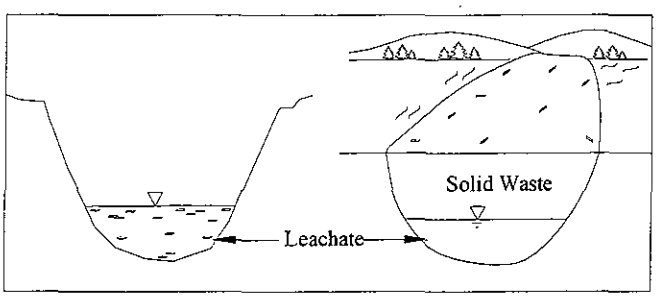
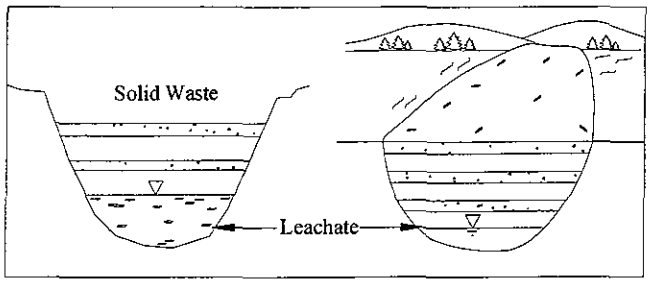


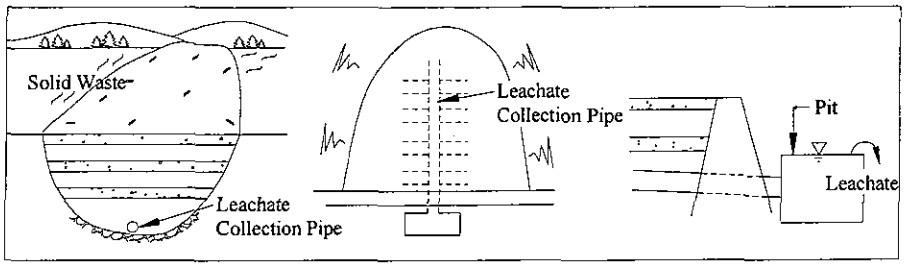
Figure I-1(a) Recirculatory Semi-aerobic Landfill Type



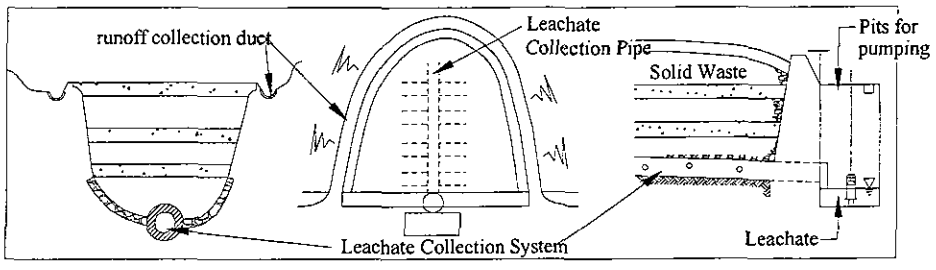
Anaerobic Landfill



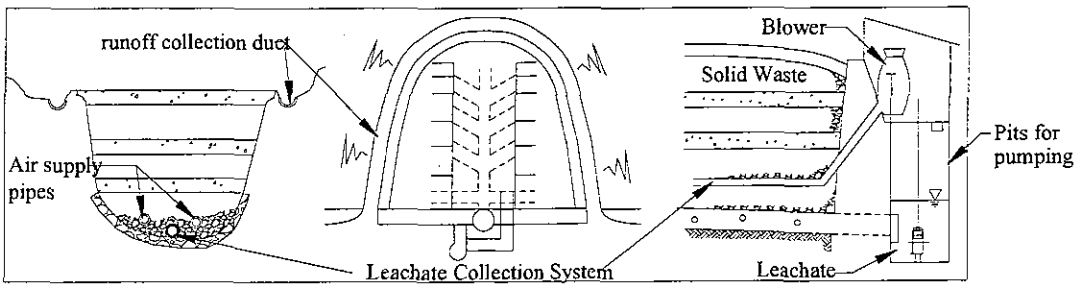
Anaerobic Sanitary Landfill



Improved Anaerobic Sanitary Landfill
(Improved Sanitary Landfill)



Semi– Aerobic Landfill



Aerobic Landfill

Figure I-1(b) Classification of Landfill Type

1.3 Decomposition and Stabilisation of Waste at the Sanitary Landfill

The biological, physical and chemical changes occurring between layers of landfill play important roles in the process of transformation and stabilisation of the waste. Household or municipal wastes tend to contain more organic putrescible material which are more susceptible to bacterial decomposition and hasten the stabilisation period.

Generally the solid waste doing into the landfill can be divided into two categories, i.e. Degradable and Non-Degradable wastes. The degradable waste can further be divided into biologically degradable (or biodegradable) and non-biodegradable.

(1) Degradable Waste

The degradable wastes are wastes that can be transformed either by chemical or biological processes, i.e. by corrosion or by decomposition. Such waste can be sub-divided into biodegradable and non-biodegradable waste.

The stabilisation mechanism of sanitary landfill system is shown in **Figure I-2.**

a) Biodegradable Waste

Biodegradable solid waste includes all organic matters such as meat, vegetables and plants waste that can be decomposed by biological digestion and fermentation. The decomposition process, with the aide of micro-organisms, breakdown the higher molecular compounds like carbohydrates and protein into lower molecular compounds such as sugar, organic acids, alcohols, etc, which will then be fermented to form carbon dioxide, methane, inorganic salts and water. The decomposition process results in the volume reduction and achieves stabilisation of the waste.

The rate of decomposition depends mainly on the type of waste and the condition of the environment. Soft less fibrous waste such as kitchen waste will decompose faster then fibrous waste such as wood or paper. Wet and warm environment will also hasten the decomposition process by promoting bacterial growth.

b) Non-biodegradable Waste

The non-biodegradable waste can also be considered as chemical-degradable waste, i.e. waste that can degrade by undergoing the processes of corrosion, ionic exchanges and liquefaction, due to chemical reactions and oxidations. Such matter includes all types of metals and some inorganic salts. The metals coming in contact with the water or acid present in the waste layers will oxidise to form rust or other forms of metallic oxides, which will eventually breakdown further to the ionic compound, and react with other chemicals to form gasses and salts. The combustion process, i.e. by incineration, paralysis, gasification etc. is also form of chemical transformation processes.

(2) Non-Degradable Waste

The non-degradable wastes are wastes that will not degrade naturally and requires transformation by physical processes, i.e. waste such as concrete, rocks, majority of the plastics, glass etc. The reduction in volume and size can only be achieved by shredding, grinding and compression.

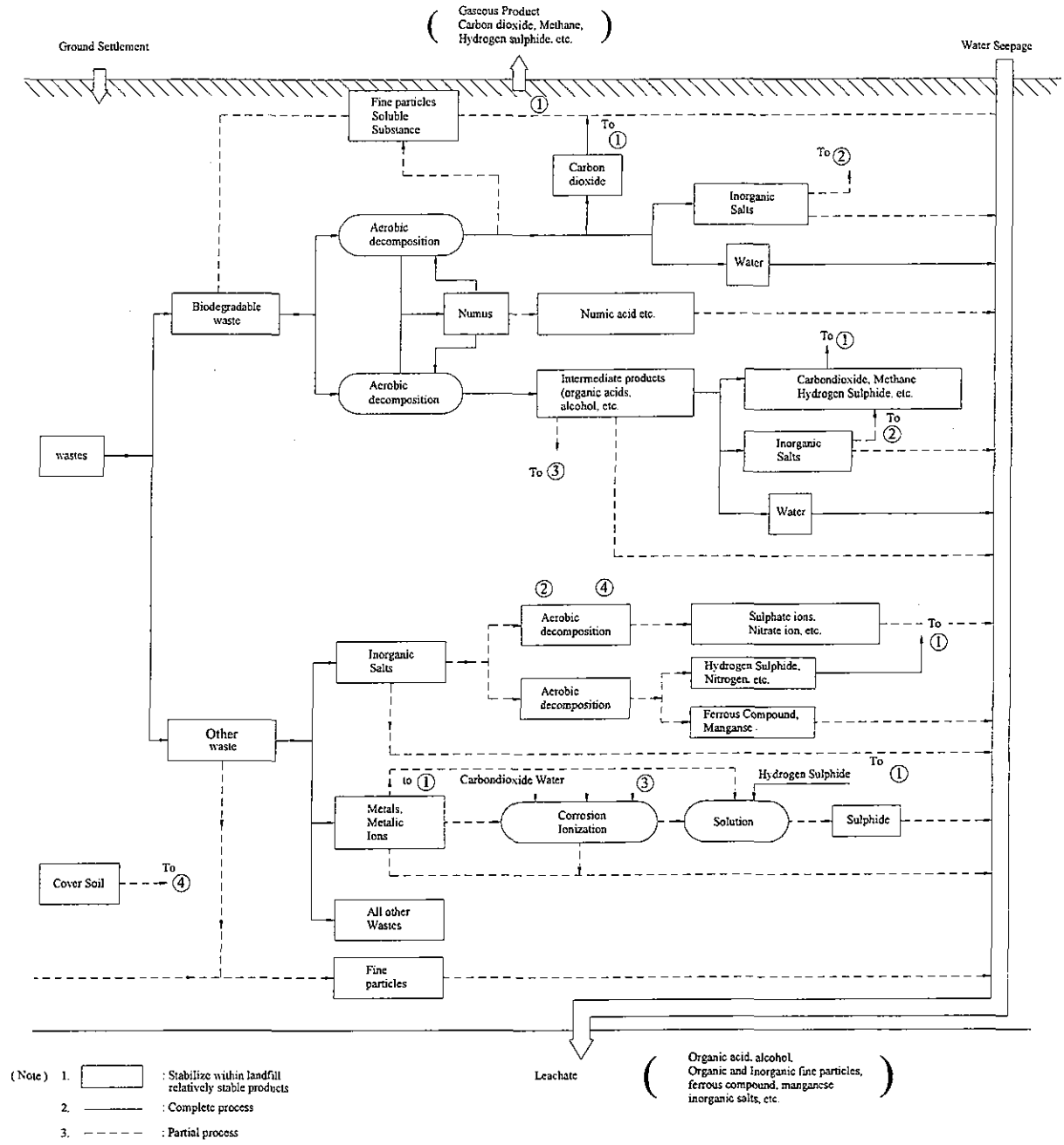


Figure I-2 Stabilization Mechanism of Sanitary Landfill System

Chapter 2 Scope of Application

2.1 Scope of Application

The Technical Guideline shall be applicable for the final disposal site for solid wastes or the target solid wastes are prescribed in "the Action Plan for a Beautiful and Clean Malaysia (ABC Plan)".

In the ABC Plan, which was established in 1988, the target solid wastes were referred to as follows:

- Domestic wastes
- Commercial wastes
- Institutional wastes (markets, schools, hospitals, public offices, etc.)
- Street cleansing wastes
- Garden wastes and grass cutting wastes
- Construction wastes
- Wastes collected from drains and water courses, in urban areas
- Beach cleansing wastes
- Industrial wastes which are and/or can be accepted in municipal landfills (schedules/hazardous wastes are excluded)

Note : A national plan for the management of toxic and schedules/hazardous wastes has already been prepared by Department of Environment (DOE), Ministry of Science, Technology and Environment, Malaysia.

Chapter 3 Planning of Sanitary Landfill System

3.1 Solid Wastes Management Master Plan

The establishment of the Solid Waste Management (SWM) Master Plan is crucial for the setting up and implementation of the solid waste management system to adequately resolve the solid waste treatment and disposal problems.

In recent years, the Federal Government, State Governments and Local Authorities have been confronted with the continuing problems of the steady increase in the quantity and the variety of composition of the solid waste. They are also further aggravated by the high cost of disposal and financial constraint. There has been a growing public awareness towards the waste disposal issues and the higher demand for services and solutions to such problems. Hence, in order to fulfil the Government's social responsibilities and to satisfy the demands of the public, it has become increasingly important to promote more sustainable solid wastes treatment processes and management philosophies. The Solid Waste Management Master Plan has to be established and implemented to meet such demands.

3.2 Laws and Regulations Related to Solid Waste Management

At present, there is no specific Federal Government Legislation that deals with any aspect of SWM in Malaysia. Nevertheless, there are numbers of legislations and regulations which contains major relevant provisions which can be utilised for the purpose of formulating the SWM Master Plan.

The related laws and regulations are as follows:

- Local Government Act, 1976
- Town and Country Planning Act, 1976
- Street, Drainage and Building Act, 1974
- Environmental Quality Act, 1974
- Land Conservation Act, 1960
- The Water Enactment Act
- The National Land Code, 1965
- Environmental Quality (Sewage and Industrial Effluents) Regulations, 1979
- Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) October 1987
- Environmental Quality (Prescribed Premises) (Scheduled Waste Treatment and Disposal Facilities) Regulations 1989
- Uniform Building By-laws

- Earthworks By-Laws
- Public Cleansing By-Laws
- Anti Litter By-Laws
- Refuse Collection, Removal and Disposal By-Laws

3.3 SWM Intermediate Treatment

The SWM Master Plans shall be established not only taking into account of the sanitary landfills but also to consider the other intermediate treatment methods.

Table I-1 shows the various SWM intermediate treatment technologies that may be applicable in Malaysia.

Table I-1 SWM Intermediate Treatment Technologies

Category	Intermediate Treatment Methodology
Physical Processing	• Shredding and Cutting • Trommel Screens • Magnetic Ferrous Separation • Baling • Refuse Derived Fuel (RDF)
Biological Treatment	• Composting • Anaerobic Digestion
Thermal Treatment	• Combustion • Gasification • Pyrolysis • Plasma
Resource Recovery	• Energy-from-Waste (EfW) • Landfill Gas Recovery

3.4 Formulation of The Implementation Plan

The Implementation Plan for the landfill site shall be used to determine the best policies and implementation step necessary to equip and arrange the required facilities so that the proposed landfill site is able to receive solid wastes from the designated service area throughout its designed lifespan.

The Implementation Plan for the landfill site is a plan at the initial stage to be adopted by those responsible for handling solid wastes disposal. The plan shall provide the recommendation and administration mythology on how to implement the policies as set out in the Master Plan for solid wastes disposal.

The programmes that have been determined in the Master Plan for Waste Disposal shall also be carried out in the Implementation Plan. The types of facilities to be provided together with their respective specifications should also be included in the Implementation Plan.

The Implementation Plan shall also include sections on budget estimation and control, financial planning and project administrative functions.

Generally, the Implementation Plan shall be implemented according to landfill management activities as set out in **Figure I-3(a)**. The stages are as follows:

i. Stage 1 – Planning
ii. Stage 2 – Design/Construction
iii. Stage 3 – Operations and Maintenance
iv. Stage 4 – Closure (Post Closure)

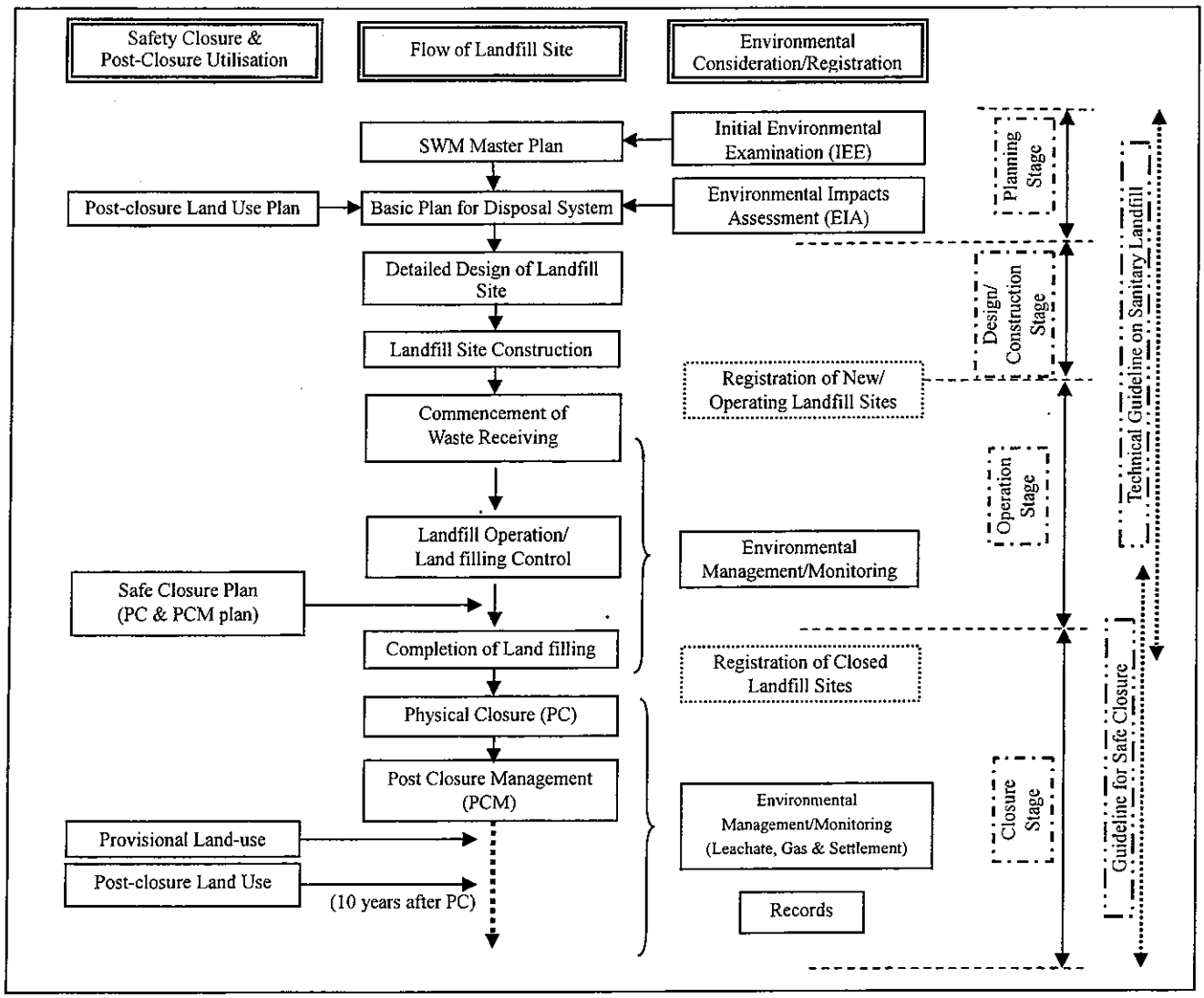


Figure I-3(a) Implementation Plan for Sanitary Landfill System and its Inter-relationship with Other Processes

Figure I-3(b) shows an example of the flowchart for the Implementation Plan for a particular Sanitary Landfill System in Japan.

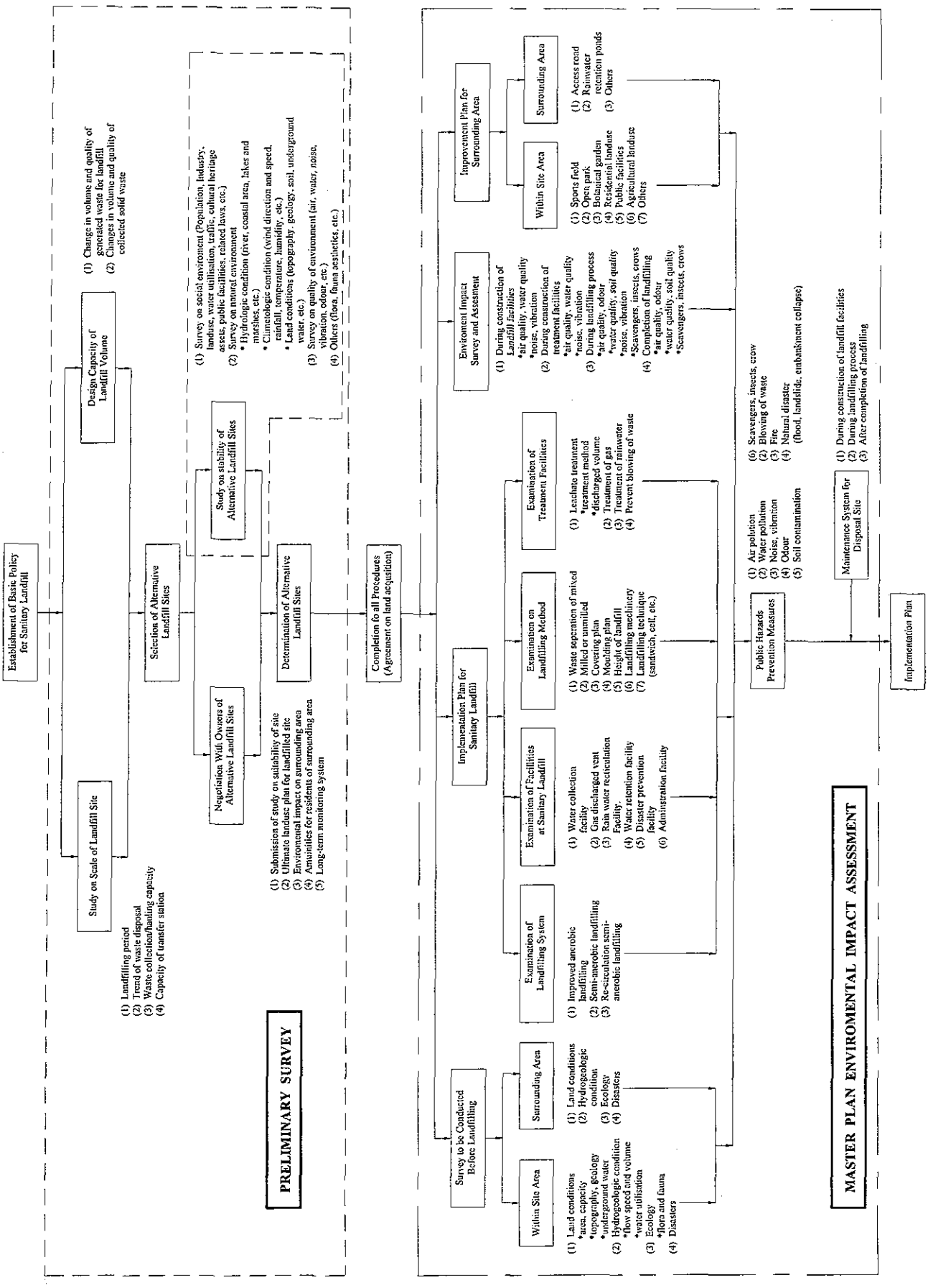


Figure I-3(b) Example of Flowchart for The Implementation Plan

3.5 Basic Design Parameters

3.5.1 Target Lifespan / Target Year

The target lifespan shall be the designed operational duration of the landfill site and should be set at approximately 15 years of operations.

The target year shall be the year the designed lifespan shall be reached, for example, the year 2020, etc.

In general, the target year for the landfill should be the same as the target year as set out in the Master Plan for solid wastes disposal. Ideally, the target lifespan should be established for between 10 to 15 years after first formulating the plan. This corresponds to the policy of implementing adequate solid wastes treatment projects from the long-term plan.

Once the target year has been determined, considerations must be given towards finding a suitable site, carrying out financial analysis and determining the construction schedule of the landfill. Other considerations must also be taken into account, such as the projected quantity and analysis of wastes haulage, and consideration of the actual conditions on the designated service area. Such process of planning, surveys and preparation of the detailed design may take several years. Hence, in order to prevent excessive build up of waste, it is recommended to provide some reserve margin or buffer in the plan so that the life span of landfill may be increased by a further 10-year period, if necessary, to allow for the transition period.

3.5.2 Designed Landfill Capacity

a) The Designed Landfill Capacity (DLC) shall be determined by calculating the product of the sum of planned waste to be landfilled (ADLV) and soil covered (CMV) per year, by the number of years that the landfill is to be operated.

$$DLC\ [m^3] = (ADLV\ [m^3/year] + CMV\ [m^3/year]) \times target\ lifespan\ [year]$$

b) The Annual Designed Landfill Volume (ADLV) shall be determined by dividing the Annual Designed Landfill Weight (ADLW) by the specific weight (SWW) (or weight per unit volume) of the solid waste that is landfilled and compacted.

$$ADLV\ [m^3/year] = ADLW\ [ton/year] / SWW\ [ton/m^3]$$

c) The Cover Material Volume (CMV) shall be determined by dividing the Annual Designed Cover Material Weight (ADCMW) by the specific weight (SWCM) (or weight per unit volume) of Cover Material which is landfilled and compacted.

$$CMV\ [m^3/year] = ADCMW\ [ton/year] / SWCM\ [ton/m^3]$$

[Notes]

Usually, after determining DLC, the site which can secure the capacity which fills DLC is selected. The required area for landfill site depends on the situation of a securable site.

However, when DLC is first determined by the reason the site was already decided etc., target lifespan will change according to DLC.

(1) Designed Landfill Capacity (DLC)

The DLC is the ultimate designed volume of the landfill for the target lifespan, including the volume of waste and covering material that is landfilled and compacted. The DLC will be used to determine the physical size of the landfill and the total area required.

(2) Annual Designed Landfill Volume (ADLV)

The ADLV is the most important parameter in the equation necessary to determine the size of the landfill site for the proposed target lifespan. It is generally determined by calculating the correlation factor between the estimated average annual volume, or amount of the waste brought into landfill, by the reduced volume after compaction in the landfill.

The average annual volume of waste has to be estimated based on the historical records of the actual volume of waste landfilled, at least, for the past five years.

Alternatively, the ADLV can also be estimated by comparing the past records of the vehicle haulage volume (ton) and the landfill volume (m^3) of the other LAs with similar urban populations and employing similar wastes treatment methods.

If only the data on the carrying capacity of vehicles is available, then the vehicle haulage volume (VHV) may be calculated using the following equation:

$$VHV\ [ton] = [Carrying\ Capacity\ (m^3)] \times [Typical\ Specific\ Gravity\ of\ Waste\ (ton/m^3)]$$

The typical specific gravity of the various types of waste for the different types vehicles are tabulated in **Table I-2** below.

Table I-2 Typical Specific Gravity of Waste

Type of Waste / Vehicle Type	Non-Combustible Waste	Combustible Waste	Bulky Waste	Recyclable Waste
4 ton Open Dump Truck	-	0.17	0.07	0.11
4 ton Compactor Truck	0.13 - 0.16	0.25 - 0.35	-	-

Source: Data collected in Fukuoka City during 1981 to 1987

(3) Annual Designed Landfill Weight (ADLW)

The ADLW is the estimated weight of solid wastes to be landfilled during a particular year. It is estimated by taking into account of the types of waste, the average weight of the waste, the generation rate per capita and the population concerned. The average weight of the waste and the generation rate can be determined based on the historical records and past trends of the actual weight of waste collected from the households.

The projected solid waste amount should be estimated, up to the target lifespan, with increments of 5-year intervals. The solid waste amount will steadily increase year by year due to the following factors:

- Increase in the population
- Expansion of service area coverage
- Increase in per capita generation rate with the rise in living standards*
- Increase in commercial activities

* The increase in per capita generation rate should be estimated based on historical records and past trends. If information is not sufficient, then a 2% per year increase factor should be used as an approximate figure on condition that the review of the Master Plan be made based on the past trends.

Example on the estimation of the projected solid waste amount, for the first 5 years.

Assumptions.

- Increase in the generation rate per capita = 2% per year.
- Increase in population = 4% per year.

1990:	Sample population	500,000
	Service coverage	70%
	Generation rate of domestic waste[*1)]	0.91 kg/capita/day
	Commercial and institutional waste	50 ton/day

The total amount = $500,000 \times 0.70 \times (0.91 \times 10^{-3}) + 50 = 368.5$ ton/day

1995:	Population (4% per year increase)	608,000
	$500,000 \times 1.04^5 = 608,000$	
	Service coverage (increased by additional 10%)	80%
	Generation rate of domestic waste	1.0 kg/capita/day
	$0.91 \times 1.02^5 = 1.0$	
	Commercial and institutional waste	73 ton/day
	(8% per year increase)[*2)]	
	$50 \times 1.08^5 = 73$	

The projected total amount = $608,000 \times 0.80 \times (1.0 \times 10^{-3}) + 73 = 559.4$ ton/day

Thus, the above example showed that the projected solid waste amount for the first 5 years will increase from 368.5 ton/day to 559.4 ton/day, an increase of about 191 ton/day.

Note: *1) The waste generation rate of 0.91 kg/capita/day was taken from the estimated average generation rate for Malaysia, as tabulated in **Table I-3**.

*2) The annual increase rate of the commercial and institutional waste is usually greater than that of the domestic waste. The assumed annual increase rate of domestic waste is roughly calculated to be about 6% (2% + 4%). Therefore, for the commercial and institutional waste, the rate of increase of, say 8%, is assumed and adopted.

(4) Waste Amount Generated

Estimated waste amount generated in Malaysia in the year 2002 is shown in **Table I-3**.

Table I-3 Estimated Solid Waste Generated in Malaysia

No	States	Estimated Population (2002)	Per Capita Generation Rate (kg/cap/day)	Waste generation amount (ton/day)	Waste generation amount (ton/year)
1	Johor	2,366,934	0.88	2,083	760,260
2	Melaka	636,007	0.88	560	204,290
3	N. Sembilan	935,683	0.88	823	300,540
4	Selangor	3,493,602	0.88	3,074	1,122,140
5	Pahang	1,183,004	0.88	1,041	379,980
6	Terengganu	1,091,007	0.88	960	350,430
7	Kelantan	1,278,368	0.88	1,125	410,610
8	Perak	1,887,527	0.88	1,661	606,270
9	Kedah	1,636,095	0.88	1,441	525,790
10	P. Pinang	1,344,243	0.88	1,183	431,770
11	Perlis	241,644	0.88	213	77,620
12	Sarawak	2,007,528	0.70	1,405	512,920
13	Sabah	2,115,546	0.70	1,481	540,520
14	FTKL	1,470,875	1.87	2,751	1,003,950
	Total	21,688,063	0.91	19,801	7,227,090

Note: - Data for Peninsula Malaysia is taken from publications by Ministry of Housing and Local Government, Malaysia, 2002
- Data for Sarawak and Sabah is taken from "NREB and DANCED, 2001"

The unit generation rate of solid waste in Malaysia is estimated to increase from 0.91 kg/capita/day in 2002 to 1.15 kg/capita/day in 2020. Based on population growth projections for the period 2002-2020, waste generation is estimated to increase by an average of 3.59% per year. Accordingly, waste generation amount in the year 2020 is estimated to 31,500 ton/day; equivalent to about 11,500,000 ton/yea.

(5) Specific Weight of Solid Waste (SWW)

The SWW (or weight per unit volume) of the solid waste that is landfilled and compacted is generally estimated from a range of data obtained from past records. Since solid waste is not homogeneous, and also subject to the variation in the compaction, the specific weight is usually expressed in a range of values and typical values is assumed. The typical specific weight is tabulated in **Table I-4** below.

Table I-4 Typical Specific Weight of Landfill Waste

Type of Waste	Range (kg/m^3)	Typical (kg/m^3)
Normally Compacted	362 - 498	450
Well Compacted	590 - 742	600

Source: "Integrated Solid Waste Management Engineering Principles and Management Issues" by Tchobanoglous, Theisen and Vigil.

(6) Cover Material Volume (CMV)

There are many types of cover material that can be used ranging from gravel, sand, soil and some geotextile material. However, final cover material must be suitable for planting and sustain plant growth. Generally good top soil is recommended.

The cover material quantity is generally expressed as the thickness of the applied material. With the known thickness, the area of covering and the type of material to be used, the weight and volume can easily be calculated. The specific weight of the material varies according to the material quality and the degree of compaction.

The cover material volume should be planned and estimated based on the required volume necessary for the daily cover material, intermediate cover material and final cover material.

3.5.3 Designed Composition of Solid Waste in Sanitary Landfill

The designed composition of the solid wastes generally refers to the components and types of waste, the moisture content and the specific weight the waste. The components can be further divided into two main groups, namely the organic waste and the non-organic waste. The type of waste is generally determined by the geographical and economical situation of the waste generation area or sector, and also determined by type of intermediate treatment method used.

The determination of the waste composition will have to depend on past available information either from actual samples taken from existing landfill sites or from studies carried out by various institutions and governmental bodies. It may be necessary to periodically monitor and re-sample the waste being sent to the landfill sites in order to determine the variations in the waste composition.

The waste composition data is crucial for the planning, design, operations and maintenance, and the post closure land use planning for the landfill.

Examples of the waste composition for Kuala Lumpur, Malaysia, are tabulated in **Table I-5**, and **Table I-6**, showing the percentage of the particular type of waste from the various sectors, for the wet and dry basis.

The waste composition will tend to vary according to the trends and changes in the social and economical development of the country. A more affluent society will result in more waste being produced but with recent awareness towards recycling, waste reduction, source separations, etc, the waste being sent to the landfill for disposal may be reduced and the composition changed.

Table I-5 Composition of Solid Waste (% wt, Wet Basis) in Kuala Lumpur (2002)

Composition (%)	Residential	Commercial	Institutional	Cleansing	Light Industry	Mixed SW LI & Comm	SW from River	Overall (mixed waste)
Combustible								
Food waste & organic	63.1	76.6	40.6	6.0	0.0	59.5	37.9	56.3
Mix paper	6.7	7.6	16.0	2.6	12.9	8.9	11.9	8.2
Mix plastic	14.3	9	17.2	2.4	18.5	8.8	35.6	13.1
Textile	1.7	0.5	0.7	0.4	1.7	6.7	0.6	1.3
Rubber & leather	0.6	0.3	0.1	0.0	0.0	0.7	0.6	0.4
Wood	0.8	2.1	0.7	2.4	16.3	1.2	0.0	1.8
Yard waste	6.3	0.9	18.4	17.6	2.1	3.1	8.6	6.9
Fine	0.6	0.2	0.5	0.0	0.0	0.0	0.4	0.4
Sub-total	94.1	97.4	94.2	31.4	51.5	88.9	95.6	88.4
Non combustible								
Glass	2.1	0.9	1.5	0.6	2.6	0.9	1.8	1.5
Ferrous	2.3	1.4	2.8	0.5	6.9	0.3	1.8	2.1
Aluminium	0.1	0.1	1.3	0.1	0.9	0.0	0.8	0.3
Nonferrous	0.0	0	0.0	0.0	0.0	0.0	0.0	0
Other inorganics								
OBW	1.4	0.2	0.2	1.7	2.7	9.9	0.0	1.3
Sub-total	5.9	2.6	5.8	68.6	48.5	11.1	4.4	11.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table I-6 Composition of Solid Waste (% wt, Dry Basis) in Kuala Lumpur (2002)

Composition (%)	Residential	Commercial	Institutional	Cleansing	Light Industry	Mixed SW LI & Comm	SW from River	Overall (mixed waste)
Combustible								
Food waste & organic	42.4	58.1	26.7	3.1	0.0	35.5	18.5	39.0
Mix paper	8.6	11.2	14.0	2.4	5.7	8.9	10.4	9.4
Mix plastic	25.9	17.1	27.4	3.4	20.4	14.3	52.9	22.9
Textile	2.1	0.7	0.7	0.4	0.8	12.2	0.7	1.7
Rubber & leather	1.2	0.7	0.1	0.0	0.0	1.5	1.1	0.8
Wood	1.2	4.3	1.0	2.9	14.3	1.4	0.0	2.6
Yard waste	4.7	0.5	16.5	11.4	1.4	2.6	7.3	5.3
Fine	0.7	0.2	0.7	0.0	0.0	0.0	0.6	0.5
Sub-total	86.8	92.8	87.1	23.6	42.6	76.4	91.7	81.7
Non combustible								
Glass	4.6	2.3	3.2	1.0	3.1	1.9	3.4	3.3
Ferrous	5.2	4.1	6.4	1.0	8.1	0.6	3.4	4.6
Aluminium	0.3	0.3	3.0	0.1	1.1	0.0	1.5	0.7
Nonferrous	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other inorganics	0.0	0.0	0.0	71.6	41.9	0.0	0.0	7.1
OBW	3.1	0.5	0.3	2.7	3.2	21.1	0.0	2.6
Sub-total	13.2	7.2	12.9	76.4	57.4	23.6	8.3	18.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Nazeri (2002)
Notes:
1. Mixed SW LI & Com. = Mixed Solid Wastes From Light Industry and Commercial
2. SW = Solid Wastes
3. For Light Industry, mixed solid wastes from light industry and commercial and solid waste from river – only one sample taken from each source

Chapter 4 Formulation of Sanitary Landfill System

4.1 Functions of Sanitary Landfill System

4.1.1 Landfill Functions

The main functions of a sanitary landfill system are as follows:

- Storage and Treatment
- Environmental Protection
- Land Development

The Sanitary landfill system must be designed with consideration towards preserving the living environment by preventing undue incidents such as overflowing of the waste and leachate seepage; propagation of vectors and attracting wild animals; scattering of wastes; and emission of unpleasant odour.

As a waste disposal facility, the main function is in the storage and treatment so that the waste may be stabilised and the volume reduced. However, landfills are treated as dirty and undesirable by the neighbouring residents who tend to be more concerned about the environmental aspects and on land development aspects. Thus, it is necessary to plan and design the landfill system which can maintain a balance of the three functions.

(1) Storage and Treatment

An effective sanitary landfill must be designed to have the capability of storing and safely containing the waste with in its boundary and retaining the leachate from seeping out and polluting the surrounding environment. It is also necessary to prevent the waste from scattering and emitting unpleasant odour. It is essential that leachate quantity be reduced and treated. The amount of emitted gasses such as methane should also be minimised.

The storage and treatment function can be further divided into three standard sub-functions, these are the retaining function, seepage control function and treatment function.

a) Retaining Function

Each of the designated cells must be filled in an orderly manner and the landfill site must be kept in a workable condition throughout target lifespan of the site. The stability of the closed landfill must also be maintained over a predetermined period. Suitable retaining bunds, embankments, walls and dykes must be provided to retain the waste. Such waste retaining facilities must be maintained throughout the operational period, closure and also during the post-closure ultimate use period. The retaining structures must be robust and constructed to prevent against erosion and weathering.

b) Seepage Control Function

Leachate from the landfills must not be allowed to seep into the waterways, rivers,

ground water sources, aquifers etc. Pollutants from the waste can be transported by contaminated water inherent in the waste layers and by rainwater or ground water percolating through the waste. As precautionary measures, it is essential that any excess water seeping in from the surrounding to the landfilled waste be minimised and diverted by the construction of surface drains for the storm water run-off and drainage.

Liner may also be installed at the bottom and sides of the landfill area as to prevent the leachate from seeping through and also to divert and channel the leachate to the leachate collection pipes and to the treatment facilities. The selection of the liner material must take into account of the stabilisation period and should last through out this period. Alternatively, selecting sites with non-permeable ground layer such as clay may be advantages as these layers will acts as natural barriers.

Once the landfilled waste has stabilised over a period of time, the effects on the surrounding environment due to leachate and gases will be lesser.

c) Treatment Function

The landfill can also be considered as a treatment facility whereby the solid waste undergoes a process of decomposition and stabilisation. The biological, physical and chemical changes occurring in the waste layers play an important role in the treatment process. Municipal solid wastes contain a large amount of organic putrescible matter and depend entirely on bacterial decomposition in the stabilization process.

As for the by-product of the decomposition process, such as leachate and gases, suitable treatment facilities should be provided in order to prevent and minimise further contamination and pollution to surrounding environment.

(2) Environmental protection function

The environmental protection function is essential to minimise and prevent harmful effects to human health and to protect the surrounding natural environment. Such harmful effects are caused by problems associated with the discharge of leachate for the landfill, emission of volatile greenhouse gases, foul odour, vectors and other forms of pollutants such as noise and disturbances.

a) Leachate (Prevention of Ground and Surface Water Pollution)

The quality of the leachate discharged from sanitary landfill system are bound by a series of environmental regulations and laws such as "Environmental Quality Act 1974", "Environmental Quality (Sewage and Industrial Effluents)", and other standards and by-laws adopted by the Local Authorities. Therefore the leachate discharge from sanitary landfill system must be treated to comply with the requirements as stipulated in the relevant laws.

Leachate from the sanitary landfill site may be harmful and contaminate the water sources if it was discharged without treatment. Adequate and effective leachate treatment system must be provided with sufficient treatment and retention capacity to handle the leachate quantity, and provided with enough buffer to treat any

temporary increases in the quantity that may be caused by excessive rainfall.

b) Vectors

Landfill areas tend to become breeding and feeding for vectors and animals such as flies, rodents, birds and stray dogs. In order to minimise and prevent such occurrences, daily cover soil should be laid to cover up the landfilled wastes. Insecticides may be sprayed over the area to prevent the breeding of flies and insects. Perimeter fence should be installed to prevent wild and gracing animals from entering the site. This will also prevent human scavengers from getting to the waste.

c) Gaseous products

The main gaseous products emitted from the sanitary landfill site are methane, ammonia and hydrogen sulphide. The composition of the gases depends on the decomposition conditions of the waste layer, i.e. either aerobic or anaerobic. Attention must be paid to the anaerobic landfill that contains mostly organic waste which can produce significantly high concentration of methane. Excessive build up of such volatile gasses may ignite and cause explosions. Such hazardous conditions may persist long after the landfill has been closed. Most of these gasses are harmful to human and the surrounding but the amount produced at the landfill are generally low and not concentrated enough to have any immediate effect. It may be necessary to install gas-venting system to facilitate the dispersion of the gasses to the atmosphere.

d) Unpleasant Odours

There are generally two kinds of unpleasant odour that are emitted from the landfill site, i.e. the odour from the fresh putrid waste matter and the odour produced as the result of the decomposition process. It may be necessary to control the dispersion of such odour to the surrounding environment especially when the landfill site is located near populated areas. The recommended measure is to provide suitable cover material on the waste layer at the end of the day's activities. Another more enhanced method is to provide gas collection and treatment facilities.

e) Noise Pollution and Disturbances

Excessive noise and disturbances that may be cause by dusts or vibrations emitting from the landfill are a nuisance and causes discomfort to the neighbouring population. These are usually caused by activities associated with the waste transport vehicles, machinery used at the site or from the leachate treatment facilities. For the landfill located near populated areas, it may be necessary to improve on the way the site is operated by reviewing the waste transportation system, and the selection and use of machinery and equipment so as to limit the effects of noise pollution and nuisance.

(3) Post-Closure Land-use

Post Closure land-use must be evaluated and decided carefully with considerations

towards the ground conditions, the environmental conditions and the surrounding conditions.

Ideally, post-closure land-use should be limited to non-residential and low-construction development such as for parks or recreational amenities. However, in the developing areas where residential and commercial land are in demand, the post closure land may be developed and used for low density and low rise buildings. Any such development must be carefully evaluated. Additional ground stabilisation and mitigation countermeasures may be necessary prior to constructions.

At the closed landfill site, the continuing decomposition process will result in ground settlement and subsidence over a period of time, and continuous emission of toxic gasses. Thus, it is recommended that for all the closed landfill sites, including those sites that have not been earmarked for redevelopment, continuous monitoring must be carried out in order to check on the environmental effects and their conditions.

4.1.2 Landfill Facilities

All the individual functions must be supported and provide with the relevant facilities in order to enhance the functionality and improve on the effective of the entire landfill system as an integrated SWM disposal facility.

The type of facilities to be provided can be divided into 3 groups, namely:

- The Operations Facilities
- The Management Facilities, and
- The Supporting Facilities

(1) The Operations Facilities

The operations facilities shall be the facilities necessary for the actual operations and use of the landfill site, i.e. the retaining structures, bunds, lining system, drainage system, leachate collection and treatment facilities, gas collection system, cover system, etc.

(2) The Management Facilities

The management facilities shall be the facilities necessary for the daily management activities of the landfill site. Such include the administration office, weighbridge and weighbridge station, etc.

(3) The Supporting Facilities

The supporting facilities shall be the common facilities necessary to support the other management and operations facilities such as access road, fencing, workshop, vehicle cleansing facility, fire-prevention system, etc.

The relationship between the individual functions and the necessary facilities is tabulated in **Table I-7.**

Table I-7 The Relationship between the Functions and the Facilities in the Landfill

Facilities \ Functions		Storage and treatment	Environmental protection			Land development
			Prevention of ground water pollution	Prevention of surface water pollution	Others (Prevention of air pollution and living environment)	
Operations Facilities	Solid waste retaining structure	++		+		
	Ground water drainage system		++			
	Seepage control work	+	++			
	Rainfall collection system			+		
	Leachate collection/treatment system	+	++	++		
	Daily cover facility	+	++	++	++	
	Gas treatment equipment	+			+	
Management facilities	Vehicles monitoring office	++			++	
	Environmental monitoring facility		++	++	++	+
	Administration building	+				
	Weighbridge	+				
	Machinery management	+		+	+	
Supporting Facilities	Access road	+			+	
	Workshop equipment				+	
	Notice board, gate, fence				+	
	Fire-prevention equipment				+	
	Disaster prevention equipment				++	
Post-closure land-use						++

Key: ++: Important relationship +: Mutual Relationship

4.2 Determination of Site Location

4.2.1 Site Selection

In the sanitary landfill site selection process, all necessary criteria such as the design capacity, target lifespan, social & environmental issues, operational effectiveness, cost, etc must all be assessed and evaluated. Some of the important criteria are a follows:

- Available area
- Surrounding environment / conditions
- Topography and geological conditions
- Transport infrastructure and access
- Post closure land-use plan
- Availability of supplies

(1) Available Area

It is important to select the site with sufficient area for construction of the landfill to cater for expansions up to the target lifespan. Area must also be allocated for the supporting facilities such as the administrative buildings, leachate treatment ponds, access roads, perimeter drains, fencing etc. Additional area for the buffer zones (green belt) may also be necessary.

(2) Surrounding Environment/Conditions

The situation and conditions of the surrounding environment, and the neighbouring activities must be carefully assesses by paying particular attention to the following:

- The surrounding development, i.e. housing, commercial, industrial, institutional, agricultural, etc. Consideration must be towards the sensitivity of locating the landfill near to the populated areas.
- Proximity to rivers, watercourses, lakes, ponds, water intake points etc. Consideration must be towards preventing leachate or other pollutants from contaminating the area.
- Availability of basic utilities such as electric power supply, water supply and telephone lines.
- Meteorological conditions of the area so as to avoid the area with high rainfall and strong winds. This is to minimise the wastewater and drainage from the site, and to prevent the waste or cover material from being blown away.

(3) Topography and Geological Conditions

It is important to consider areas where minimal surface earthworks and soil disturbances are necessary, i.e. to minimise hill cutting or earth filling, and tree cutting. Swampy areas, areas prone to flooding, and areas prone to land sliding should be avoided. The ideal land must be flat with a hard non-permeable ground.

Soil investigation should be carried out in order to determine the ground conditions of the area and also to determine the locations of groundwater sources or aquifers.

(4) Transport Infrastructure and Access

Although the landfill site must be located as far away from populated areas, its main purpose is to receive waste from such areas and therefore a good transport infrastructure is essential and must not be isolated. The area must be easily accessible by the waste collection vehicles and all the landfill machinery, at all times. It is also important to consider the accessibility for the emergency response services in case of accidents or fire at the site.

(5) Post closure land use Plan

When the site has been selected, it will be gazetted by the authorities to be used as a landfill site for the duration of the target lifespan. However, after the landfill has been closed, the land may be used for other purposes. Ideally, post-closure land-use should be

limited to non-residential and low-construction development such as for parks or recreational amenities. Nevertheless, decisions must be made during the selection process to assess and determine the post closure post closure land use for the area.

(6) Availability of Supplies

It is necessary to identify the availability of supplies and material in the surrounding area so that procurement and delivery may be expedited efficiently and economically. Such include the supply of cover material, machinery spare parts, etc. Proximity to supplier of cover soil for example will reduce the cost of transportation and thus reduce the operations cost of providing the daily covering.

4.2.2 Survey of Present Conditions

The present conditions of the site, i.e. the hydrological profile, topography, geography, geology, meteorology, biological diversity, etc must be surveyed and documented for a better understanding of the characteristic of the area.

The survey activities should be carried out during the environmental assessment stage so that enough data can be obtained for evaluation and planning during the project implementation evaluation stage. Some of the recommended survey parameters to be obtained as follows:

- Geological maps (Scale 1/2500 to 1/5,000), to indicate the surface layers, underground structures etc.
- Plant life distribution map (Scale 1/5000 or 1/1000), to indicate the types, location and density of trees, vegetation and crops, etc.
- Meteorological data and distribution map, to indicate the amount of rainfall, evaporation rate, wind speeds and directions.
- Hydrological data, to indicate the location of rivers, streams, basin or marshes, the normal water levels and the flood levels, water quality, etc.
- Underground water table diagram, to indicate the presence of aquifers and wells, together with information on the water quality.
- Soil profile diagram and characteristics, to indicate the physical properties, the N-value, core sampling rate, coefficient of permeability, electrical resistance, chemical components of soil, tests for heavy metal, etc.
- Demographic survey, to ascertain the population, distribution etc of the surrounding area
- Traffic survey, to obtain data of the traffic situation of the vicinity.

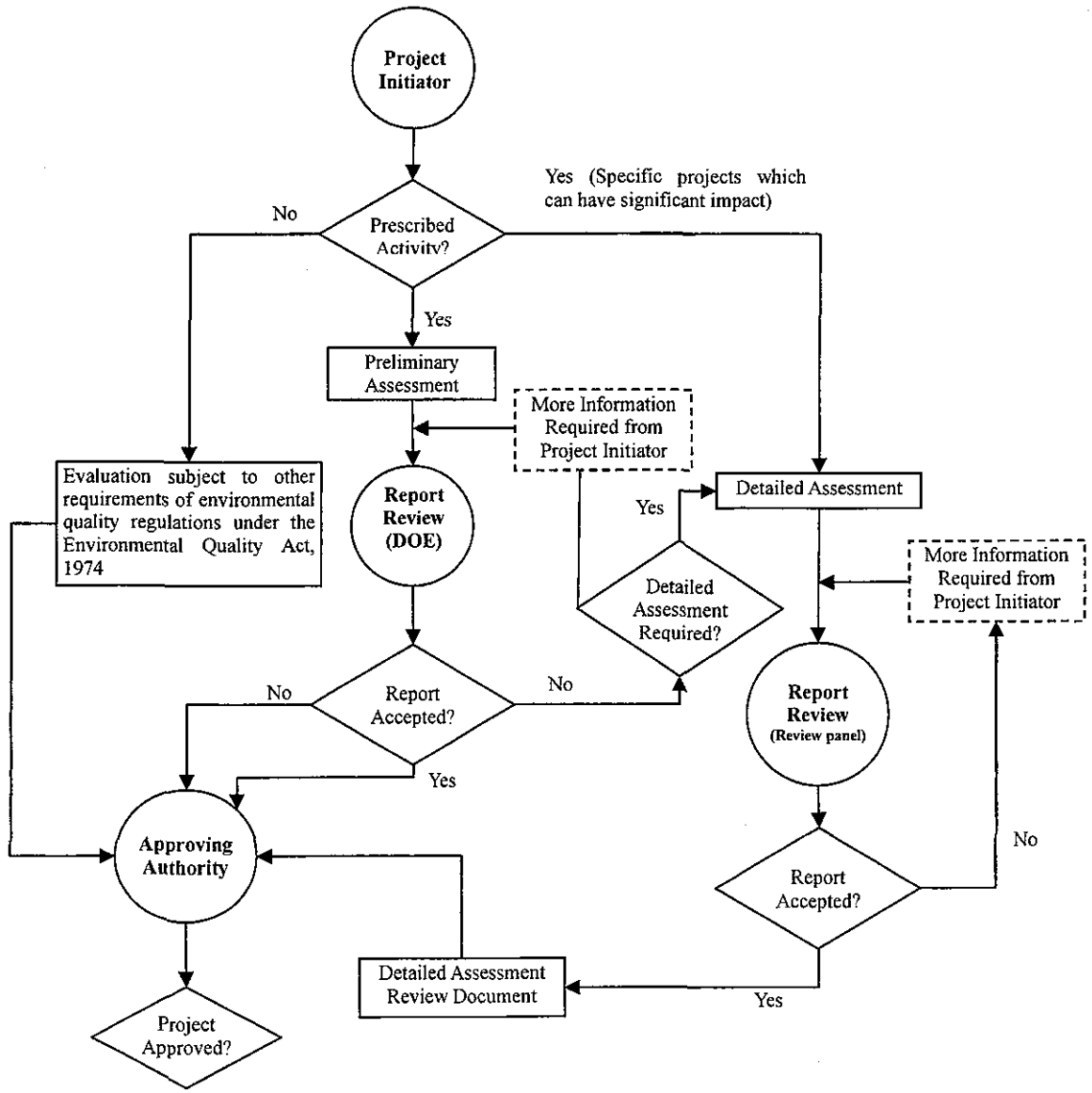
4.3 Environment Protection

An environmental impact assessment (EIA) must be carried out to determine the impacts and effects of the sanitary landfill on the environment, such as the air quality, water, noise levels, vibration and disturbances, odour, and other sources of pollution.

The EIA must be carried out in accordance with the regulations and guidelines as set out in the Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Act, October 1987.

4.3.1 Environment Impact Assessment

Figure I-4 shows the flowchart for the recommended procedures for carrying out the EIA for the landfill planning of Malaysia.



Source: DOE, Environmental Impact Assessment (EIA) Procedure and Requirements in Malaysia, 1994

Figure I-4 Outline of Environmental Impact Assessment Procedure in Malaysia

4.3.2 Impact to the Surrounding Environment

It is important to consider the potential impact the landfill will have on the surrounding environment such as the increase in traffic and transporting activities, increase in odour and noise, etc.

Suitable countermeasure and improvement plan must be established that will minimise the impact and preserve the harmony between the landfill and the surroundings.

(1) Traffic/Transportation

One of the major impacts to the surrounding will be the increase in transportation and traffic activities due to the movement of refuse collection vehicles, cover material vehicles and machinery. The roads leading to the landfill must be properly maintained and improved to cope with the increase in the volume of traffic.

Sufficient ingress and egress to the landfill site must be provided as to prevent any congestion or traffic obstructions at the entrance.

(2) Harmonisation with Surrounding Environment

It is important that the presence of the landfill site will not overburden and destroy the harmony between the site and the surrounding environment.

Perimeter fencing and buffer zones, and planting of trees and bushes should be encouraged to beautify landscape and preserve the aesthetic view of the surrounding natural environment.

4.3.3 Environmental Monitoring Plan

The environmental monitoring plan must be established to provide continuous monitoring of the landfill site and its surroundings throughout the operations period and also during the post closure phase.

The environmental monitoring plan should include procedures on carrying out the necessary activities to monitor the effluent discharge such as the conditions of leachate, gaseous emissions, groundwater and surface water, etc.

Regular sampling exercise must be carried out and the samples analysed in order to assess the quality of the samples. The data collected from the monitoring activities can be used to assess the conditions and impact the landfill will have on the surrounding environment.

4.4 Management of Sanitary Landfill System

The operations, maintenance and environmental monitoring activities must be managed efficiently with strict adherence to the laws and regulations, inline with the technical standards and requirements, and with consideration to the surrounding environment.

The management activities can be divided into three main activities, i.e. the operations management, the environmental management, and the closure management.

(1) Operations Management

The operations management includes managing the activities of the day to day operational functions of the landfill, from management of the transportation traffic flow, the landfilling procedures, laying of cover material, management of the supporting facilities, collection of tipping fees, etc. The keeping of daily operational logs, records and relevant data must also be carried out.

(2) Environmental Management

The environmental management includes managing the necessary activities related to preserving and protecting the environment, such as monitoring the leachate and gasses emissions, Managing the effluent discharge after treatment, prevention of scavengers and propagation of insects, preserving the aesthetic and harmony of the surrounding, etc. The keeping of regular monitoring logs, test results, records and relevant data must also be carried out.

Consideration must also be given to the social aspects of management, i.e. managing the staffs and suppliers, fostering good relationships with the councils, clients, and with the surrounding residents.

(3) Closure Management

Consideration for the safety closure and post closure utilisation must be made during the operations stages. The closure management activities will include monitoring and ensuring that the landfill site has been operated satisfactory so that safety closure activities can be carried out in the future. Such activities included the monitoring of the stabilisation of the waste layers, the ground settlement, planning for the final cover and landscaping, etc.

4.5 Performance Indicators for the Landfill Management/Control

The performance indicators for the landfill management/control comprises of the following parameters.

- Waste record
- Landfill works
- Facility and equipment
- Environmental protection and monitoring
- Social consideration

In line with new privatisation programme as encouraged by the Government of Malaysia, the landfill operation concessions have been awarded to private contractors to operate and to maintain the landfill. The Government will still maintain the responsibility for the overall management and control of landfill operation.

The main parameters for the performance indicators for the landfill management/control are shown in **Table I-8** below.

Table I-8 Performance Indicators for the Landfill Management/Control

Items	Indicators
1. Waste Records	• Amount of waste received • Record of incoming collection vehicles • Number of checks of arriving waste and the results • Total accumulated waste and remaining capacity • Density of filled waste • Amount of recycling carried out at landfill site
2. Landfill Works	• Amount of waste disposed • Records of filling by area/cell/phase • Amount of cover soil provided • Records of accident and hazard incidents
3. Facility and Equipment	• Records of Operations and Maintenance (O&M) of landfill facilities (including expenditures) • Records of landfill equipment O&M (including cost) • Records of staff attendances
4. Environmental Protection and Monitoring	• leachate quality and quantity • Landfill gas quantity and quality • Surface water quality • Groundwater quality • Odour, scattered waste, dust, vector etc. • Ground settlement
5. Social Considerations	• Records of public complaints • Scavenging activities (if any) • Records of visitors

4.6 Post Closure Land-use Plan

The post-closure land-use plan must be considered and planned at the initial stages of the planning of the landfill, however such plan will only be implemented after the safety closure of the site has been carried out. It is necessary to formulate the improvement plan such that it will become possible to use the land after the landfill has been closed safely. The post closure land use plan can be used to plan and decide on how the landfill should be operated, the covering material to be used, the depths of the waste layers, etc.

In the preparation on the post closure land use plan, consideration must be towards the stability of the closed site, and the period of time required for the completed landfill to stabilise. The stabilisation process depends on the types and volume of the solid wastes, types and volume or thickness of cover material applied, the type and method of intermediate treatment processes being carried out such as crushing or compaction. All these factors must be evaluated to confirm whether the land of the closed site is suitable for the proposed post closure land use.

Prior to implementing the post closure land use plan, it is important to ensure that all the factors that have impact on the environment be dealt with and active countermeasure are in placed. Such include ensuring that proper post-closure procedures have been carried out prior to closure; all leachate and gasses discharge are being monitored and treatment facilities provided; the slopes and ground have been properly compacted and showing no signs failure; and all the waste have been properly covered and all pollutions are being contained.

In order to determine the suitability and evaluating the stability of the closed site, all necessary tests and ground/soil analysis must be carried out so that the data obtained may be used to estimate the degree of stability, to predicted subsidence rate, and to estimate the load bearing capacity of the ground.

4.7 Other Considerations

4.7.1 Compliance to Other Guidelines and Standards

In addition to complying to the series of laws and regulations related to solid waste management, some Local Authorities have set up a series of local government guidelines and standards which must be adhered to. Such additional standards may be decided on a case-to-case basis and the conditions may vary depending on the present situation and circumstances. However, there are also conditions whereby exemptions, variations or contraventions to certain regulations may be granted by the relevant authorities.

Although all the best endeavours will be put towards complying to all the laws and regulations in the planning and setting up the new landfill, not all regulations or standards can be met and contravention order, variation or exemptions may be submitted to the authorities for their consideration.

Generally there are three levels of application for the exemptions, they are;

Level A :
- Exemption from strict adherence to the Development Regulations that requires approval by the Local Authority
- Exemption to regulations that are not applied to construction of the sanitary landfill system.

Level B :
- Exemption to conditions that requires approval by the State Government.
- This may also require the acknowledgement by the relevant Federal Department or Ministry. However, this process relatively simple.

Level C :
- Exemption to conditions that requires approval from the Federal Government

Generally, Level A or Level B are preferred, however, there are increasing cases where it becomes necessary to select a site for which Level C is applied. In such cases, it is necessary to take into consider the period required for application and obtaining approval.

4.7.2 Occupational Health and Safety

It is essential to protect the occupational health and safety for the workers and also the general health and safety of the public. These can be achieved by fostering good housekeeping philosophies, good hygiene conditions and implementing strict safety directives.

The landfill site can be considered to be a hazardous workplace considering the unsanitary nature and danger present at the site. The putrid wastes are full of harmful bacteria and pathogens that are detrimental to human health. The proliferation of vectors such as flies, mosquitoes and wild animals feeding on the waste; the presence of sharp and hazardous objects, toxic chemical spillages and fumes, noxious gasses emissions, all pose a health hazard to the workers and to the general public. Other hazards such as gaseous explosions, fire, land slides etc are also a great concern for the workers.

(1) Prevention of Hazards

In order to prevent and preserve the well being and safety of the workers, the landfill must be operated with considerations to eliminating the potential courses of the hazards and to prevent accidents from occurring. All these can be achieved by adopting good housekeeping practices and good safety practices. Some of the major steps to be taken are:

- Eliminate the presence of vectors by installing fences, laying the cover material and spraying of insecticide.
- Minimising excessive pilling of waste to prevent waste sliding
- Preventing fire by banning all form of open burning of waste and smoking
- Provide suitable covering and compaction to ensure all dangerous and sharp objects have been properly covered
- Provide proper gas collection and dispersion systems, and monitoring all gas emissions

- Provide proper leachate collection and treatment systems
- Implement proper vehicles traffic system to prevent accidents
- Provide suitable vehicle washing facilities and disinfections systems

(2) Workers Welfare Amenities and Health Care Facilities

Proper health care management philosophy may be implemented to provide the adequate emergency treatment and support to the workers and to develop a suitable working environment which is healthy and pleasant to work in. The basic necessities are:

- Provide all workers with proper safety gears
- Provide regular emergency and safety training to the workers
- Provide washing and cleansing facilities for the workers
- Provide standard emergency medical supplies
- Provide regular medical check-up for the workers.

4.7.3 Weather Conditions

The design and planning of the landfill must take into account of the local weather conditions and seasonal climatic changes. The type of facilities provided, the operations and maintenance methodologies, etc must be able to support the landfill throughout the year during both the dry or wet weather conditions. Emergency response plan must also be establish to cater to abnormal weather conditions such as flash floods, drought or high winds.

In Malaysia, the tropical climatic conditions are generally either wet or dry, with heavy rainfall during the wet monsoon season and occasionally drought during the dry season.

(1) Wet Season

During the wet season, the rain usually comes in short burst of rainfalls, and during the monsoon season storms and heavy rainfall could last for a long period of time. In the design of the landfill, it is essential that proper rainwater drainage systems are provided together with the provision of adequate leachate collection and retention facilities.

Additional waste surface cover may have to be provided in order to minimise the rainwater from penetrating into the layers. Suitable drainage network system must also be provided on the cover surface to collect and diverted the rainwater to the perimeter stormwater drains.

Excessive rain will also result in flash flooding and causing soil erosions. Hence it is important to constantly monitor the conditions of the retaining walls, water retaining structures, the slopes, access roads etc.

(2) Dry Season

During the dry season, there could be periods of time without any rainfall and the grounds

and earth roads can become very dry and dusty. It is important to ensure that the level of airborne dust be minimised by monitoring the activities of laying the cover soil, the wind conditions, and also monitor the vehicles movements. It may be necessary to spray water on the dry roads to wet down the dust and to prevent them from being airborne.

4.8 Rehabilitation of Waste Landfill Site

Waste landfill sites which have not been properly operated and/or proper landfill facilities have not been facilitated shall be rehabilitated as soon as possible, in order to minimize environmental risks caused by the landfill sites.

Based on the landfill inventory survey carried out by the JICA study in the year 2003, named "The Study on the Safety Closure and Rehabilitation of Landfill Sites in Malaysia", more than 90% of landfill sites in Peninsula Malaysia are open dumping or level 1, and are therefore sources of environmental risks.

Rehabilitation of existing landfill sites shall be carried out sooner based on the technical components described in this guideline.

Part II

Technical Guideline on Sanitary Landfill System

Part II Technical Guideline on Sanitary Landfill System

Chapter 1 General

1.1 Integrated Landfill Facilities

A proper sanitary landfill must be provided with all the necessary facilities in order for the system to function effectively. The supporting and ancillary facilities must be integrated with the core facilities to form the Sanitary Landfill System.

A typical sanitary landfill system must be provided with all the necessary facilities as shown in **Figure II-1**. Generally the sanitary landfill system comprise of the core facilities, such as the waste retaining facility, leachate collection piping facility, gas vents, access roads, drainage system, fencing etc; and the supporting facilities, such as the leachate treatment facility, administrative facility, machineries etc.

The supporting facilities must be able to function independently as individual standalone facilities. However, their functions are generally interdependent and should be operated as integrated facilities, mutually support each other's functions. The design of the individual facilities differs from site to site, depending on the size, the requirements and the design service lifespan. All the facilities must be designed to operate and used throughout the designed target lifespan of the landfill. Some facilities must also be able to function beyond the target lifespan, i.e. to function even after the closure of the site. Such facilities include the gas venting systems, the leachate collection and treatment facilities etc.

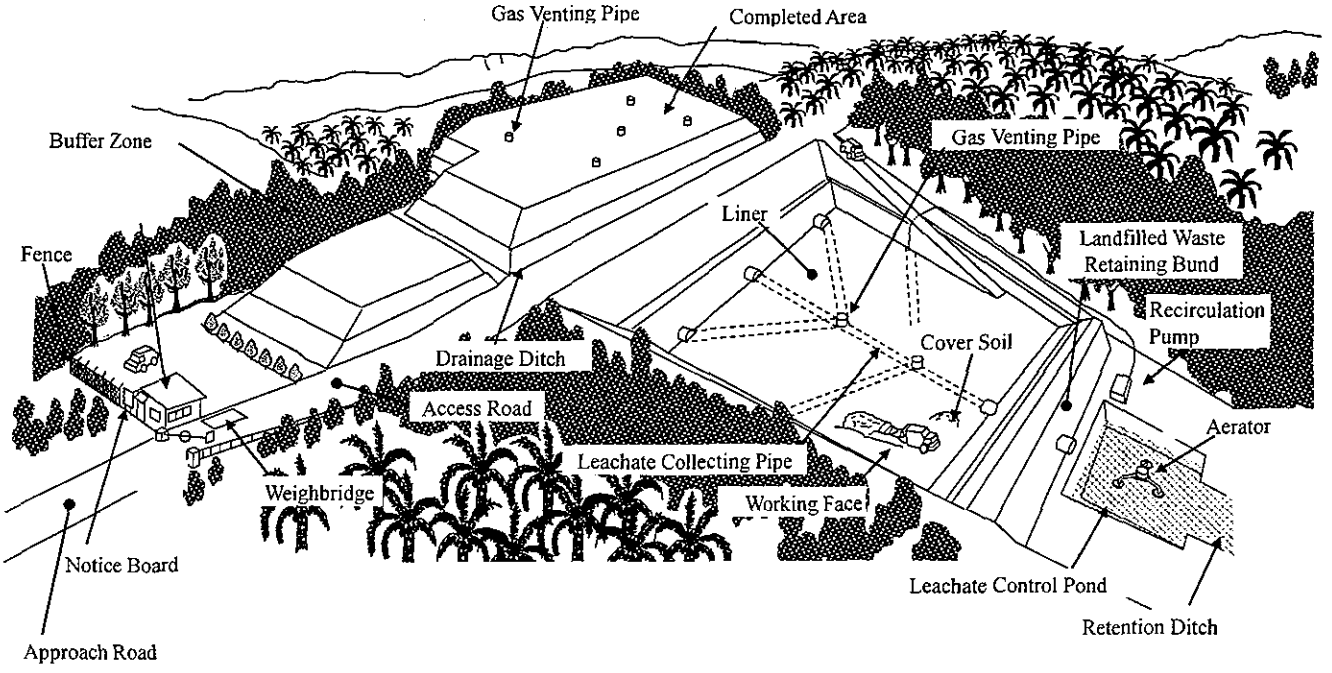


Figure II-1 Typical Sanitary Landfill System

1.2 Classification of Sanitary Landfill Levels

The level of improvement of the sanitary landfill system can be classified into four (4) levels. They are;

Level 1: Controlled tipping

Level 2: Sanitary landfill with a bund and daily cover soil

Level 3: Sanitary landfill with leachate recirculation system

Level 4: Sanitary landfill with leachate treatment facilities

The classification is used to determine the required standard of improvement to be achieved based on considerations to the site conditions, financial constraints, proposed technology, post closure land use, etc.

* "Sanitary Landfill" is defined as follows.

A method of disposing of solid wastes on land without creating nuisances or hazards to public health or the environment. Using the princeples of engineering the solid waste is confined to the smallest practical area, reduced to the smallest practical volume, and covered with a layer of earth at the conclusion of each day's operation (daily cover), or at more frequent intervals as may be necessary.

The levels are also used to determine the environmental impact and countermeasure of the landfill. The higher the level will result in lower environmental impact and thus fewer countermeasures will be necessary for closure and subsequent post closure utilisation.

New landfill should be designed to achieve Level 3 or Level 4, whilst for the existing landfill sites, the rehabilitations and improvement targets must achieve Level 3 or below. Landfills that do not meet the minimal standards are considered as open dump sites and should not be encouraged. Such sites must be closed safely and immediately.

The summary of the classification of the levels and the proposed facilities are tabulated in **Table II-1**.

Table II-1 Level of Sanitary Landfill System

Facilities	Level 1	Level 2	Level 3	Level 4
Soil Cover	+	++	++	++
Embankment		++	++	++
Drainage facility		++	++	++
Gas venting		++	++	++
Leachate collection			++	++
Leachate re-circulation			++	++
Leachate treatment				++
Liners				++
			Semi-aerobic	

Note: + / To be provided periodically.

++ / Level 2, 3 and 4 : To be provided daily.

1.2.1 Level 1

The level 1 is the lowest level to be adopted by any a sanitary landfill system. Basically waste is just dumped on the landfill in a controlled manner and levelled. Soil cover should be laid periodically.

(1) Target

- Introduction of controlled tipping. Waste shall be dumped in an orderly manner.

(2) Achievements

- Provision of well maintained access to the site
- Provision of periodic cover material to prevent scattering of wastes, minimise odour and fire
- Provision of basic management systems to inspection, control and daily logs of incoming wastes.

(3) Necessary Improvements to the Next Level

- Establishment of the site boundary
- Provision of environment protection facilities
- Provision of basic staff amenities such as office space, toilets, locker room
- Introduction of semi-aerobic sanitary landfill.

(4) Environmental Issue

Since only periodic cover materials are provided, the environmental impacts are still present, such as:

- Surface and groundwater pollution by leachate
- Scattering of waste and dusty
- Breeding of insects and rodents
- Unpleasant view of landfill
- Noise pollution
- Unpleasant odour

1.2.2 Level 2

The level-2 sanitary landfill shall be provided with the solid waste retaining structure, clearly defined cells and surface water drainage. The soil cover shall be provided daily.

(1) Target

- Sanitary landfill with a bund and daily cover soil

(2) Achievements

- Establishment of site boundary to clearly demarcating the disposal site
- Provision of sufficient daily cover soil
- Provision of surrounding bund to contain the waste
- Provision of surface and perimeter drainage system to divert the storm water
- Provision of environment protection facilities such as buffer zone, litter control and gas ventilation facilities
- Introduction of semi-aerobic sanitary landfill by providing gas ventilation facilities
- Provision of basic staff amenities such as office space, toilets, locker room

(3) Necessary Improvements to the Next Level

- Improvement of semi-aerobic sanitary landfill
- Provision of leachate collection system
- Provision of leachate treatment facilities

(4) Environmental Issue

In this level, since disposal site and drainage system are already established, landfill operations can be controlled effectively. With the application of sufficient cover and provision of some environment protection facilities, impacts from landfill operation will be much lower than Level 1. The installation of gas ventilation facilities will result in achieving semi-aerobic conditions. However, leachate is still not under control and a environmental monitoring system should be established.

1.2.3 Level 3

The level-3 is an improvement to the level 2 sanitary landfill by the provision of leachate collection and recirculation system. The leachate collected through a series of collection pipes will be recirculated back to the waste layer so that it may be reprocessed and further decompose to improve leachate quality. Recirculation will also promote faster evaporation and thus reducing the quantity of the effluent.

(1) Target

- Sanitary landfill with leachate recirculation system

(2) Achievements

- Establishment of leachate control by the installation of leachate collection, recirculation and monitoring facilities

(3) Necessary Improvements to the Next Level

- Provision of leachate treatment system
- Establishment of semi-aerobic sanitary landfill

(4) Environmental Issue

The leachate accumulated at the bottom layer of landfill will be collected and recirculated thus improving the quality and reducing the odour by the semi-aerobic decomposition process. The installation of leachate collection pipes beneath the waste layers will also promote ventilation and allow oxygen to penetrate into the waste to maintain the landfill site in the semi-aerobic condition, and accelerate the stabilisation of the wastes.

1.2.4 Level 4

The level-4 is an improvement to the level 3 sanitary landfill by the provision of the leachate treatment facilities and liner system.

The liner system will act as barriers to provide sealing function by preventing the leachate from penetrating deeper into the ground. The leachate will flow to the collection pipes and diverted to the leachate retention pond for further treatment. Aerators or air diffusers will be provided to enhance and hasten the treatment process for the effluent to be discharged.

(1) Target

- Sanitary landfill with leachate treatment facilities

(2) Achievements

- Provision of leachate treatment facilities with the installation of oxidation pond, etc.
- Provision of liners to control the seepage
- Establishment of semi-aerobic sanitary landfill

(3) Environmental Issue

The provision of seepage control facilities and leachate treatment facilities will enhance and promote semi-aerobic decomposition, and thus hasten the waste stabilisation period.

The leachate treatment facilities should be able to treat and improve on the quality of the effluent for discharge to the drains or watercourses. However, if the effluent discharge quality have to adhere to the more stringent requirements of Environmental Quality Regulations 1979, then it is necessary to provide higher level of treatment facilities that are able to treat the effluent to the requirement of Standard A.

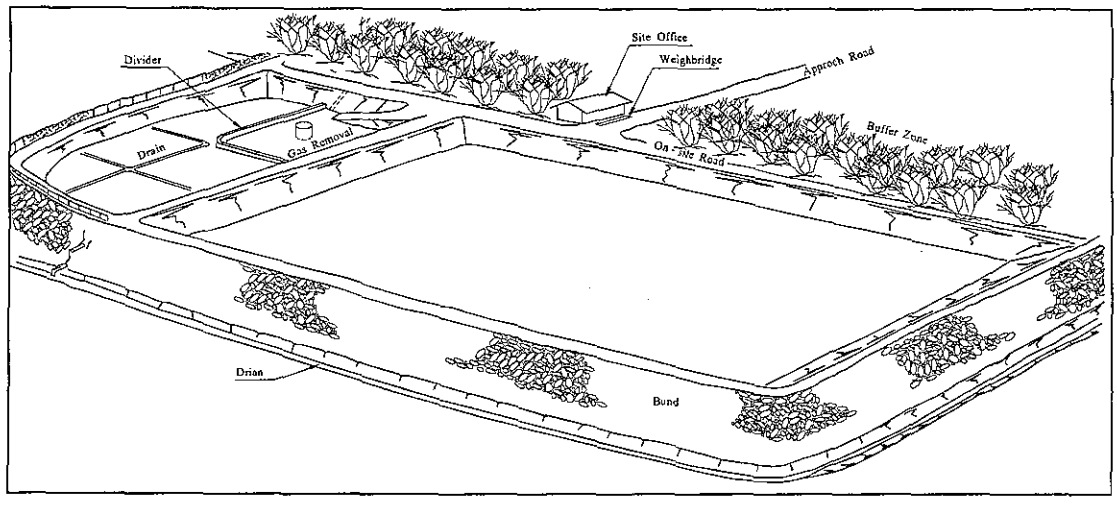


Figure II-2(a) Typical Layout for the Level 2 Sanitary Landfill

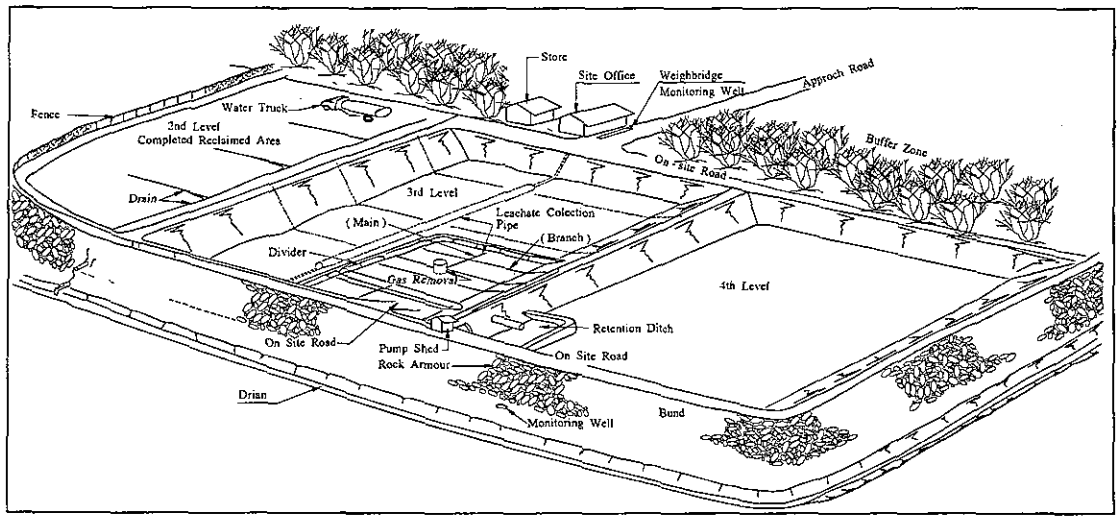


Figure II-2(b) Typical Layout for the Level 3 Sanitary Landfill

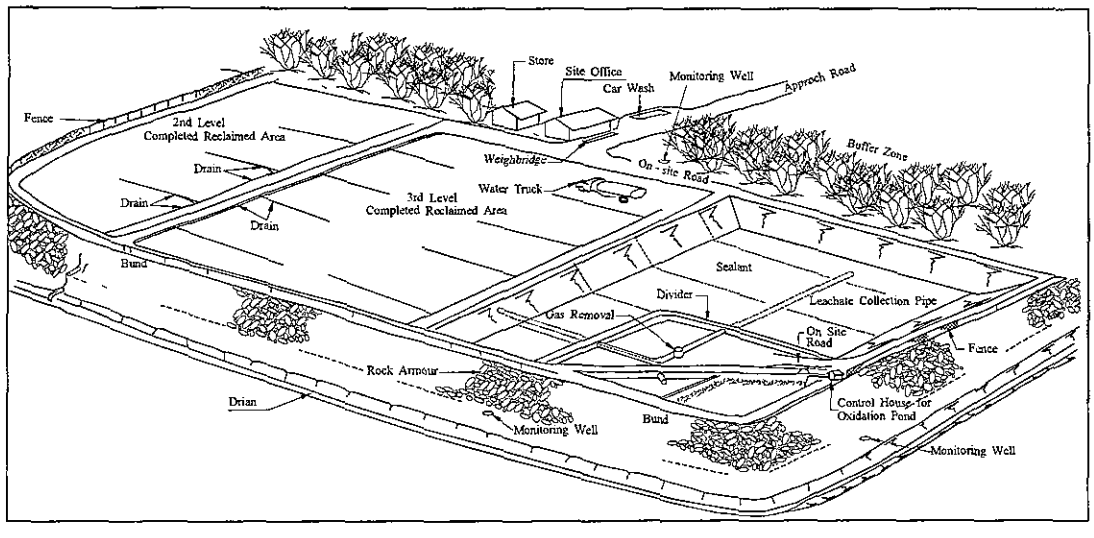


Figure II-2(c) Typical Layout for the Level 4 Sanitary Landfill

Chapter 2 Waste Retaining Facility

2.1 Functions of Waste Retaining Facility

Waste retaining facility is necessary to store the solid wastes in a safe manner, as well as to prevent overflow and collapse of the landfilled wastes.

Retaining facility are constructed to prevent overflow of landfilled wastes, collapse of working face and to ensure that the landfilled wastes are stored safely. In many cases, these structures also prevent discharge and seepage of leachate from the landfill site.

Generally a retaining facility is constructed to store waste, not water. However, in the event of an abnormal downpour, temporary retention of rainwater inside the retaining facility can happen. Hence, it is also crucial for the retaining facility to be able to store the water safely.

In short, the functions of retaining facility can be summarized as follows:

- Store the designated landfill volume.
- Prevent collapse of working face and overflow of landfilled wastes.
- Prevent discharge of leachate and seepage from the landfill site.
- Retain rainwater temporarily in the landfill site safely.
- Retain wastes safely during the landfilling process as well as after completion.

2.2 Planning and Design Concepts

Waste retaining facility has an important function at sanitary landfill, thus its structure shall be planned and designed carefully with appropriate concepts.

(1) Planning and Design Concepts

Structures of the retaining facility shall have the abovementioned functions and at the same time be sufficiently strong. The basic criteria in the planning and design of retaining facility are functionality, safety as well as economic consideration. The guidelines for planning and design of retaining facility are:

- Select structure that is suitable with the designed landfill configuration or landfill type.
- Select structure that is suitable with the landform of the site areas and natural conditions such as geological and soil conditions.
- Ensure safety factor for loading on the structure. This includes considerations on landfill deadweight, pressures from landfilled wastes, water pressures, etc.
- Ensure the loading on foundation is below the acceptable bearing load.
- Install liner facility if required to prevent discharge of leachate or seepage from the

landfill site to the surrounding areas.

- Predetermine the designed highest water level in the case when water needs to be temporary retained in the landfill site.
- Install appropriate stormwater collection facility so that to protect the foundation especially in the case when water retained in the landfill site overflows into the retaining facility during a heavy downpour.
- Take necessary countermeasures to prevent corrosion in retaining facility caused by wastes, leachate or underground water.
- Design structure to be harmonized with the surrounding environment.
- Select type of structure with consideration given to the ultimate use of the landfill site after closure.
- Select type of structure with consideration on the economical aspects and expected lifespan of the structure.

(2) Design Procedures

The type, structural configuration and foundation of the retaining facility vary according to its height, soil conditions, construction methods, landfilling plan etc. Some basics for design procedures are given as follows:

- Investigation on the basic items required for the design such as types and characteristics of wastes to be landfilled, topography of the construction site, geology, soil conditions and construction methods, etc.
- Comprehensive evaluation of the inter-relations between the above and the overall planning of the landfill, including the landfill lifespan, liner facility, leachate collection facility, leachate treatment facility etc. and their economic viability.
- Determine the design criteria required for the calculation of pressures caused by the landfilled wastes. Carry out stability analysis on the selected structural type and configuration.
- Calculate the stresses on each structural item. Determine all design parameters and make technical drawings.

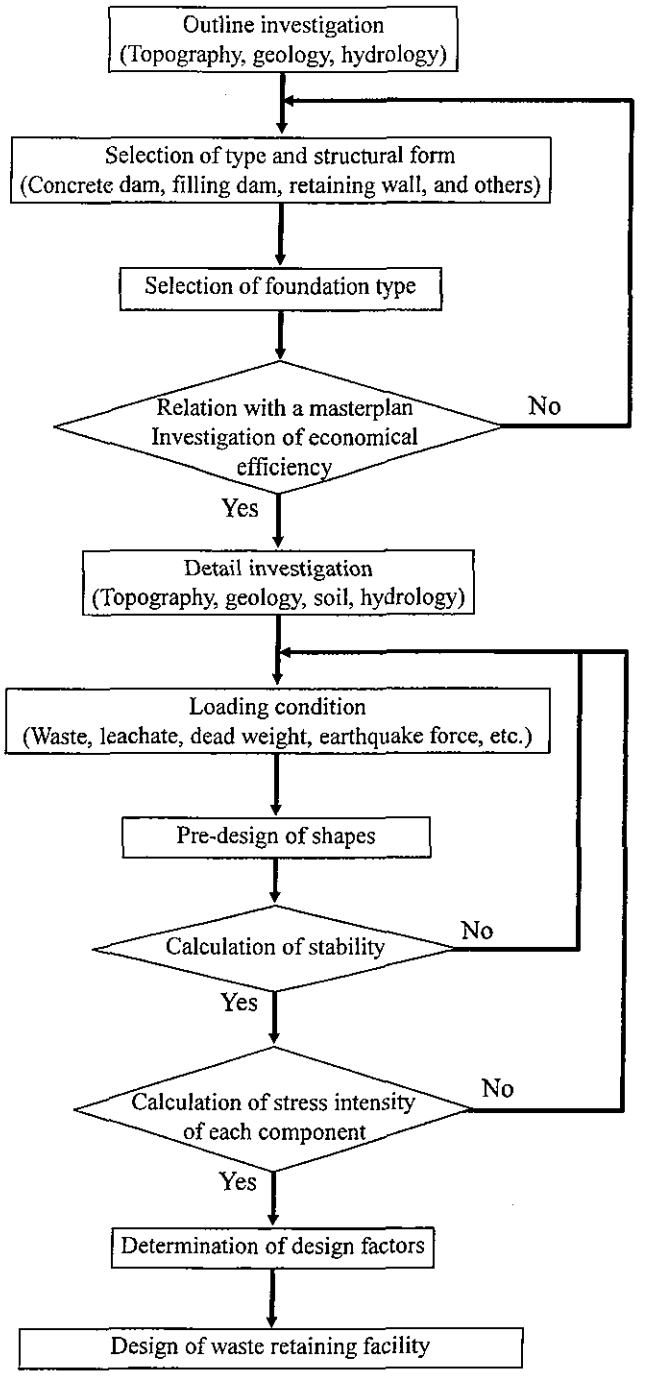


Figure II-3 Design Procedure of Waste Retaining Facility

2.3 Selection of Waste Retaining Facility and Structural Configuration

It is crucial to select an appropriate structure type of waste retaining facility in order to formulate an effective plan for landfilling activities. Factors to be considered in the selection are such as the topographical conditions, waste loading, soil conditions of the foundation etc.

(1) Types of Waste Retaining Facility

Examples of retaining facility for inland landfilling are concrete dike, bund, earth embankment, retaining wall, sheet piling etc. The design conditions and loading for each structure are different depending on its purpose.

Therefore, the most suitable structural configuration shall be determined based on the topographical conditions of the surrounding area, waste loading according to the landfilling plan and soil conditions of the foundation. At the planning stage, it is necessary to compare various types of structure. While in the design stage, it is important to reconfirm whether the structural configuration selected in the planning stage is the most viable and appropriate.

An example of actual design for the waste retaining facility is illustrated in **Figure II-4** below.

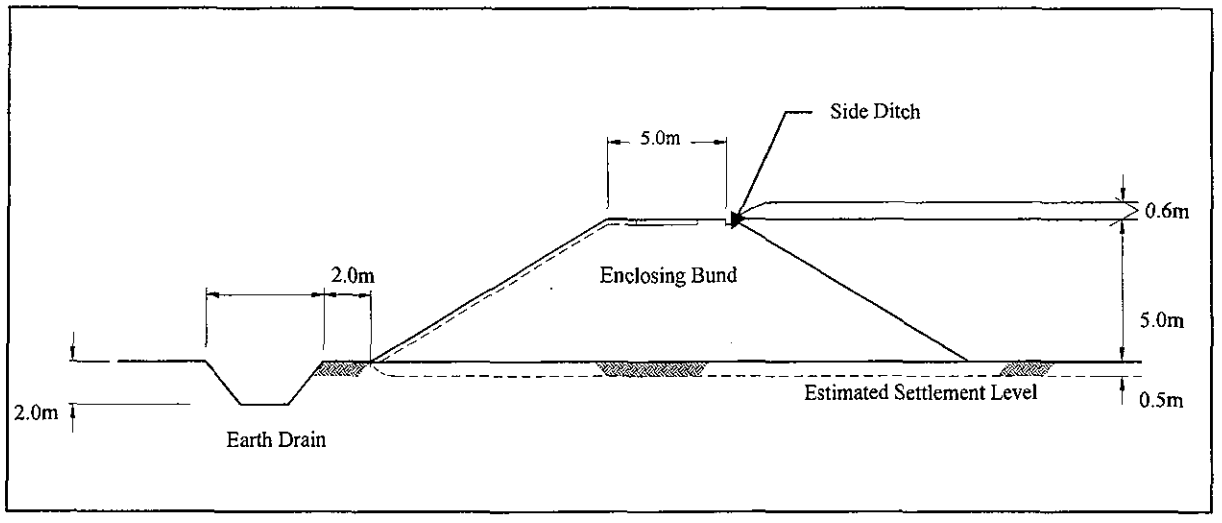


Figure II-4 Enclosing Bund for Landfilled Waste Retaining Facility

2.4 Loading on Waste Retaining Facility

When waste retaining facility is designed, it is important to take into consideration the loading information such as empty weight, waste pressures, hydrostatic pressures, uplift pressures etc., which affects the lifespan and usage of the retaining facility.

The loads acting on the retaining facility are landfill dead loads, landfill layer pressures, static waste pressures, uplift force, pore water pressures etc. In order to select the types of loading to be considered in the structural design, decision shall be made based on information concerning the characteristics of wastes, topography, geology, soil conditions, expected lifespan of the facility, surrounding environment etc.

The loading conditions on the retaining facility are different depending on the size as well as the expected lifespan of the landfill site. For small landfill site, too large loading conditions shall be avoided so that the design of the retaining facility becomes more viable economically. A rational

plan and design can be achieved by selecting the most appropriate structural type based on the evaluation criteria of safety, compatibility as well as economic consideration.

Table II-2 shows the design conditions for landfilled layer pressure established for several actual designs of landfilled waste retaining structures in Japan.

Table II-2 Design Examples of Waste Retaining Facility in Japan

Categories \ Structure Types		Gravity type concrete dike H ≥15m	Gravity type concrete dike H<15m	Reinforced concrete wall	Sheet piling	Embank-ment	Others	Total
Cohesiveness	0 < C < 1.0 t/m^2	4	3	2	0	13	0	22
	1.0 < C < 5.0	0	1	1	0	9	0	11
	5.0 < C < 10.0	0	0	0	0	2	0	2
	10.0 < C	0	1	0	0	0	0	1
	Total	-	-	-	-	-	-	-36
Internal angle of repose	0 < f < 25°	1	3	1	0	14	0	19
	25 < f < 30°	4	4	5	0	6	0	19
	30 < f < 35°	0	1	0	0	4	0	5
	35 < f	0	0	0	0	0	0	0
	Total	-	-	-	-	-	-	-43
Bulk density	q < 1.6 t/m^3	3	2	3	0	11	0	19
	1.6 < q < 1.8 t/m^3	2	3	3	0	13	0	21
	1.8 < q < 2.0 t/m^3	0	2	0	0	2	0	4
	2.0 < q	0	1	0	0	0	0	1
	Total	-	-	-	-	-	-	-45

2.5 Corrosion Control

In case of using concrete or stainless steel for the construction of waste retaining facility, accidents such as overflow of wastes may occur due to corrosion. Hence, corrosion prevention measures are necessary.

Corrosion control is important in order to prevent accidents such as the extrusion of landfilled waste due to reduction in material strength caused by corrosion. In selecting corrosion control measures, the causes of erosion shall be identified according to the working environment, whether it is due to leachate or gas produced by decomposition of wastes or other corrosive elements carried in the atmosphere, fresh water or seawater, underground or it could be due to chemicals oxidation etc.

(1) Concrete

The constituents of concrete are mainly calcium salts of silica acid, aluminium and ferric oxide. Therefore, the corrosion of concrete is caused by the chemical iterations of its chemical constituents where the degree of corrosion is different depending on the composition of mixture.

The corrosion prevention of concrete structure is basically to prevent concrete from losing its alkali condition. It is important to prepare a good cement aggregate mixture and control the concreting and curing processes. Other measures are such as coating the concrete with

a layer of organic compound, paint or asphalt.

(2) Steel

Corrosion of steel can be caused by electro-chemical, purely chemical or biological mechanisms. The electro-chemical effects are more common. Some of the corrosion control measures for steel are:-

- Mortar or concrete coating
- Organic compound coating
- Painting
- Application of electricity

Table II-3 shows the rate of corrosion of steel under different conditions.

Table II-3 Corrosion Rate of Steel

Corrosion Environment		Corrosion Rate (mm/year)
Land	Exposed and above ground level	0.1
	Buried above ground water level	0.03
	Buried below ground water level	0.02