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 3

Guideline for Safe Closure and Rehabilitation of MSW Landfill Sites

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 3 Guideline for Safe Closure and Rehabilitation of MSW Landfill Sites**".

Guideline for
Safe Closure and Rehabilitation of
MSW Landfill Sites
(Draft)

Ministry of Housing and Local Government
MALAYSIA

GUIDELINE FOR
SAFE CLOSURE AND REHABILITATION OF MSW LANDFILL SITES

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ABBREVIATIONS

Note: Abbreviations used in this Report

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOE	Department of Environment, Malaysia
EC	Electric Conductivity
EIA	Environmental Impact Assessment
EPU	Economic Planning Unit
EQA	Environmental Quality Act
GL	Ground Level
HDPE	High Density Polyethylene
JICA	Japan International Cooperation Agency
LA	Local Authority
LACMIS	Landfill Closure Management Information System
LGA	Local Government Act
LGD	Local Government Division
LSMC	Landfill Sites Management Committee
MP	Majlis Perbandaran (Town Council)
MHLG	Ministry of Housing & Local Government, Malaysia
MLSS	Mixed Liquor Suspended Solids
MOF	Ministry of Finance, Malaysia
MOH	Ministry of Health, Malaysia
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
ORP	Oxidation Reduction Potential
PC	Physical Closure
PCM	Post-closure Management
PVC	Poly Vinyl Chloride
QC/QA	Quality Control/Quality Assurance
SC	Safe Closure
SDBA	Street, Drainage and Building Act
SS	Suspended Solids
TCMLS	Technical Committee for Management of Landfill Site
TOC	Total Organic Carbon
UPEN	Unit Perancang Ekonomi Negri (State Economic Planning Unit)
USD	Urban Services Department

Part I GENERAL

I-1 Purpose of the Guideline

The purpose of the landfill safe closure is as follows.

(1) Protecting public health and the environment by proper management of landfill safe closure and post closure land use,
(2) Prevention of environmental pollution and risks from the closed landfill sites,
(3) Prevention of environmental pollution and risks from the uncontrolled development of closed landfill sites

Municipal solid waste landfills generate environmental pollution and hazards long after the waste landfill ceases in operation. Degradation of the waste layers takes a long time whilst they continue to produce leachate and landfill gases. It is necessary to manage the site properly after the operations and to manage the post closure land use in order to protect the public health and preserve the environment. These problems are further aggravated by the fact that majority of landfills in Malaysia have not been managed and closed properly.

In order to achieve a safe closure of the landfill, it is important that the various measures for safe closure have been considered even at the initial stages, from planning through to design and construction, and eventually throughout the operations.

This guideline provides the recommended steps necessary to close the landfill in a safe manner, including steps to rehabilitate the closed landfills and on how to manage the closed landfill site properly. This guideline also provides the recommendations for the post closure land use of closed landfill sites.

This guideline is to be used in conjunction with the "Technical Guideline on Sanitary Landfill, Design and Operation (Revised draft)", and should cover the entire lifespan of the landfill site. It should be noted that for landfills with proper facilities and operation, the burden on the safe closure might be significantly reduced. In other words, in order to reduce the risks of pollution and hazards caused by the landfill and reduce the safe closure cost, improper operating landfill sites are necessary to be rehabilitated in accordance with the *Technical Guideline. (For further information, refer to **Appendix 1**)*

I-2 Scope of the Guideline

I-2.1 Landfill Sites Covered by the Guideline

This guideline shall cover the landfill sites that accept municipal solid waste. These are categorised as follows:

a. Closed landfills and open dump sites
b. Existing landfills in operation
c. New landfills

According to the existing Government policy, all new landfill should be sanitary landfill and requires EIA approved from DOE.

I-2.2 Landfill Closure Stages Covered by the Guideline

This guideline mainly covers the following landfill closure stages.

a. Physical closure (PC) of landfill sites
b. Post-closure management (PCM) of landfill sites
c. Post-closure land use of closed landfill sites

In this guideline, the "Safe Closure (SC)" process shall include the "Physical Closure (PC)" and the "Post-closure Management (PCM)". The "Post-closure land use" is regarded as part of PCM.

I-3 Definitions of Terms

Landfill site: The site where municipal wastes are disposed off by land filling. Such sites should be provided with adequate landfill facilities. In accordance with the "Technical Guideline on Sanitary Landfill, Design and Operation (Revised draft)", the landfill sites can be categorised into 4 types; i.e. from Level 1 (L1) to Level 4 (L4). Open Dumpsite is categorised as Level Zero (L0.)

Closed landfill site: The landfill site where the waste filling activities have been completed.

Abandoned site: The landfill site where the owners/operators could not be identified "Illegal dump site" will be included in this category.

Safe closure (SC): "*Safe closure*" consists of the activities of "Physical closure (PC)" and "Post-closure management (PCM)".

Physical closure (PC): The action by which the necessary measures for safe closure has been applied to the entire landfill area.

Closure levels (C1, C2, C3, C4): There are 4 closure levels, i.e. from C1 to C4. These closure levels indicate the countermeasures necessary to control the environmental pollution and hazards from the landfill sites. Each landfill site should be assigned with a targeted closure level at the initial stages of the safe closure process.

Post-closure management (PCM): The management activities necessary to operate, maintain and monitor the landfill facilities such as the leachate treatment, landfill gas treatment, cover soil etc. The activities also include the environmental monitoring, landfill stabilization monitoring and management of information/records of the closed landfills.

Post-closure land use: The re-utilization of closed landfill sites for purposes other than for waste filling. The PCM activities should be continued through out the post-closure land use.

I-4 Related Regulations and Legislations

The related laws, regulations and guidelines on the safe closure of landfill site are as follows.

(1) Land and Sanitation & Cleansing

- Local Government Act 1976 (LGA)
- Town & Country Planning Act 1974
- Land Acquisition Act 1965
- Street, Drainage and Building Act 1974 (SDBA)
- By-laws under the LGA on collection and disposal of solid waste

(2) Environment

- Environmental Quality Act 1974 (EQA)
- Environmental Quality Order (Prescribed Activities Environmental Impact Assessment) 1987

(3) Guidelines

- Guiding Principles for the Design of a Municipal Solid Waste (MSW) Sanitary Landfill, DOE (draft)
- Technical Guideline on Sanitary Landfill, Design and Operation (revised draft)
- The Environmental Impact Assessment Guideline for Municipal Solid Waste, Sewerage Treatment and Disposal Project, DOE

(4) Others

- Action Plan for Beautiful and Clean Malaysia (The ABC Plan)

I-5 Basic Concept of the Guideline

I-5.1 "Safe Closure"

(1) A landfill where waste-filling activities have been completed shall be closed properly for safe storage of the waste and prevention of pollution to the surrounding environment.

(2) When a landfill is being closed, appropriate measures shall be taken to prevent environmental pollution caused by leachate or landfill gas resulting from the decomposition and degradation of the waste. Even long after closure of the landfill, post-closure management (including environmental monitoring) should be carried out continuously.

Parameters that indicate the stability of the landfill site and may lead the termination of the post-closure management are shown in **Table I-5.1**.

Table I-5.1 Parameters to Measure the Landfill Stabilization

Parameter	Target value
Leachate	Below DOE Standard A or B (depend on location of the landfill) <Mainly for BOD, COD, SS and Heavy Metals>
Landfill gas	Methane (CH_4): below 1.0%[1]
Subsidence rate	Below 2 cm per year[2]

(*For further information, refer to **Appendix 11 and 12**.*)

(3) Preceding and precautionary approach

When a landfill site ceases in operation and closed, it is necessary to formulate a "safe closure plan" that which comprises of the physical closure (PC) and the post-closure management (PCM) for submission to the relevant authorities for approval. This also applies to the abandoned sites.

(4) Appropriate technology

In order to minimize the risks of pollution and hazards caused by the landfill, *the Appropriate Technology* should be applied to close the site safely and to manage the closed site.

[1] UK DOE (1991) Waste Management Paper No 26, 27

[2] "Guidance for Forming of Appropriate Residential Estate" (Japan Society of Architectures and Ministry of Construction) 1975

(5) Site-specific approach

In order to determine the "safe closure" requirements, the conditions of each individual site shall be investigated. Their risks to environmental pollution/hazards and potential for post-closure land use should be evaluated based on the site-specific conditions. From the evaluations, the proper countermeasures can than be applied ranging from the basic level (C1) to the advanced level (C4).

I-5.2 "Post-closure Land Use"

(1) The type of post-closure land use of closed landfills should be carefully considered based on the clear understanding of the landfill conditions during operations, closure, and together with impacts it may have had on the surroundings. The post-closure land use should also take into considered the aspects pertaining to environmental protection and the health and safety of the users and the public.

(2) The "Post-closure land use plan" (including the land use plan, safe measures and post-closure management) will have to be formulated and submitted to the relevant authorities for approval. Once approval has been obtained, then only the new land use for the closed landfill can be implemented.

(3) Operation and maintenance of the landfill facilities should be continued throughout the post closure land use redevelopment. Those facilities that may have been affected by the redevelopment works, such as the gas ventilation pipes and surface drainage, must be re-installed at suitable locations in order to preserve their functions.

(4) The stabilization period of landfill site after waste filling has completed is expected to be minimum 10 years. Therefore, post-closure land use shall be considered and can be preceded after this period. This is to minimize the effects of land subsidence and landfill gas generation on the development site.

(*For further information, refer to **Appendix 12.***)

However, for the landfill sites 5 years has past after waste filling has completed, provisional land-use might be applied under the following conditions.

1. Utilization of only surface layers of the closed landfill site and access of the people to the site shall be very limited; such as green space, parking etc.

2. Prior to the utilization, monitoring of environment and landfill stabilization shall be carried out and then the landfill condition shall be clarified.

I-5.3 Legal Framework of Landfill Safe Closure

In order to implement and manage the sustainable landfill safe closure efficiently and effectively, institutional and legal systems will have been set up in accordance with the following principles.

(1) The registration system of landfill sites will have been established to ensure better enforcement of the required measures and long-term operation and maintenance of the closed landfills in accordance with the appropriate safe closure measures.

(2) The State Governments will be responsible for registration of the landfills, management/monitoring of landfill safe closure and post-closure land use.

(3) The Federal Government will set up a new funding system to subsidize the additional financial expenditure necessary to implement the safe closure of landfills.

(4) The landfill management activities will have to be managed by the State Governments and Local Authorities complying with the relevant regulations and laws. The Federal Government will provide the necessary technical advice and assistance with the human resources development.

I-5.4 Roles of Stakeholders

The roles of the main stakeholders are as follows:

(1) Federal Government

The Federal Government will provide technical advice and assistance to the State Governments for the management of the landfill safe closure and post-closure land use. The Federal Government will prepare and allocate sufficient financial resources for the physical closure and post-closure management of the landfills.

An inter-ministerial committee or advisory board could be established in the Federal Governmental level to manage and oversee the safe closure and post closure activities.

The Federal Government will be responsible for the following major tasks:

a. To provide the Guideline for safe closure of landfills. (MHLG)
b. To provide technical support and assistance to the State Governments and LAs. (MHLG and DOE)
c. To set up the landfill registration system and determine the priority of each

operating and closed site based on the information obtained from the State Governments and LAs. (MHLG)

d. To set up and manage the specific funding system for the landfill safe closure, and allocate funds to the State Governments and LAs. (Economic Planning Unit (EPU), Ministry of Finance (MOF) and MHLG)
e. To set up a technical advisory committee to determine and provide technical assistance to the State Governments and LAs
f. To monitor and verify the re-development plan for the closed site with regards to the technical issues and to assist the State Governments when required

(2) State Governments

State Governments should play the main role in the registration of landfill sites in their boundary and management/monitoring of the landfill safe closure and past closure land use.

A new committee could be established in the State Governmental level to handle these roles.

The State Governments should be responsible for the following:

a. To collect information and data on the landfills in their respective boundaries (through landfill registration) and to evaluate and determine the priority and closure level for each site, and forward the data to MHLG
b. To review the Safe Closure Plans (PC plan and PCM plan) and provide approval to the site owner/operator, and monitor the activities with the cooperation of LAs
c. To manage/control the PC and PCM for the abandoned sites
d. To request funding from the Federal Government for implementation of the PC and PCM of landfills
e. To monitor the funds and verify the expenses for the SC
f. To review the post-closure land use plan and provide approval to the developer, and monitor the activities with the cooperation of the LAs
g. To collect the portion of the tipping fee which is to be paid into the specific Fund for the landfill closure with the cooperation of LAs
h. To set up a working committee to oversee the landfill safe closure in the State Government.

(3) Local Authorities (LAs)

The Local Authorities shall support the State Government in carrying out the duties and activities on safe closure of landfills.

For the "*abandoned site*", the LAs should assume the role of the site owner or operator, with support from the State Governments and the Federal Government.

The roles of the LAs are as follows.

a. To collect the information and data on the landfills in their respective jurisdictions and forward to the State Government, and assist in the registration, evaluation and clarification of landfills
b. To monitor/supervise the activities of operation and closure of the sites carried out by the landfill owner/operator and/or developer with the cooperation of the State Government
c. To implement the PC and PCM for the abandoned sites
d. To collect the portion of the tipping fee which is to be paid into the specific Fund for the landfill closure under the instruction of the State Government

(4) Site Operator/Owner

The operator/owner of the landfill site should construct and operate the landfill in accordance with good practices as set out in the "Technical Guideline on Sanitary Landfill, Design and Operation (revised draft, 2004)". When the waste filling activities have been completed, the site operator/owner should implement the physical closure (PC) work and commence on the post-closure management (PCM), and with support from the State Government.

The site owner/operator is major players for landfill site operation/management and their roles are as follows:

a. To document and manage the information and records of their landfill site properly (i.e. the geological survey report, EIA report, construction records, operation and monitoring records, etc)
b. To operate the site properly and to keep daily records of the operations (i.e. the tonnage of waste accepted, cover soil work, leachate treatment, etc)
c. To inform the LAs and the State Government on the schedule of final waste acceptance (more than one year but less than two years in advance).
d. To prepare the SC plan (PC and PCM) with the cooperation of the State Government and other relevant parties
e. To implement the SC properly by using the subsidies from the specific Fund
f. To pay the additional tipping fee to the specific Fund of landfill safe closure, under the instructions of the Federal Government, State Government and the Las

(5) Developers and Land Owner

Developers and/or the landowners planning to use a closed landfill site for other development purposes will have to consider the necessary measures for environment protection and hazards control as for a past closure management.

The major role of the developers and landowner are as follows:

a. To collect the information and records of the landfill from the relevant parties
b. To investigate the site from the aspects of environmental pollution and possible hazards
c. To prepare the post closure land-use (i.e. the re-development plan, PCM plan and safe plan) of the site and to obtain the approval from the State Government
d. To take over the obligation for PCM from the site owner/operator
e. To inform the future land users on the conditions of the site and any other issues that may have arisen.

(*For further information, refer to **Appendix 3** and **4**.*)

I-5.5 Landfill Registration System and Record Management

All operating and closed landfill sites should be registered and the records should be kept and managed by the relevant authorities of the State Government.

The relevant authorities of the State Government should collect the information of all the landfills within their boundary and generate a database and registering the sites. This information will be opened to the land authorities and planning authorities at the State level. This information will be collated and managed by the Federal Government, i.e. by MHLG.

(*For further information, refer to **Appendix 5**.*)

I-5.6 Financial Resources and Funding

The strategic funding system will be set up at the Federal Governmental level for implementing the sustainable landfill safe closure. The general concepts for the funding system are as follows.

(1) The setting up of a specific *Fund* for implementing the safe closure of the landfill sites.

(2) During landfill operation, a necessary fee should be added to the tipping fee to allow for contributions towards the *Fund.*

(3) The Federal Government will manage the *Fund* and apportion the funds accordingly upon the requests from the State Governments and by taking into account of the landfill closure priorities.

(*For further information, refer to* ***Appendix 6.***)

I-6 Process of Landfill Safe Closure

The processes of landfill safe closure are as follows.

(1) The operator/owner of landfills should assess their respective sites in order to clarify the environmental pollution potential and land use potential.

(2) Based on the assessment, the operator/owner should setup a closure level of the landfill site.

(3) The operator/owner of landfills should prepare the "Safe Closure (SC) Plan" for submission to the State government for approval. The SC plan should be submitted one year before closure of the landfill site.

(4) After the approval, the operator/owner of landfills will implement the physical closure works and post closure management activities. These activities should be informed to the related authorities periodically.

(5) State government should examine the SC plan and approve if it meet the requirement. Safe closure activities (PC and PCM) carried out by the operator/owner should be managed and monitored by the State government.

(*For further information, refer to* ***Appendix 2.***)

(6) The developer should prepare the "Post-closure Land Use Plan" and submit to the relevant authority in the State government for approval.

(7) The developer can implement the post-closure land use after obtaining the approval. Implementation activities including PCM shall be informed to the related authorities periodically.

I-7 Human Resources Development

Regarding to the landfill management including landfill safe closure, it is necessary to establish and continue with the "human resource development" exercises for all the stakeholders.

MHLG will organize and provide the necessary training courses regularly.

Part II TECHNICAL REQUIREMENTS

II-1 Technical Requirements for Safe Closure of Landfill Sites

The technical requirements for safe closure of landfill sites are as follows.

(1) Landfill sites should be closed safely and the post-closure management should be carried out properly.

(2) Measures for safe closure of landfill sites.

a. To prevent wastes from littering or overflowing from the landfill site
b. To prevent fire or explosion that may be caused by landfill gases
c. To minimize offensive odours emitting from landfill site
d. To provide storm water run-off and drainage facilities
e. To minimize environmental pollution caused by leachate from landfill site
f. To prevent groundwater contamination
g. To take measures for wastes stabilization

(3) Measures for post-closure management of landfill sites.

a. To implement appropriate operation and maintenance activities of landfill facilities such as providing the final cover soil
b. To continuously operate the landfill facilities such as the leachate treatment plant
c. To continue with the environmental monitoring work
d. To continue with the waste stabilisation monitoring

(4) Appropriate measures and activities required to achieve safe closure should be determined based on the conditions of the site including operation level, existing facilities, surrounding environment and post closure land use.

II-2 Determination of Priority and Safe Closure Level

All landfill sites should be assigned with the targeted safe closure level at the initial stages of the safe closure of landfill sites. The procedure to clarify the safe closure level for each landfill site is as follows.

(1) Site assessment survey should be carried out in order to determine the general conditions, environmental conditions and land use conditions of the site. From the results of the survey, the environmental pollution potential and land use potential can be evaluated. (*For further information, refer to* ***Appendix 18.***)

(2) From the evaluation, the closure priority of the landfill site and applied closure level should be setup.

(3) The proper safe closure plan should then be formulated and the physical closure works and the post closure management activities should be carried out.

II-2.1 Priority of Landfill Sites for Safe Closure

All the landfill sites should be evaluated and ranked according to their priority for safe closure implementation. From the priority list, the sites requiring urgent remedial actions can be identified and the necessary funds can be allocated to the site. The evaluation and priority of each site that has been identified for safe closure should be determined by the State Governmental and approved by the Federal level lead by MHLG. The ranking will be based on two criteria, i.e. the environmental pollution potential and the land use potential.

The sites can be classified into 4 groups, namely Group A, B, C and D, as shown in **Table II-2.1**.

Table II-2.1 Grouping of Landfill Sites for Safe Closure Priority

	Priority	Environmental Pollution Potential	Land use Potential
Group A	High	High	High
Group B	Middle	High	Low
Group C	Middle	Low	High
Group D	Low	Low	Low

(*For further information, refer to **Appendix** 7.*)

II-2.2 Closure Level Applied for the Landfill Sites

The appropriate closure level should be assigned and applied for the prevention of environmental pollution and hazards. The relevant authorities at the State level should be responsible to determine target closure level for each landfill site within their jurisdiction. The closure levels are classified into 4 categories as follows.

Level C1: Minimal closure level (to provide final cover and drainage system around the site)

Level C2: Low closure level (similar to C1, but with the addition of dike, controlled slope and gas ventilation system)

Level C3: Middle closure level (similar to C2, but with the addition of semi-aerobic landfill system with leachate re-circulation)

Level C4: High closure level (similar to C3, but with the addition of groundwater pollution control measures with leachate treatment)

The measures necessary to be taken for each of the closure levels are tabulated in **Table II-2.2.**

Table II-2.2 Closure Levels and Required Measures/Facilities

Measures	Safe closure Level			
	C1	C2	C3	C4
Final cover soil	++	+++	+++	+++
Storm-water drainage	+	++	+++	+++
Safely storage	+	++	+++	+++
Gas vent		++	+++	+++
Leachate		+	+++	+++
Groundwater			++	+++
Early stabilization		+	+++	+++
Post closure measures		+	+++	+++
Monitoring	+	++	+++	+++
Landfill system			Semi-aerobic System	

Notes: 1. The methodology of closure level set-up is described at the **Appendix, Chapter 5, Volume 2.**
(Refer to article 3.1 of Chapter 3.)
2. +: minimum equipped/ operated, ++: fair, +++: fully equipped/operated
3. As for C3 and C4, in line with the semi-aerobic landfill concept, aerobic area of existing landfill site will be expanded by safe closure measurement. For further information of semi-aerobic system, refer to **Appendix 10.**

The landfill sites identified for safe closure that has been assigned with the higher priority should be given the higher closure level. The relationship between the landfill closure levels and the priority groups are tabulated in **Table II-2.3.**

Table II-2.3 Relationship between Landfill Closure Priority and Safe Closure Level

Group	Priority for closure	Safe closure Level			
		C1	C2	C3	C4
Group A	High			+++	++
Group B	Middle		+	+++	+
Group C	Middle		+++	++	
Group D	Low	++	+++		

Note: +, ++, +++: magnitude of the relation (+: low, ++: medium, +++: high)

*(For further information, refer to **Appendix 8.**)*

II-3 Site Survey for Evaluation and Design

The landfill site should be evaluated properly based on the site survey/investigation. The following items will be required to evaluate the landfill site and to provide the proper measures for safe closure.

Table II-3.1 Survey Items for the Site Assessment

Items	Proposed Measures
(1) Topographic and Geological survey	The topographic and geological data of the sites should be collected and further surveys be carried out where necessary.
(2) Structures and facilities of landfill site	The details of the landfill facilities and records of the landfill operations should be collected. All the landfill facilities should be clearly identified and indicated on the plan.
(3) Shape and stability of filled waste	The shape of the site should be clarified in order to evaluate the stability of the landfill site.
(4) Total amount of disposed waste	The total amount of the filled waste should be estimated based on the operation record and topographic profile of the site.
(5) Degradation of the filled waste	The information and data of the following should be collected and/or measured; a. The amount and quality of the leachate b. The amount and quality of the landfill gas c. The temperature of the waste layers d. The physical composition of the waste (if available) The variation in the leachate and gas concentration should be used to determine the rate of decomposition, degradation and the stabilisation of the landfill waste.
(6) State of the surrounding environment	The conditions of surrounding environment should be surveyed and/or measured. All relevant information including the monitoring data should be collected.
(7) Surrounding land use	The surrounding land use should be identified and the land use plan of the site should be collected (if any).

Note: As for items to be surveyed and/or identified related to (6) and (7) above are shown in **Appendix 18**.

II-4 Requirements of Safe Closure

In order to implement the safe closure of landfill site, proper physical closure and post closure management should be carried out.

(1) The Physical Closure (PC) consists of the measures or facilities necessary for the safe storage of waste, prevention of environmental pollution and early stabilization of waste.

(2) The Post Closure Management (PCM) consists of the operation of landfill facilities such as leachate treatment plant, the maintenance of the facilities including covering soil, and the monitoring of environment pollution and stabilization of waste.

II-4.1 Requirements of Physical Closure

The closed landfill should be provided with the necessary facilities for the safe storage of waste, to prevent environment pollution and to accelerate early stabilization of waste. Also the facilities for post closure management, such as control building for operation and maintenance and the monitoring facilities should be provided.

The facilities required for landfill safe closure should be planned, designed and implemented based on the following requirements.

(1) Reformation for Landfill Shape/Slope and Waste Storage Facility

The shape or slope of the filled waste should be modified if they are deemed to be unstable and/or when the waste has been overfilled. The gradient of the slopes should be less than 1:2. In order to prevent soil erosions, gentler slope will be preferred.

The waste storage bank and/or retaining wall should be constructed if the shape of the filled waste is not stable, and if the boundary of the site is limited. The proposed modification and improvement works should be described in details in the safe closure plan.

(2) Final Cover Soil

The final cover soil should be provided for environmental protection measures, i.e. to minimise the leachate production, prevention of waste scattering, minimize odour and prevention of fire. The recommended thickness of the final cover soil should be more than 750mm.[3] In areas where trees and scrubs are to be planted, the thickness should be increased to be more than 1500mm.[4] Regular maintenance of the cover soil will be necessary.

(3) Storm Water Drainage

Storm water drainage system should be installed at the upper part, at the slopes and at the surroundings of the landfill site. This is to prevent the water from seeping into the waste layers and reduce the leachate production amount and protect the landfill site. Regular maintenance of the storm-water drainage will be necessary.

[3] US EPA. (1994) Design, Operation, and Closure of Municipal Solid Waste Landfills. EPA report no. 625/R-94/008. Washington, DC.
[4] Guideline for Construction of Landfill Site, Japan Waste Management Association, 1989

(4) Gas Ventilation Facility

Gas ventilation facility should be provided and the venting pipes should be installed at 50m intervals. The purpose of the venting pipes is to allow the landfill gas to be released into the atmosphere and thus preventing gas explosion. This facility will also assist the acceleration of the landfill stabilisation by enhancing the waste decomposition process.

(5) Leachate Collection Pipes and Leachate Re-circulation Facility

The leachate collection pipes and leachate re-circulation facilities should be installed in order to provide semi-aerobic conditions to the landfill waste layers. The effects of these facilities to the landfill site are as follows.

- To minimize the groundwater contamination by removal of leachate accumulated in the waste layers
- The improvement of leachate quality through contact with air and aeration
- Promote early stabilisation of the landfill waste by accelerating the waste decomposition process
- Reduction in the generation of methane gas

(6) Leachate Treatment Facility

The leachate treatment facility should be installed to treat the leachate in order to comply with the DOE standards prior to discharging the effluent into the public water bodies via the drainage system. The purpose of the facility is to prevent contamination of the public waterways and the groundwater sources.

(7) Groundwater Protection Facility (liner)

The groundwater protection facility, such as artificial liner systems, should be installed in order to prevent leachate seeping into the groundwater sources and contaminating the groundwater.

(*For further information, refer to **Appendix 9**.*)

II-4.2 Requirement of Post Closure Management

The facilities installed for safe storage of waste, prevention of environmental pollution and accelerating early stabilization should be operated and maintained properly, up until the closed landfill site has stabilised.

The monitoring of the environmental pollution and stabilisation of waste should be carried out continuously.

The result of the monitoring and record of the operation and maintenance should be reported to relevant authority periodically.

(1) Operation and Maintenance of Landfill Facilities

a. Top cover

Major subsidence may occur during the first two years after completion of waste filling works, therefore, special care for landfill facilities shall be taken into considered of this period.

After a period of time, major subsidence may not occur, but risk of minor subsidence and damage to the top cover will still remain. It is necessary to maintain the top cover to prevent the percolation of rainwater into the waste layers and to protect the landfill site.

b. Surface drainage

The surface drainage system should be inspected and maintained regularly over the long period of time. This facility will channel the surface water to the drains and resulting in the reduction in leachate production and also protecting the landfill site.

c. Gas ventilation

The landfill gas ventilation system should be operated for a long time to prevent the build up of toxic gases and to prevent fire/explosion hazards.

The gas ventilation pipes will also act as air pipes and provide air (oxygen) to the waste layers and accelerate the waste degradation process. Therefore, the gas ventilation pipes should be maintained over the long term and new ventilation pipes should be installed where necessary.

d. Leachate treatment

The proper operation and maintenance of the leachate treatment facility is very important to prevent any further environmental pollution that may occur after the physical closure.

The concentration and the amount of the leachate will eventually decrease and improved gradually with time, and it may take a long time to do so. When the concentration of leachate has improved and comply with the relevant environmental effluent discharge standards and will not cause serious damage to the surroundings,

then the leachate treatment process could be changed or even terminated. However, it should be noted that the Nitrogen levels in the leachate could remain at high concentration for a long time.

e. Groundwater monitoring wells

The groundwater monitoring wells should be maintained over a long period of time in order to preserve the well for use periodic monitoring activities.

f. Other supporting facilities

Other supporting facilities like the access road and the vegetation growth on the top/slopes should be maintained where necessary for a long period of time.

The typical example of the maintenance items of the landfill facilities, method and scale/frequency are shown in **Table II-4.1**.

Table II-4.1 Summary of maintenance items

Facilities	Items	Methods	Scale/ Frequency
Top cover & dykes	Cracks, pools and soil erosion on the surface, State of plants	Periodic visual inspections	The entire site, weekly
Surface drainage on the top cover	Clogging by soil/leaves, Damage by sedimentation	Periodical visual inspections	The entire site, weekly (more frequent during the rain season)
Cut-off drainage around the site	Clogging by soil/leaves, Damage by traffic	Periodical visual inspections	The entire site, weekly (more frequent during the rain season)
Gas ventilation pipes	Clogging, damage to pipes, corrosion	Periodical visual inspections	all pipes, weekly
Leachate collection pipes	Clogging, damage to pipes, corrosion	Periodical inspections & comparison of the effluent quantity data	daily
Leachate treatment facility	Quality of treated effluent	Daily inspections (colour of effluent) Periodical effluent analysis	daily monitoring frequency
Monitoring facility	Conditions of the monitoring wells	Periodical inspections	all wells, weekly

(*For further information, refer to **Appendix 13**.*)

(2) Monitoring of Environmental Pollution and Early Stabilisation

The monitoring of the environment and the waste stabilisation process should be carried out periodically.

a. Items and Frequency of Monitoring

The typical examples of the monitoring items, parameters and frequency of monitoring are shown in **Table II-4.2.**

Table II-4.2 Summary of Monitoring Items

Monitoring media/parameters	Item and parameters	Frequency	Location
Preliminary site inspection	1) The surrounding environment 2) The condition of the facility 3) Nuisance condition	Once (before monitoring)	-
Leachate	• pH • BOD • COD • Nitrogen (Ammonia, Nitrate, Nitrite) • ORP • EC (Electric Conductivity) • TOC	4 times per year	1 point per leachate pond
Landfill gas	• Oxygen (O_2) • Nitrogen (N_2) • Methane (CH_4) • Carbonic anhydride (CO_2) • Hydrogen sulphide (H_2S) • Temperature	2 times per year	2 points per site
Soil subsidence	Topographic level at the top of the landfill	Once a year	1 point per landfill block
Groundwater	Groundwater benchmark parameters	Once a year	3 points per site
Surface water	Effluent standard parameters	Once a year	2 points per stream

b. Period

The duration of the monitoring period depends on the bio-degradation and stabilization of the filled waste layers. In practice, the monitoring should be continued a long term after the PC. However, the monitoring items and frequency may vary depending on the conditions of the filled waste layers.

c. Recording and reporting

The data and records of the monitoring activities should be submitted to the relevant authorities in the State Government periodically and should be documented and kept.

(*For further information, refer to **Appendix 14.***)

II-5 Safe Closure Plan

The safe closure plan for the landfill site should be prepared based on the priority and the closure level. The plan should include:

a. General information of the landfill site
- Name of the landfill site
- Owner and operator of the landfill site
- Location of the landfill site
- Area and height of the landfill site
- Brief descriptions of the landfill facility with plans or site maps and cross-sections
- Period of waste acceptance (date of start of operation and final waste acceptance)
- Tonnage and volume of the filled waste

b. Priority and closure level

c. Physical closure Plan
- Stable shape plan
- Covering soil and other facilities
- Vegetation plan
- Tentative land use

d. Post closure management plan
- Operation plan
- Maintenance plan
- Monitoring plan

e. Implementation plan and schedule of safe closure

f. Costs estimation for safe closure
- Physical closure
- Post closure management

II-6 Post-closure Land Use

The closed landfill site could be used for other purpose if proper counter-measures have been taken in order to develop the site. The post closure management (PCM) activities should be continued after the post-closure land use.

II-6.1 Required Counter Measures

When the closed site has been earmarked for be redevelopment, the appropriate counter-measures should be carried out. These counter-measures can be categorized into four functions as follows.

(1) Succession and/or Improvement of Landfill Facilities

The landfill facilities and/or safe closure facilities should be properly operated and maintained at all times even if no major problems are apparent in the closed site. Existing facilities like the gas ventilation and the surface drainage systems that may be affected by the development works should be moved and reinstalled at the appropriate new locations.

(2) Safety Measures for Development and Land Use

The safe control of the post closure land use comprises of followings:

Table II-6.1 Safety Control Items

Item	Remark
a. Landslide / collapse	The stabilisation of the slopes should be checked regularly. The weight of the equipments or facilities exerted on the site should also be monitored.
b. Fires / Explosion	Landfill gas contains highly flammable and explosive mixture of gases. Methane gas is highly explosive and volatile when the concentration in air is between the ranges of 5% to 15% (by volume). The concentration of the methane gas in the landfill gas mixture will have to be monitored regularly. It is also necessary to control the migration paths of landfill gas to prevent it from accumulation in dangerous quantities. As precautionary measures, fire protection and prevention facilities should be installed near the gas discharge points.
c. Damage to the plant life and vegetation at the sites	Landfill gas and certain waste may damage the plant life and vegetation. The top cover soil layer should be sufficiently thick to support and promote plant growth and the roots not exposed to the filled waste. Certain type of plants or vegetation are susceptible to various compounds found in the landfill gas, i.e. H_2S, NH_4, Ethylene, etc. Therefore, the selection of suitable plants for planting at the closed landfill sites should be considered carefully.
d. Damage to the equipments and facilities	Landfill gas mixtures contain various corrosive gases such as H_2S and NH_4, that may corrode and damage metallic objects and concrete structures installed at the site. Therefore, the selection of construction materials for the equipment and facilities must be carried out diligently. Ground subsidence may also damage foundations and infrastructures such as pipelines, drains and the access roads.
e. Chemical reactions	The decomposing waste layers contain large amount of hazardous chemical compounds such as ammonium (NH_4^+). The ammonium will react with the alkaline compounds in the cement and limestone present in the discarded construction waste. The resulting unintended chemical reaction will produce ammonia gas (NH_3), which is extremely toxic. This process of de-nitrification is also known as "Ammonia Stripping".

(3) Measures to Control and/or Prevent the Environmental Pollution and Hazards

The development work at the closed landfill site will definitely cause some environmental pollution and hazards. The excavation work will expose the waste layers and resulting in dust pollution and emission of offensive odour. Road surface paving works may prevent the landfill gas migration to the surface and trapped the gasses in pockets that may cause the gas explosion. Appropriate counter-measures must be provided to ensure such occurrences are prevented.

Development works of post closure land use at the closed landfill site may affect/destroy the existing environment pollution control measures. Some of the possible effects are as follows:

Table II-6.2 Environmental Control Items

Items	Remarks
a. Landfill gas migration	The developer may have constructed floors or road surfaces that are impervious and prevents the gas from escaping through the surface. This will cause the gas to migrate and seep into the neighbouring grounds and into the houses where the gas accumulates and may cause damage or explosions.
b. Leakage of leachate	Development works may damage the existing landfill facilities such as the leachate collection and treatment system and the soil cover. Care must be taken when preparing such works at the site.
c. Groundwater pollution	Development works may puncture and damage the impermeable layer of the bottom soil liner. Care must be taken to ensure the layer is not damaged and regular groundwater monitoring should be carried out during and after the development works.
d. Excavated waste	The excavated waste during development works should be disposed of in a safe and proper manner and should not be left exposed on the site.
f. Liner	Development works that require extensive excavation or piling should not be permitted on closed sites that have been previously provided with artificial bottom liner system. The construction works may puncture and damage the liners. Such work should only be allowed when alternative counter-measures to the liner have been installed around the site. Such measures may include providing sheet piles to acts as vertical liners to contain the flow of leachate etc.

(4) Facilities to Minimise Effects to the Public

If the post closure land use resulted in the increase in the population and human traffic to the developed site, then the future land use plan must include appropriate counter-measures to protect and minimise the harmful effects that may occur. Such measures may include the installation of gas collection system around the buildings to control gas migration.

(*For further information, refer to **Appendix 15.***)

II-6.2 Post-closure Land Use Plan

The developer should prepare the post closure land use plan and submitted to the relevant authorities in the State Government for approval. The content of the plan should include the following.

(1) General information/condition of landfill site and its surroundings

(2) Status of stabilisation of the filled waste

(3) Post-closure land utilisation

(4) Alteration plan of landfill facilities

(5) Safe control measures

- Construction and development
- Land utilisation

(6) Environmental pollution control measures

(7) Post closure management (PCM) plan

- Operation and maintenance of facilities
- Monitoring of environment and stabilization

(8) Implementation schedule of the above items

(*For further information, refer to **Appendix 16**.*)

II-7 Social Considerations on Closure of Landfills

There are many reasons for closing a landfill and the main reason is usually due the inherent negative social impacts it has on the surrounding population. The main health risk and impact are on those working at the landfills, i.e. the operators and scavengers, and the residents living around the sites. The social considerations on the closures should be implemented at each stage as follows.

(1) Social Consideration for the Scavengers

a. Before landfill closure

a-1. Carry out a survey on the scavengers and their activities

a-2. Preparation of relevant information on the landfill closure

a-3. Preparation of information on environmental health issues affecting the scavengers

a-4. Preparation of the scavengers evacuation plan

a-5. Organize briefings and explanatory meetings on the landfill closure

a-6. Set up an information desk on the landfill closure at the LA

b. After landfill closure

b-1. Preparation of signboards to prohibit trespassing and entry to the landfill sites

b-2. Construction of fences and/or barbed wire structures at landfill sites

b-3. Carry out regular patrols to check for illegal entries into the landfill sites

(2) Social Consideration for Surrounding Households

a. Before landfill closure

a-1. Carry out a survey on the surrounding households

a-2. Preparation of relevant information on the landfill closure

a-3. Preparation of information on environmental health issues

a-4. Organizing explanatory meetings on the landfill closure

a-5. Setting up of an information desk on the landfill closure at LA

b. After landfill closure

b-1. Preparation of signboards to prohibit entering at landfill sites

b-2. Construction of fences at landfill sites

b-3. Carry out regular patrols to check for illegal entries into the landfill sites.

b-4. Carry out public hearing to gather public opinions and reactions to the utilisation of closed landfill sites

(*For further information, refer to* ***Appendix 17.***)

APPENDICES

Appendix 1

Flowchart on the Landfill Management Activities

The flowchart on the landfill management activities is shown in **Figure A1-1**, below. The "Technical Guideline on Sanitary Landfill, Design and Operation (revised draft)" mainly covers the planning, design/construction and operation stages whilst the "Guideline for Safe Closure and Rehabilitation of Waste Landfill Sites" covers closure stage of the landfill site.

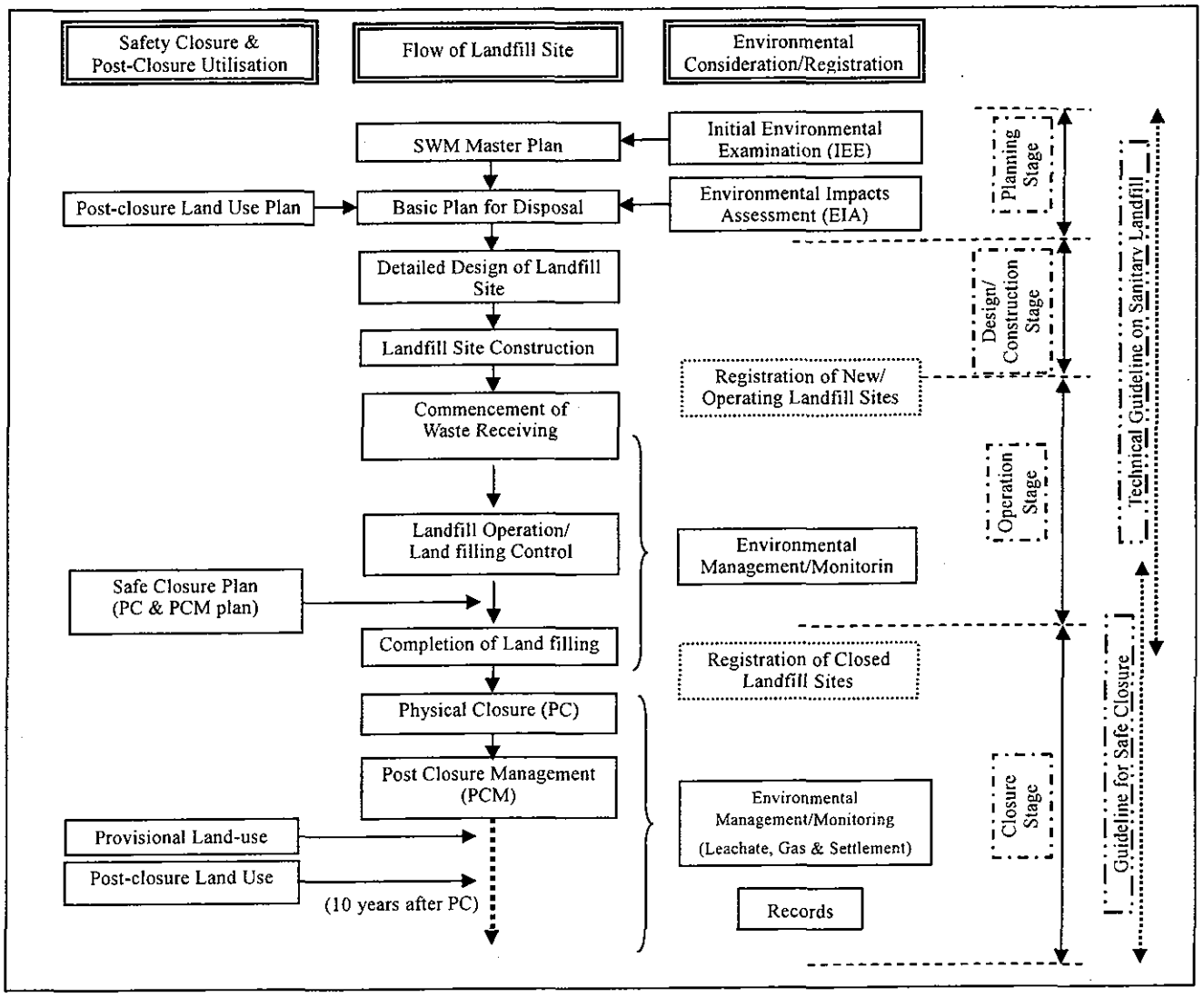


Figure A1-1 Flow chart on the Landfill Management Activities

Appendix 2

Process of Landfill Safe Closure

The flowchart on the process of landfill safe closure in line with the safe closure guideline is shown in **Figure A2-1**.

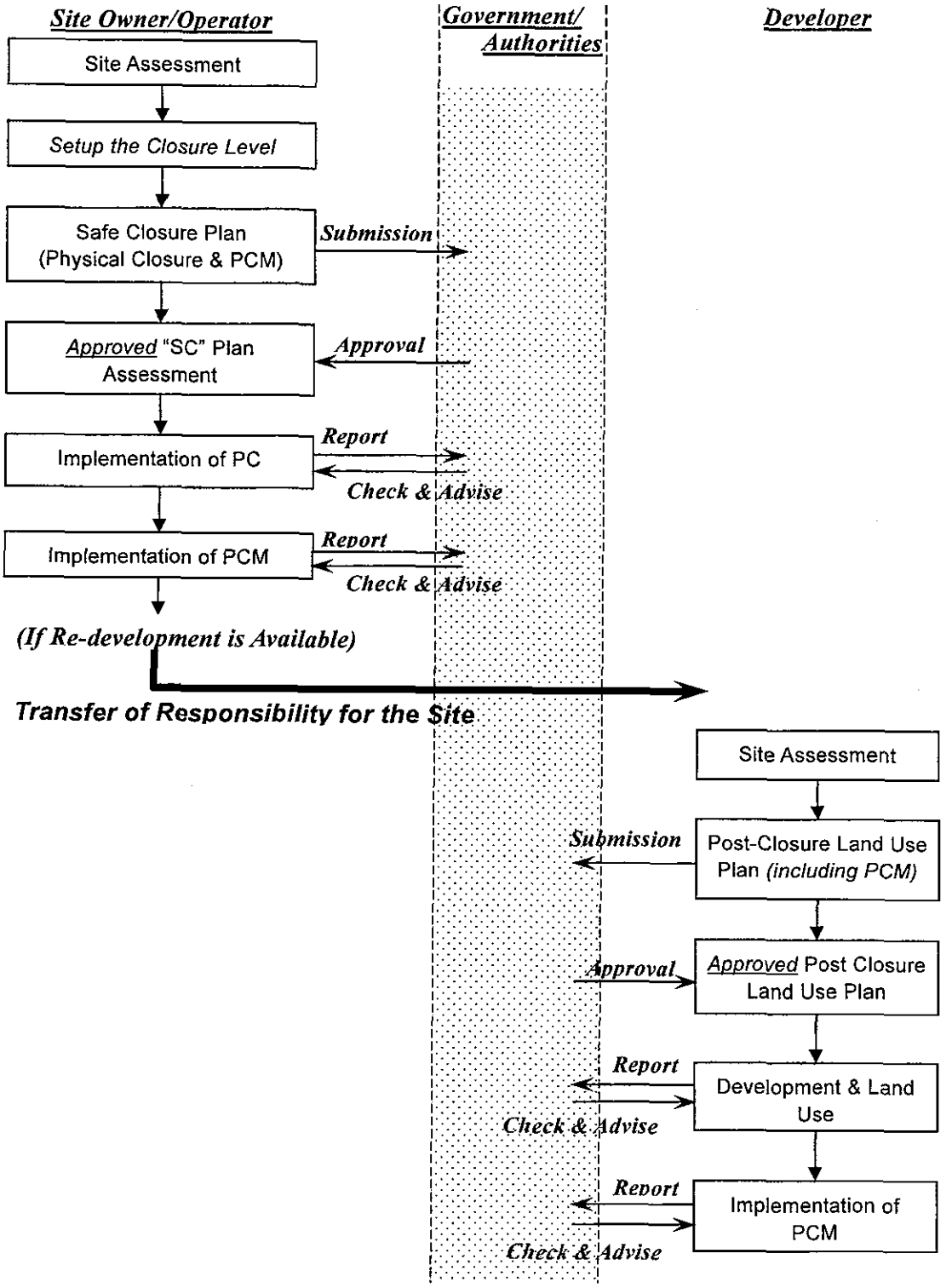


Figure A2-1 Process of Landfill Safe Closure

Appendix 3
Role of Stakeholders for Landfill Safe Closure

To implement the safe closure of landfills, the roles of the stakeholders will have to be identified. The flowchart outlining the role of the major stakeholders; i.e. Federal government, State government, Local authority and site owner/operator, is shown in **Figure A3-1**.

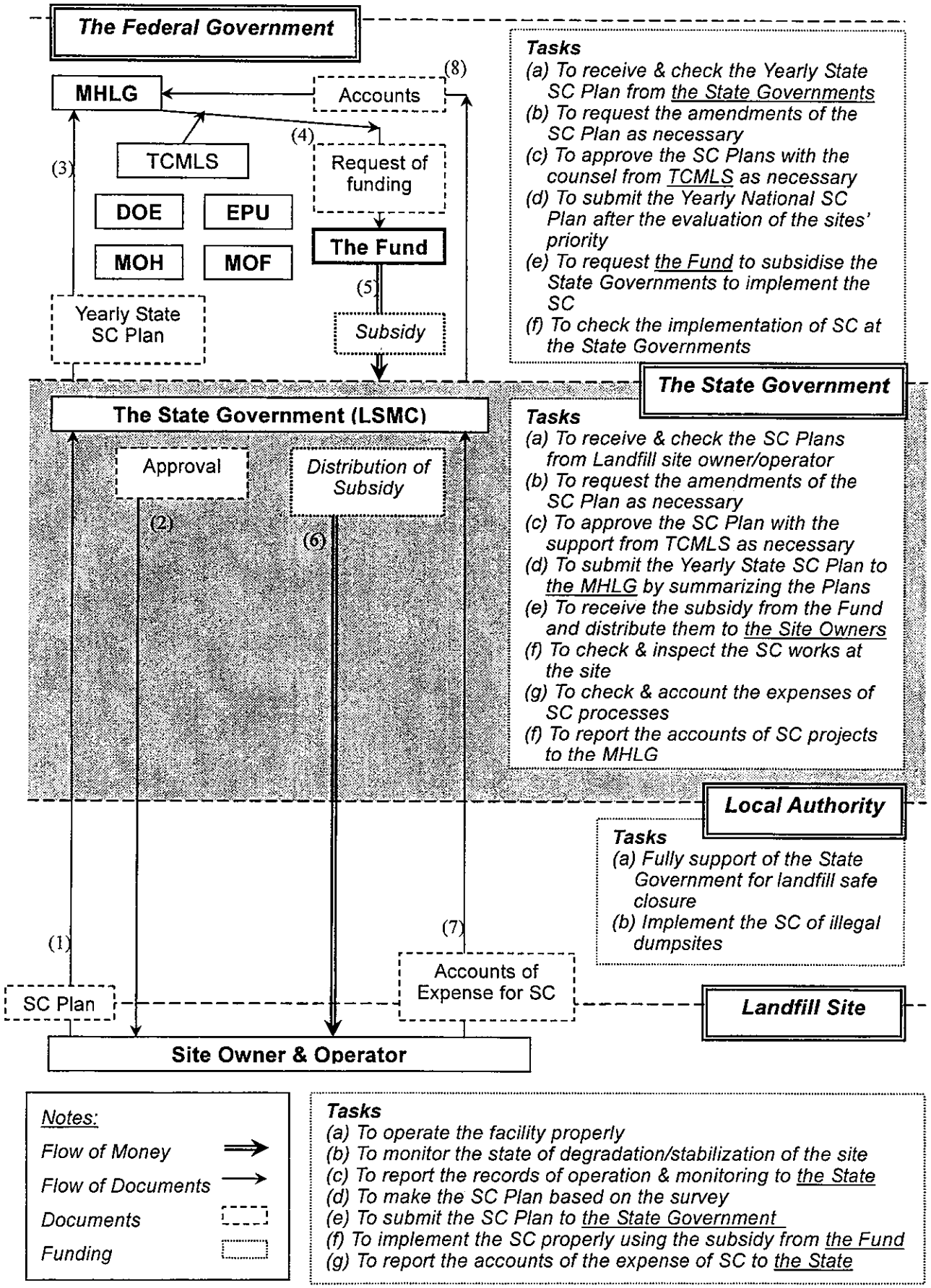


Figure A3-1 Roles of the Stakeholders for the Landfill Safe Closure

Appendix 4

Organizational/Institutional Structure for Landfill Safe Closure Management

Federal government and the State government are the key players for the landfill safe closure management. In order to introduce the practical management of landfill safe closure in Malaysia, it is recommended to establish the Technical Committee for Management of Landfill Site (TCMLS) in the Federal level and the Landfill Sites Management Committee (LSMC) in the State level. Outline of each agency is shown as follows.

(1) Technical Committee for Management of Landfill Site (TCMLS)

The Technical Committee for Management of Landfill Site (TCMLS) will be set up at the Federal Government level and will provide technical advice to the State Governments, Local Authorities, landfill operators/owners and other interested parties. The TCMLS will convene, as and when necessary, to discuss, evaluate and decide upon the implementation of landfill management activities, such includes the physical closure (PC), post closure management (PCM) and the redevelopment of closed landfills.

The TCMLS members will constitute of representatives from the Governmental Ministries and Departments, institutions and landfill owner/operators. The representatives will be from,

- The Local Government Division of the MHLG (Chairperson)
- The Ministry of Health
- The Ministry of Natural Resources and Environment
- The Economic Planning Unit, Prime Minister's Department
- Academicians
- Landfill Site Owner or Operators.

(2) Landfill Sites Management Committee (LSMC)

Since the State Governments are responsible for all land utilization and development matters, they should also be responsible for deciding and controlling the over development of post closure landfill sites.

The State Governments should set up their respective Landfill Sites Management Committee (LSMC) to oversee and manage the safe closure of landfill sites. The main functions of the committee are:

- To register and maintain updated records the landfill sites
- To review and provide approval for the "Safe Closure Plan" (including the physical closure plan and the post-closure management plan)
- To monitor the activities of the landfill operators/owners for the safe closure.
- To review and provide approval for the "Development Plan of Closed Site" (including the development plan, post closure management and safety control plan)
- To monitor the post closure land use activities at the closed landfill sites.

The LSMC should consist of representatives from the following State authorities:

- State Local Government Division (LGD)
- State Land Office
- State Economic Planning Unit
- State Engineering Department/Division
- State Department of Environment
- State Health Department

The State Government, as an alternative in setting up the LSMC, may consider the setting up of a working division to undertake the functions and responsibilities for the landfill safe closure management. The Landfill Site Management Division (LMSD) should be set up according to the proposed organization structure as shown in **Figure A4-1**. The Urban Services Department (USD) should also assist the LSMD.

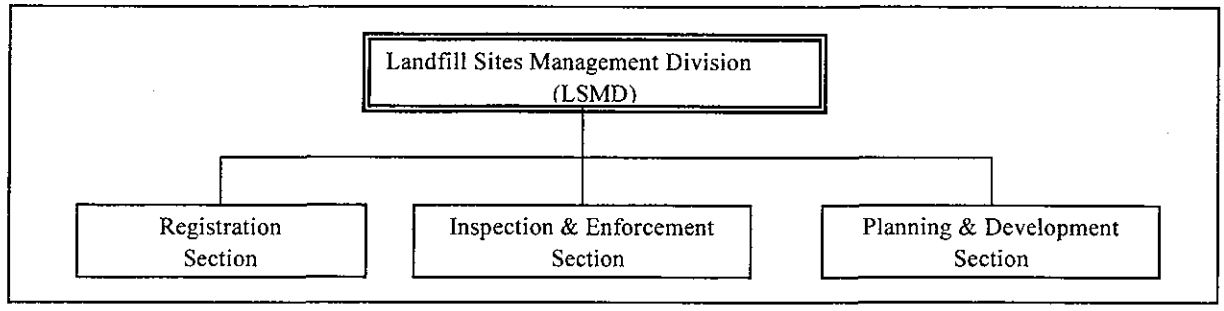


Figure A4-1 Organizational Structure of the LSMD

The Federal Government, i.e. MHLG, will provide assistance and training in the human resources development and provide technical advice to the State Government.

Appendix 5

Role of Stakeholders for LACMIS Management

Role of the stakeholders; i.e. Federal government, State government, Local authority and Site owner/operator, for the management of "Landfill Closure Management Information System (LACMIS)" is shown in **Figure A5-1**.

LACMIS information shall be published to the required agencies and/or personal especially for the developers.

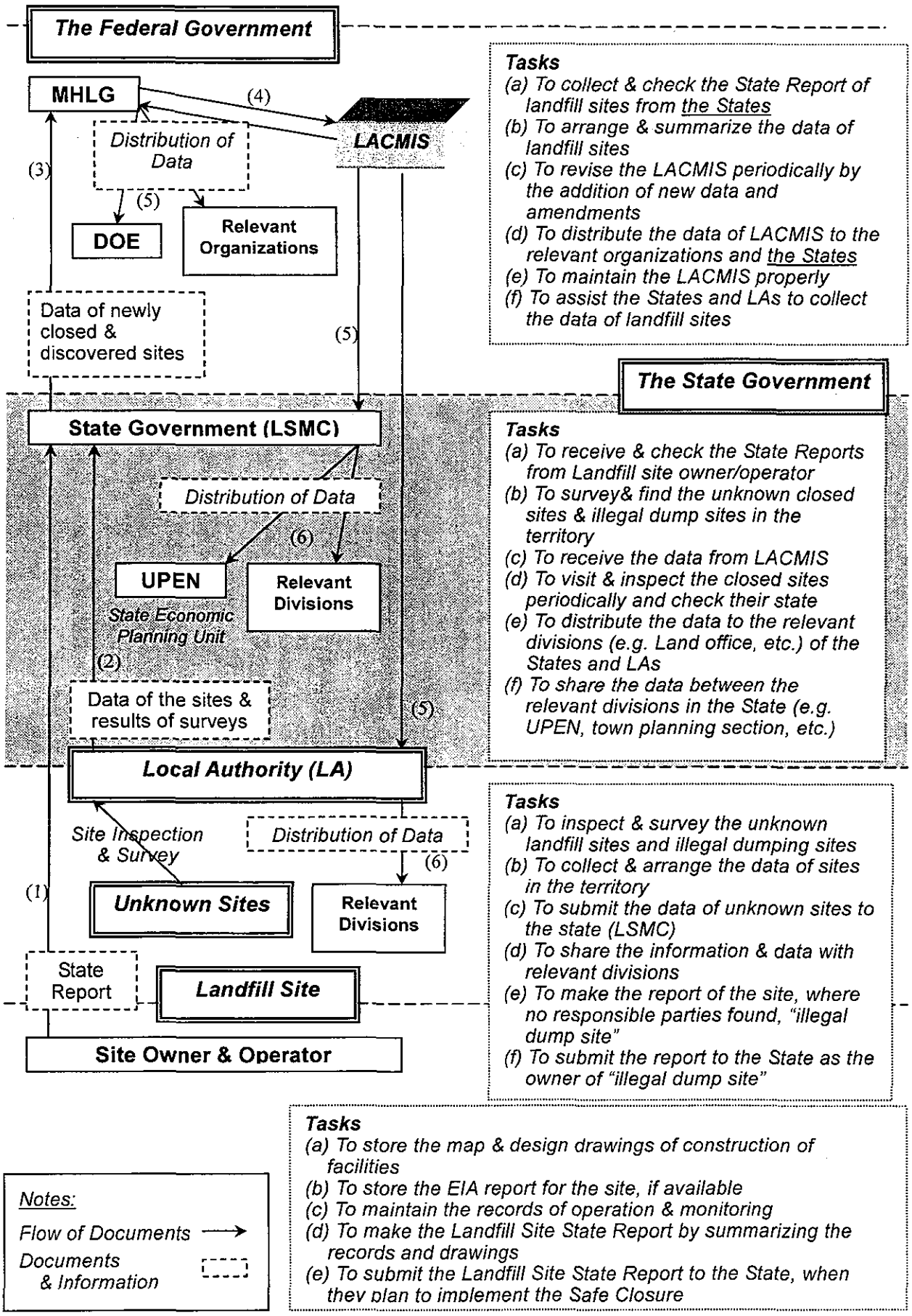


Figure A5-1 Roles of the Stakeholders for Management of the LACMIS (Landfill Closure Management Information System)

Appendix 6

Financial Resources and Funding System for Landfill Safe Closure

(1) Financial Resources

The site owner is responsible for the SC of their site in principal. Therefore, the site owner shall take into account setting aside some reserves for SC during the site operation period, through reasonable and proper methods (levies on the waste collection fees & tipping fees, etc.).

However even though the site owner prepares the reserve for SC, there is a risk that the owner may become bankrupt. Therefore, all site owners shall pay some reserves into the specific Fund set up at the Federal government level annually. It is recommended that the portion of reserves paid by each site owner shall be in proportion to the amount of waste accepted at their sites.

On the other hand, there are many closed sites and illegal dump sites. These sites also need SC. But these sites do not have any financial resources and/or responsible agencies for SC.

Therefore, it is required that the Federal government will pay some deposit for the Fund in the first several years of its creation to support SC.

Profile of the reserves for SC of landfill site is summarized as follows.

a. New landfills can set up sufficient financial resources at the Fund using their annual savings.
b. Existing landfills may not be able to set up sufficient financial resources for SC, because the period of saving the reserves might be shorter than the actual operation period.
c. Closed sites and illegal dumpsites have no financial resources.

(2) Funding System

Because the Fund is public property and the amount is limited, the subsidy for SC shall be provided, managed and used effectively at least for the first several years. In particular distribution of budget for SC to the site owners/operators is very important. In the guideline, the site-specific approach is applied, therefore, the prioritised system for SC is necessary. The priority list of sites shall be reasonable from the aspects of environmental risks, hazards, potential of post-closure land use

and expected effects. The priority setting procedures shall be transparent and subject to accountability.

The following items show the financial procedure for implementing safe closure.

(i) The site operator/owner applies to the State government for funding from the Fund for the SC of the site.
(ii) The State collects and summarizes the requests for SC every year.
(iii) The State makes the priority list for SC and cost estimates for the SC plan of following year, based on the SC plans from the sites.
(iv) The State sends their priority list and the cost estimates to the Federal government
(v) The Federal government summarizes the requests from the State governments.
(vi) The Federal government checks the SC plans proposed.
(vii) The Federal government sets up the upper limit for funding from the Fund in that year.
(viii) The Federal government distributes the subsidy to the State based on items (vi) and (vii).
(ix) The State informs the amount of budget for SC to the site operator/owner.
(x) The State checks the expenses of SC in their territory and reports them to the Federal government.
(xi) The Federal government makes a public account of the Fund.

Appendix 7

Methodology of Classification and Prioritisation of Landfill Sites

The priority of application of safe closure is set up based on the information acquired under the landfill survey.

Specifically, the priority is set up using two evaluation axes; *environmental risk potential*, and *land use potential*. The information on 14 items determining environmental risk, such as "Landfill Facility Level", "Landslide", and "Leachate Quantity", and six items on *land use potential*, such as "Existing Land Utilization", "Surrounding area", and "Post Closure Land Use", are covered in the inventory survey.

On a two dimensional graph, the *environmental risk potential* axis evaluates the risk to the environment that occurs at the landfill site, such as occurrence of fires, generation of harmful insects, and leachate pollution to the surrounding water bodies and extending to the downstream water system. In other words, the axis of *environmental risk potential* expresses the grade of environmental risk.

The axis representing the *land use potential* is an index showing the situation of land utilization that the closed landfill site is actually being used for, such as housing and the planned development in the surrounding area in the future for both the closed as well as the operating sites, and so on. In case of residential land use at closed sites, it is necessary to implement strict safe closure that sufficiently takes into consideration public health and safety. As development progresses surrounding a closed landfill it becomes a social requirement to effectively use the land formerly occupied by the closed landfill site. Furthermore, in addition to environmental risks, closed landfills create problems related to depreciation in surrounding land values and difficulties in land transactions.

Group A

In this section, based on the evaluation of the two axes of *environmental risk potential* and *land use potential*, the Study has included in the highest priority Group A, landfill sites where there is a high environmental impact risk and land use has developed on the closed site or the surroundings for both closed and operating sites. Examples of landfills classified into Group A are sites close to water supply sources located downstream of a river system and where the groundwater is a source for drinking water. Hence, advanced safe closure levels, such as C3 or C4, where

measures for leachate treatment and groundwater protection are included, are demanded.

Group B

Landfill classified in the second highest priority group, Group B, are those having high environmental impact risks but where there is lesser potential for land utilization. Landfills in this group need to be safely closed to levels C2, C3 or C4 taking into consideration measures to mitigate environmental impacts. Safe closure level C2 controls the volume of leachate generated through minimization of rainwater flow into the landfill and washout of waste to the surrounding area. Level C3, in addition to measures adopted in C2, introduces rudimentary treatment and re-circulation of the generated leachate water, while Level C4 incorporates the measures of both C2 and C3, while further implementing measures to protect against flow of leachate into the groundwater.

Group C

The JICA Study classified landfills where environmental impact risks are low, but which have a high land utilization potential in the third highest priority group, Group C. Due to the lower environmental impact risk considered, safe closure levels for landfills in this group are set at Levels C2 and C3.

Group D

Landfills classified in Group D have the lowest priority. These landfills are considered to have both low environmental impact risks and land utilization potential and there is little urgency to implement the safe closure. When implemented, levels C1 and C2 are adequate. Safe closure level C2 would apply to landfills within the same Group D, but having comparatively more environmental risk, to provide measures for control of leachate volume generated and protect against washout of deposited wastes. For landfills imposing lesser environmental risk, level C1 providing adequate final cover is sufficient.

The concept of the grouping of the priority is shown in **Figure A7-1** and the relationship between the priority and the level of the safe closure is shown in **Table A7-1**.

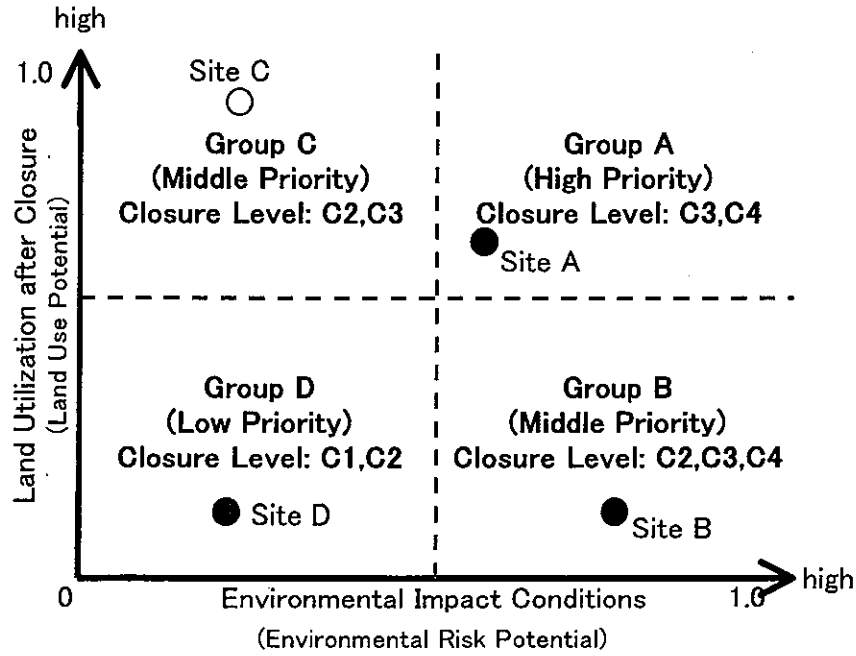


Figure A7-1 Concept of the Grouping of the Priority

Table A7-1 Relationship between Landfill Closure Priority and Safe Closure Level

Group	Priority for closure	Safe closure Level			
		C1	C2	C3	C4
Group A	High			+++	++
Group B	Middle		+	+++	+
Group C	Middle		+++	++	
Group D	Low	++	+++		

Note: +, ++, +++: magnitude of the relation (+: low, ++: medium, +++: high)

Appendix 8

Methodology for Closure Level Set-up of Landfill Sites

(1) Closure Level Applied for the Landfill Sites

The closure levels of landfill sites are classified into 4 categories as C1-C4.

C1: Minimal level (final cover and drainage system around the site)

C2: Low level (as well as above + dike, controlled slope, and gas ventilation system)

C3: Middle level (as well as above + semi-aerobic landfill system with leachate re-circulation)

C4: High level (as well as above + groundwater pollution control measures with leachate treatment)

(2) Consideration on the Setting of the Safe closure Level

By safe priority of the safe closure as shown in **Table A7-1** of Appendix 7, the rough level of the safe closure, which should be applied to each group, can be set. However, to estimate the necessary budget scale etc., it is necessary to estimate which closure level of C1-C4 should be applied to each landfill site.

The safe closure level shall be decided based on the landfill survey result. The safe closure level, which is demanded in each landfill site, depends on the degree of the environmental influence at each landfill site; therefore the closure level is set based on the items of the *environmental risk potential*, which were obtained by the inventory survey. At first, classifying each item of the *environmental risk potential* into 4 groups which relates to safe closure level C1-C4, then the necessity of each closure level is judged from the total score of each item which was calculated in setting of the priority of the *environmental risk potential.*

Relationship between the safe closure level C1-C4 and each item of the *environmental risk potential* are shown in **Table A8-1.**

In closure level C1, where the measure of the final cover with the aim of keeping a good sanitary condition is taken, the index of the environmental improvement is "waste cover", "vegetation condition", "vector and wild animals", and "odour, landfill gas and smoke".

In closure level C2, where the measure of the storage structure, re-formation and protection of slopes, storm water drainage facilities, gas vents, etc. is taken, with the aim of preventing outflow of waste and the aim of early stabilization of landfill site, the index of the environmental improvement is "landslide", "soil subsidence", "odour, landfill gas and smoke", and "leachate quantity".

In closure level C3, where the measure of a leachate collection system and a leachate re-circulation is taken, with the aim of preventing an environmental impact by leachate, the index of the environmental improvement is "leachate quantity", and "location of water intake"

In closure level C4, where the measure of leachate treatment and seepage control work is taken, with the aim of groundwater protection, the index of the environmental improvement is "location of drinking water well", and "geological condition"

One quarter of the score of "public complaint" item is distributed among every closure level, as "public complaint" is considered to be an item which relates to all closure levels equally.

Table A8-1 Relationship between the Safe Closure Level and Each Item of the Environmental Risk Potential

Safe closure Level	Risk Evaluation Items	Safe closure Countermeasures	Item of environmental risk potential													
			E1) Landfill Facility Level	E2) Site Condition	E3) Waste Covered	E4) Vegetation Condition	E5) Landslide	E6) Soil Subsidence	E7) Vector and wild animals	E8) Odour, landfill gas and smoke	E9) Leachate Quantity	E10) Location of water intake	E11) Location of Drinking Water Well	E12) Geological Condition	E13) Public Complaint *	E14) Distance to the residential area
C1	Littering, vectors, Odour, combustion	Final Cover			++	++			++	++					+	
C2	Flow of waste outside the site	Storage Structure														
	Landslide	Re-formation and protection of slopes, Storm water drainage facilities														
	Leachate generation	Final cover, Storm water drainage facilities					++	++		++	++				+	
	Landfill gas explosion	Gas Vents														
	Settlement	Gas Vents														
C3	Leachate pollution potential	Leachate collection system, Leachate re-circulation									++	++			+	
C4	Groundwater pollution	Leachate treatment, Seepage control work											++	++	+	

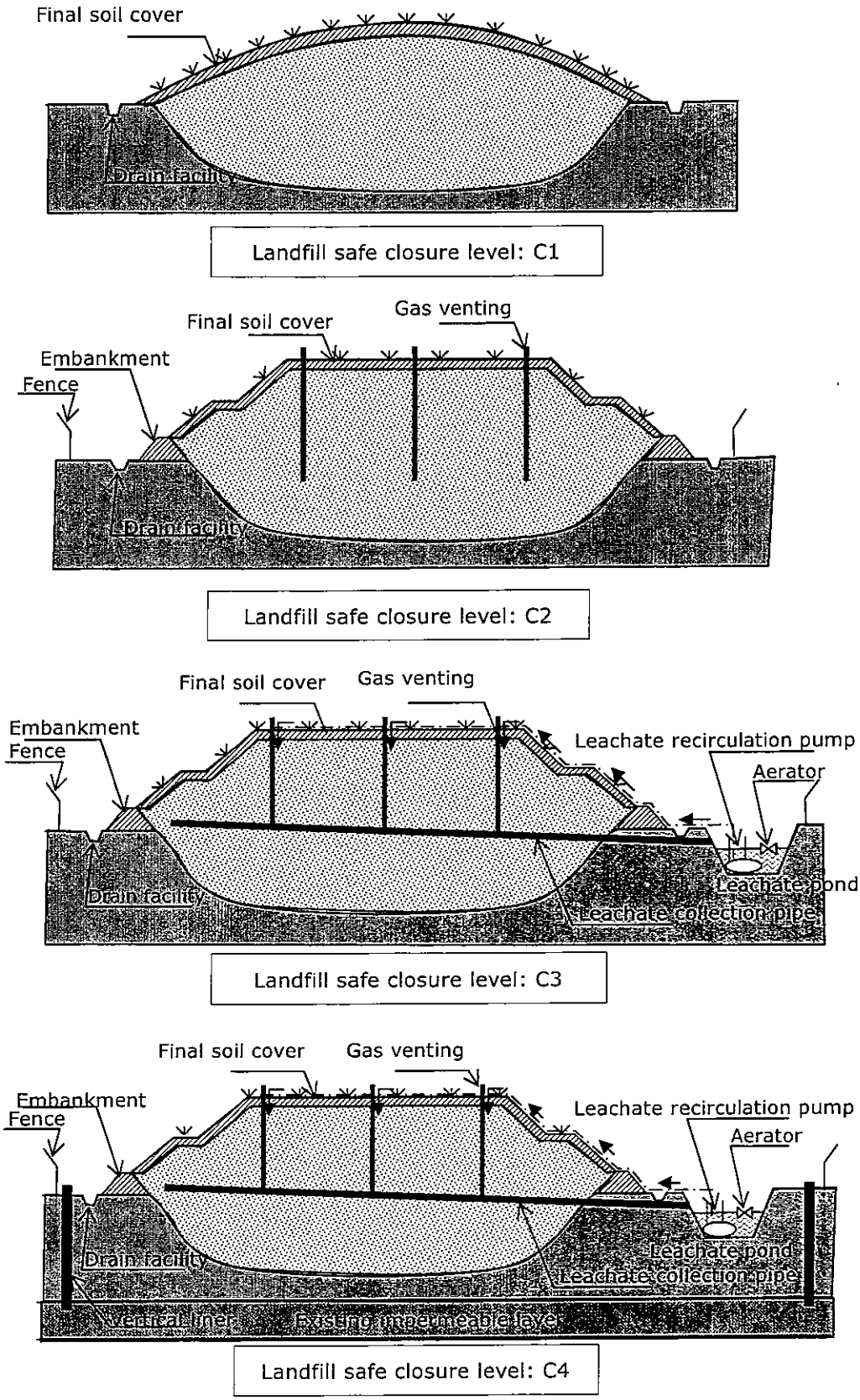
Note: * "Public Complaint" is equally divided to C1-C4

Appendix 9

Required Facilities for Each Safe Closure Level

The closure levels of the landfill sites are classified into 4 categories; i.e. closure level C1, C2, C3 and C4.

The facilities necessary to be provided for each of the landfill closure level are shown in the diagrams in **Figure A9-1**.



Note: For C3 & C4, aerobic area of existing landfill site will be expanded by safe closure measures.

Figure A9-1 Schematic Diagram of Landfill Safe Closure Level

(1) LANDFILL SAFE CLOSURE LEVEL : C1

a) Final Cover

The final cover should be the cover soil laid on top of the final landfill waste layer, after the landfilling has been completed. The purpose of final cover is to provide improvement to the sanitary conditions, the landscape, post-closure land use, the reduction of the leachate quantity, etc.

<Purpose>

- Prevention of breeding of vectors, such as flies and mosquitoes
- Prevention of scattering of waste (i.e. to ensure the waste are not exposed)
- Reduction of offensive odour
- Prevention of outbreak of fire
- Minimise the production of leachate (i.e. to prevent surface rainwater from percolating into the waste layers and hence minimising groundwater contamination. Example is shown in **Figure A9-2**)

<Specification>

- The thickness of the final cover should be at least 500mm or more.
- The final cover should be laid and compacted properly, i.e. with bulldozers, etc.
- The final cover should be compacted with an inclined slope of about 2 to 5% gradient to allow for rainwater drainage. (refer to **Figure A9-3**)
- The final cover material should be earth or soil material which possesses low permeability, resistance to erosion and suitable for vegetation growth.

<Notes>

- The final thickness of the cover soil is dependant on the post-closure landfill use. i.e. it may be necessary to increase the thickness of the final cover to cater for the actual post-closure land use.

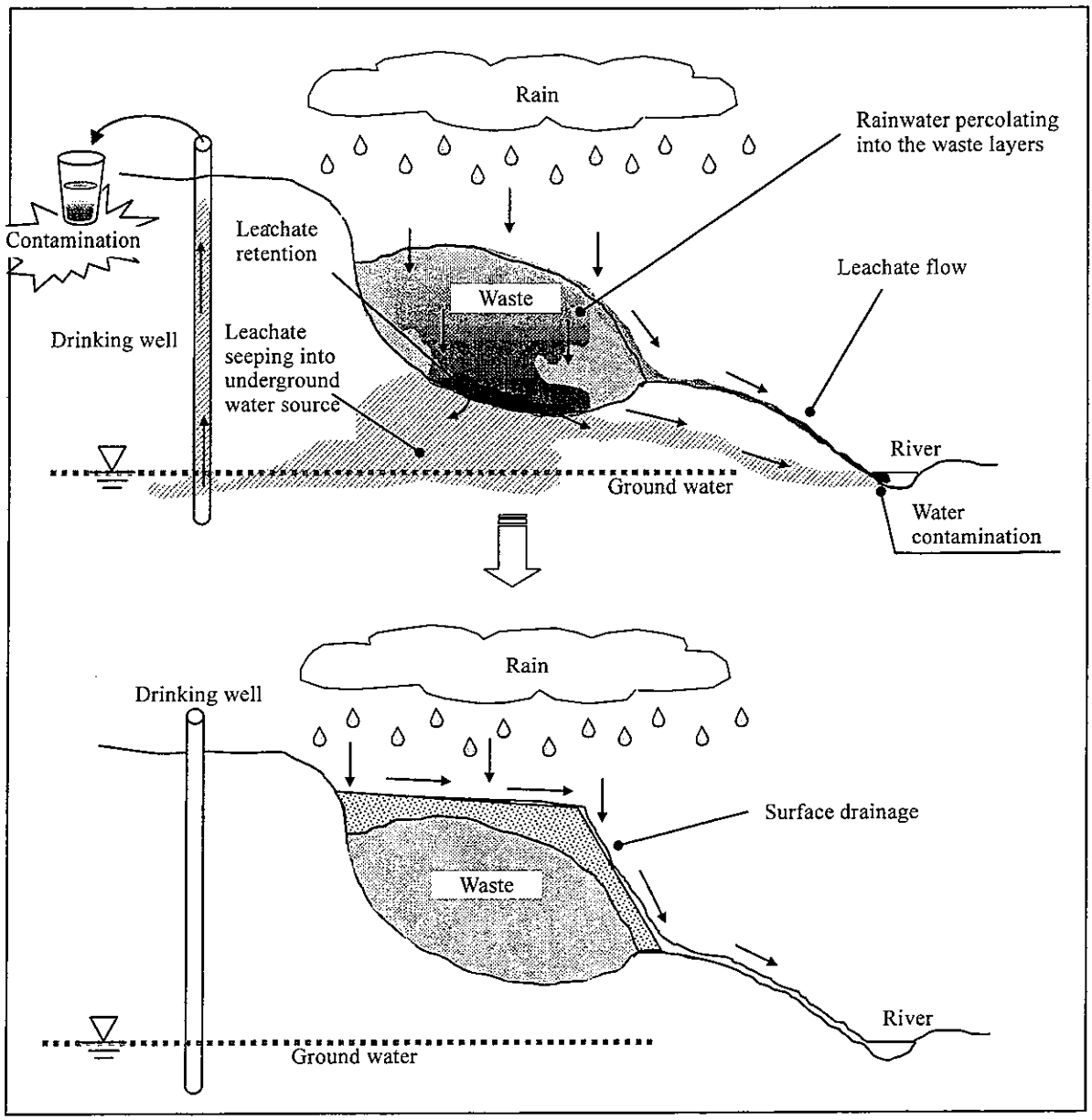


Figure A9-2 Purpose of Final Cover

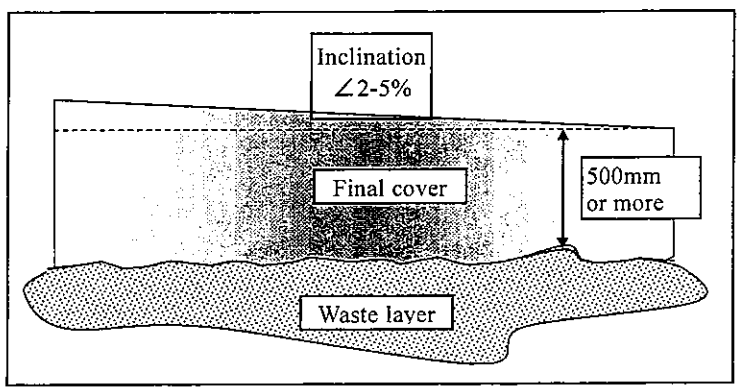


Figure A9-3 Final Cover Specifications

b) Drainage facility

<Purpose>

- The proper drainage system should be provided to channel the rainwater from the landfill site to the discharge drains. This will reduce the surface water percolating into the waste layers and to prevent soil erosion.

<Specification>

- The drains should be provided on the surface of the final cover, at the slopes, on the steps and at the perimeter of the landfill, to channel the surface water away from the landfill and to prevent soil erosion. (**Plate A9-1** shows an example of the effects of surface erosion due to insufficient proper drainage systems)
- Although the slope of drainage is influenced by geographical feature conditions, generally it becomes 1-2%. At a steep slope or a rugged place, since it is easy to cause erosion or overflow by the torrent and the curve, special cautions are required in a design.
- Proper drains should be provided such as cast-in-situ concrete channel, U-shaped drains, concrete pipes, etc. Earth trenches or drains may be provided at the areas where the ground is hard and impermeable. Trenches are the simple to excavate and economical to provide and to maintain.

(2) LANDFILL SAFE CLOSURE LEVEL : C2

a) Safe storage

<Purpose>

- For the safe storage of the waste, suitable retaining or embankment structures should be provided. These will surround and prevent the waste from spilling outside the landfilled area.

<Specification>

- The steep slopes should be re-shaped to provide a gentler slope. Step or terraces should be provided where necessary
- The inclination of the slopes should be 1:3 gradient
- Steps or terraces should be provided at 5m intervals at the slopes. The terrace width should be about 2m to 3m.
- Vertical and horizontal surface drains should be provided at the slopes and at the steps or terraces
- The slopes and terraces should be provided with topsoil suitable for turfings and plantings. These will protect the slopes from erosion and also

provide a pleasant aesthetic landscape. (**Plate A9-2** show an example of the erosion of the slopes due exposure)

<Notes>

- The slopes should be as gentle as possible to preserve the stability and to prevent land slides. (refer to **Figure A9-4**)

Plate A9-1 Surface Erosion

Plate A9-2 Slope Erosion

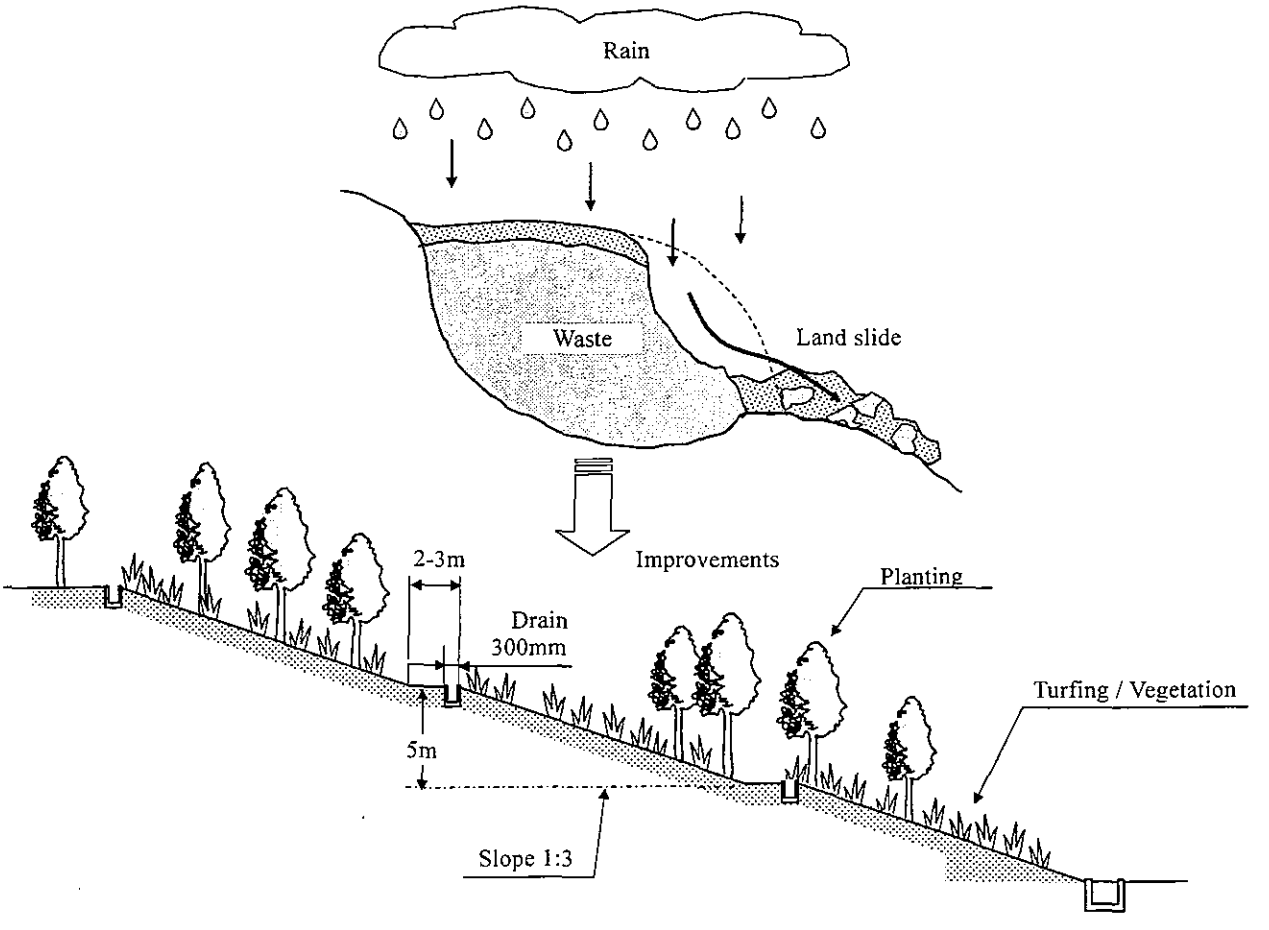


Figure A9-3 Slope Improvement

b) Gas Vents

<Purpose>

- The waste decomposition process will generate a large amount of landfill gasses such as methane and carbon dioxide, which rises and escapes through the surface. The gas vents should be provided and installed deep into the waste layers to allow the gasses to escape and vented to the atmosphere.
- The vents also act as air pipes to supply air deep into the waste layers to promote the decomposition process and to accelerate the stabilisation of landfill.

<Specification>

- Structure : perforated polyethylene pipe or perforated PVC pipe covered by gravel or crashed rock
- Diameter of perforated pipe : 75-300mm
- Installation interval of gas vents : less than 50m (one or more vents to about 2,000m^2)

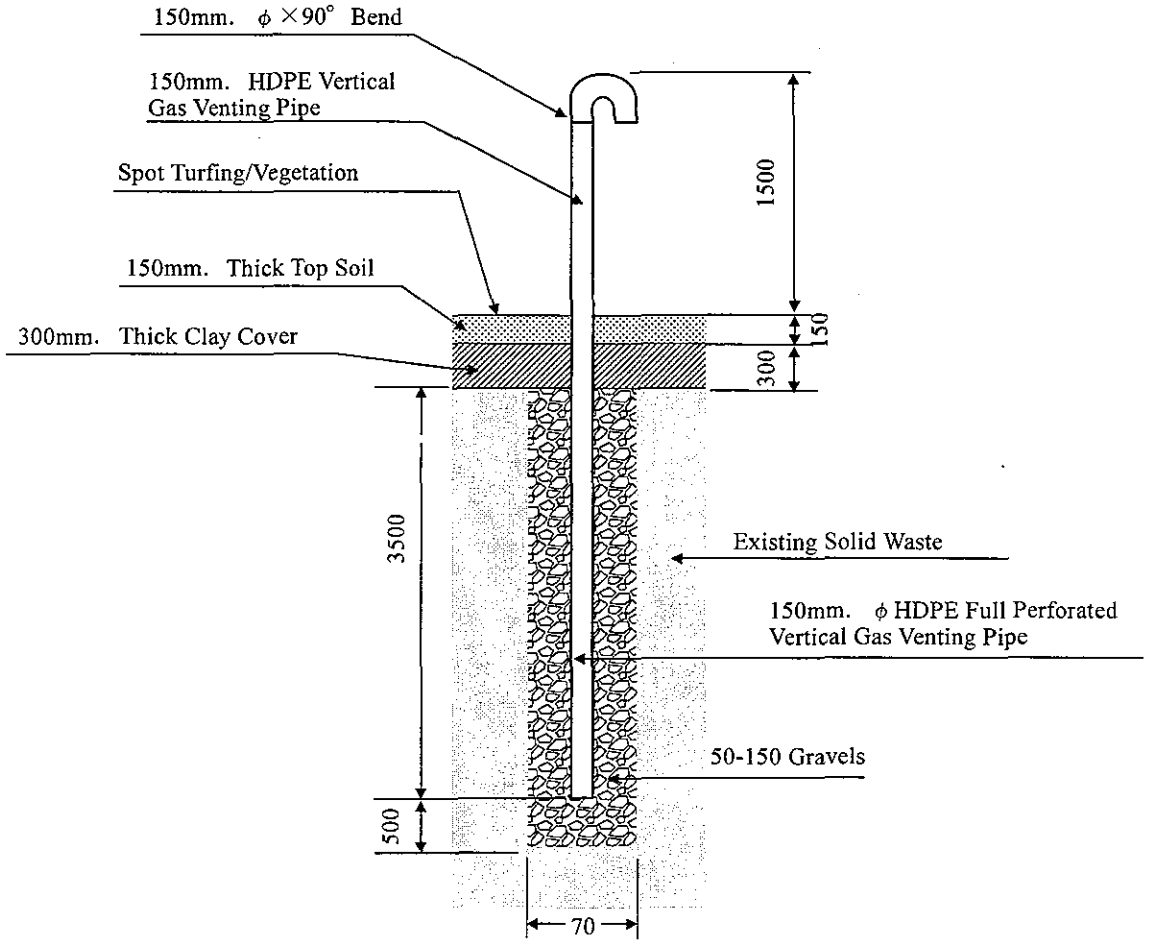


Figure A9-4 Typical 150mm. ϕ Vertical Gas Venting Pipe Detail

(3) LANDFILL SAFE CLOSURE LEVEL : C3

Equipments required for the measure of closure level C3, such as leachate collection system, leachate pond, leachate recirculation system and so on, are equipments which are desired to be installed from the construction stage of the landfill site. When these equipments are installed from the beginning, the existing equipment will be used also at the closure stage.

Here, the case where this equipment is newly installed at the closure stage is explained.

a) Leachate collection system

<Purpose>

- Collection/drainage of leachate inside landfill site
- Accelerating the stabilization of the landfilled waste by landfill gas vent and air supply for changing the inside of landfill site into a semi- aerobic condition

<Specification>

- Leachate collection/drainage pipes are installed as much as possible in the bottom of landfill. The pipe lies down with a gentle slope so that it can drain by the natural flow.
- Structure : Perforated pipes and covering material which prevents the clogging

[Pipe]

Material: perforated hume pipe or perforated synthetic resin conduit

Diameter: 400-600mm (main pipe), 200mm or more (brunch pipe)

[Cover material]

Material: cobble stone or crushed rock

Diameter: 50-150mm

Height: 50cm or more from the bottom

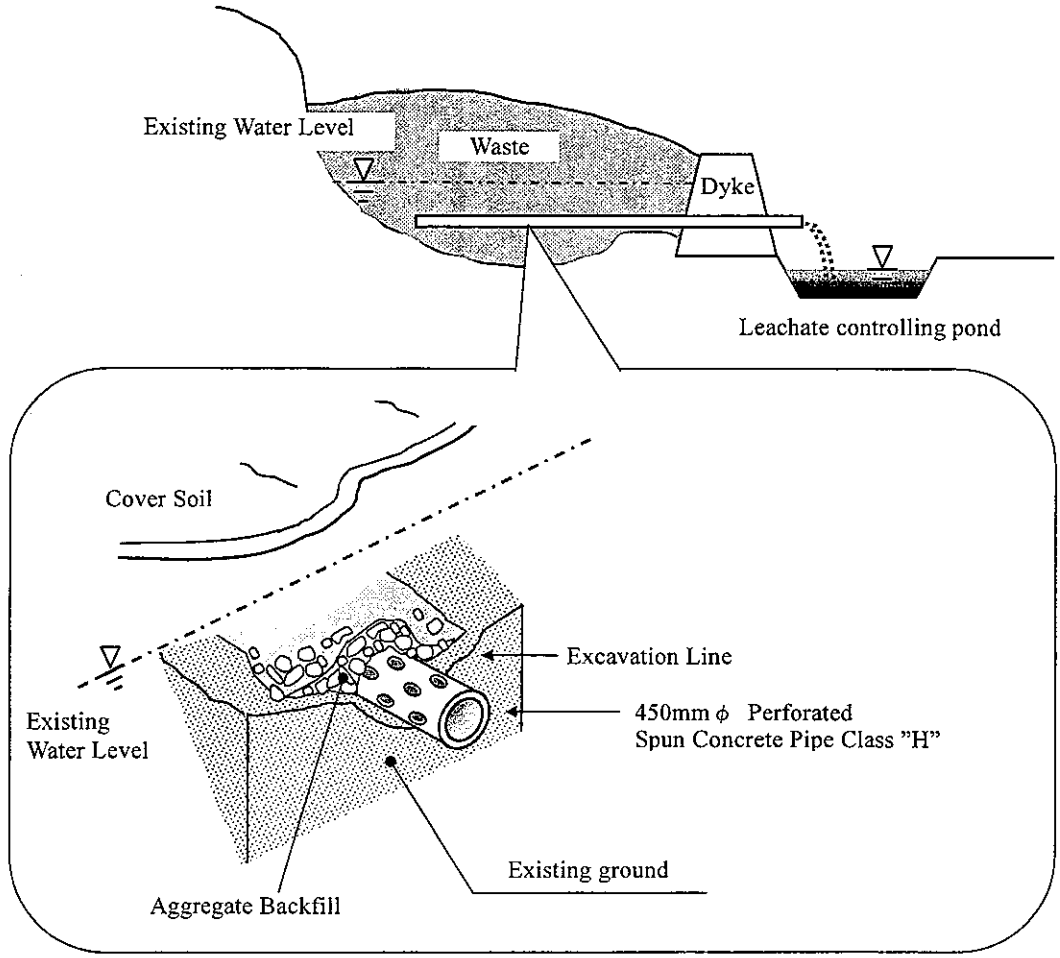
Width: 3 or more times of diameter

Figure A9-5 shows the image and section drawing of leachate collection pipe.

<Notes>

- A gas vent pipe is connected to the leachate collection/drainage pipe. The installation interval of gas vent pipes is about less than 50m (one or more vents to about 2,000m^2).

- In case of installing the leachate collection/drainpipe pipe at the landfill closure stage, the landfilled waste is excavated with heavy industrial machines, such as excavator with hoe equipment, then leachate collection/drainage pipe is installed. In this case, the installation depth of a leachate pipe is restricted to the depth which can be excavated with a heavy industrial machine etc. (about 5m from a surface).
- When using existing leachate collection/drainage pipe, or when installing a pipe newly at the bottom of the landfill, it is effective for drainage of leachate. However, when installing a pipe not at the bottom of the landfill but at the position where the construction height of a pipe is higher than water level of retaining of leachate, it is scarcely effective for drainage of leachate.
- It is effective for drainage of retaining of leachate to install a leachate drainage pipe by horizontal boring. However, since it is difficult to connect a gas vent pipe to a leachate drainage pipe, the landfill can not become semi-aerobic condition.



(Improving existing landfills by creation of aerobic zone based on semi-aerobic theory)

Figure A9-5 Typical Image of Installing the Leachate Pipe

b) Leachate pond

<Purpose>

- Collection and storage of leachate
- Improvement of the leachate quality by aerator

<Specification>

- The capacity of a leachate pond should be set up based on quantity of leachate.
- When installing the leachate pond on the high permeable ground, or when contamination of groundwater needs to be avoided, it is necessary to install preventive measures against leakage of leachate, such as covering with a systhetic sheet liners.
- Installation of the aerator for aeration of leachate (Aerator should be fixed by the cable. A power supply is needed.)
- Installation of the pump for circulation of leachate

c) Leachate re-circulation

<Purpose>

- Improvement of the leachate quality
- Prevention of environmental water pollution
- Accelerating the stabilization of the landfilled waste

<Specification>

[Pumping equipment]

- Leachate is drawn from the collection pond with the pump

[Infiltration equipment]

- Pumped leachate is infiltrated into the landfilled waste layer from the surface of the landfill site.
- Type of the infiltration equipment
  - Spray application
  - Ponds
  - Trench
  - Gravity wells or Gas vents

Figure A9-6 and **A9-7** show image of leachate re-circulation system.

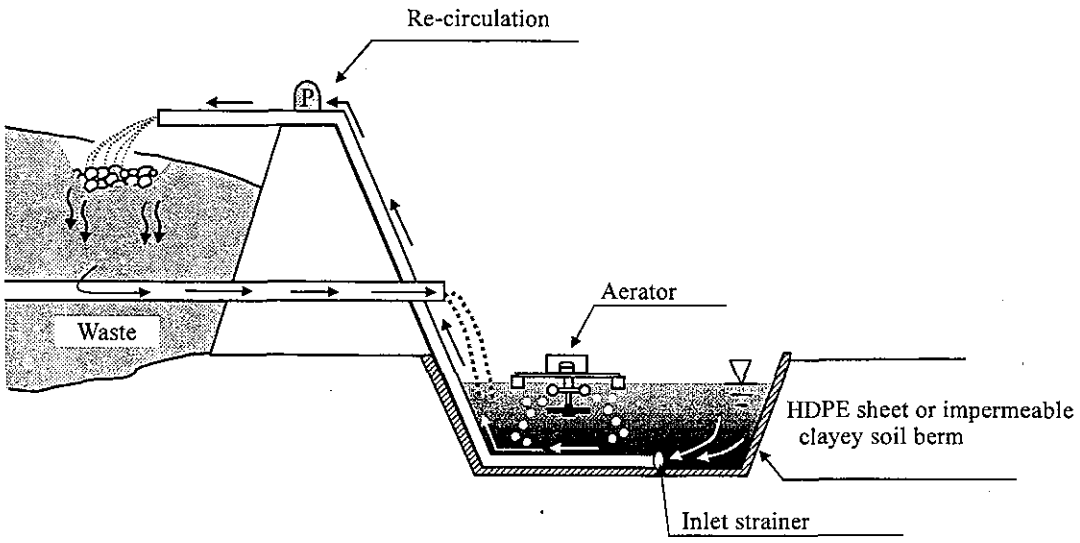


Figure A9-6 Typical Image of Leachate Re-circulation System

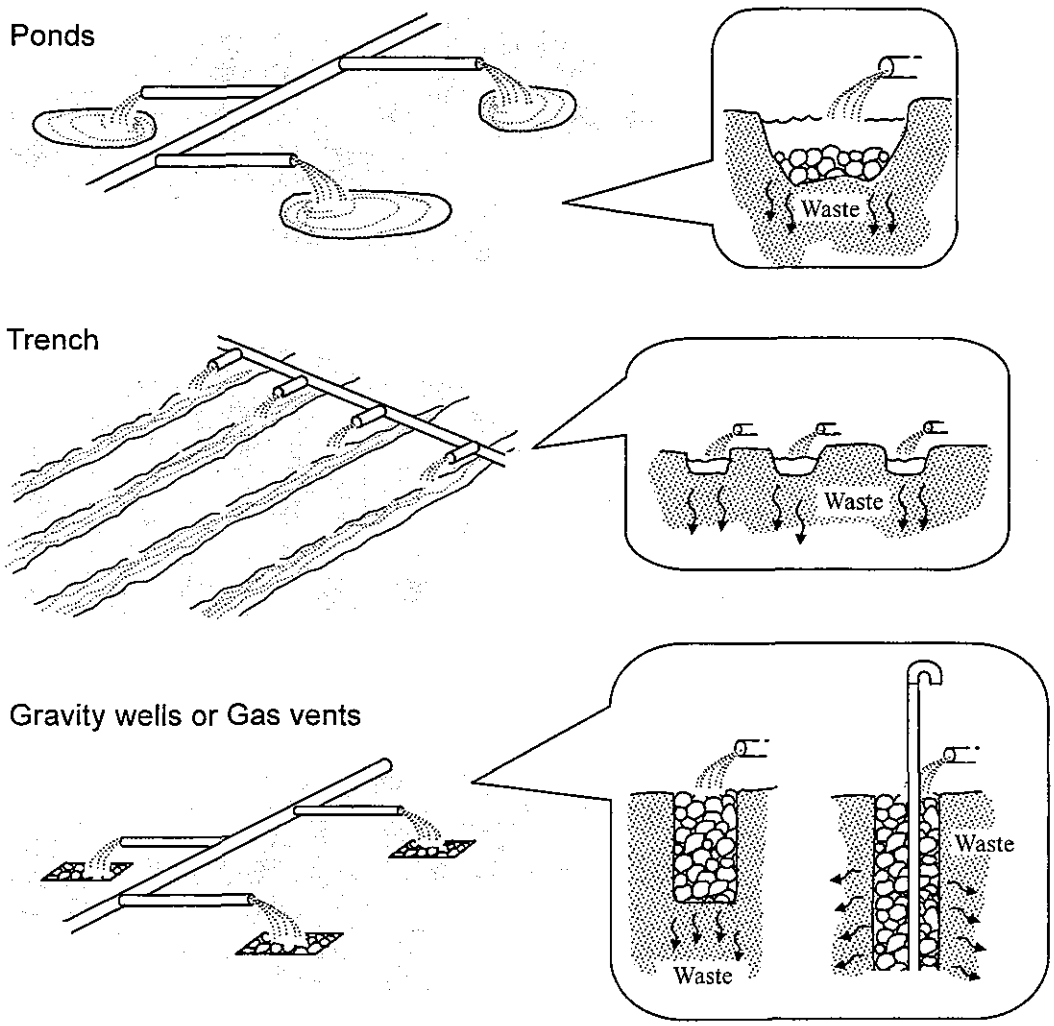


Figure A9-7 Type of the Infiltration Equipment

(4) LANDFILL SAFE CLOSURE LEVEL : C4

a) Leachate treatment

<Purpose>

- Prevention of environmental water pollution
- Prevention of the health influence in the water utilization at a down-stream region

<Specification>

- The treatment method of leachate should be designed optimally by the combination of some systems.
- For the details, refer to Technical Guideline.

<Notes>

- It is a prerequisite condition to install drain facility suitably and reduce leachate quantity.

b) Seepage control work

<Purpose>

- Prevention of groundwater pollution

<Specification>

- There are some methods in the way of controlling seepage, such as injection method, diaphragm wall method, driving method. It should be choose and design the optimal method in consideration of an effect, workability, economical efficiency, etc.

[Injection method]

- A method that infiltrates injection material into earth and sand gaps or rock cracks by compressive injection. There are various methods of injection.
- Mainly used for the lining of rock layer and boulder layer. Often used when the ground condition is poor, such as the case that excavation cannot be performed or mixing of solidifying material is difficult with the continuous underground wall method, and that steel sheet pile cannot be driven directly with the driving method.

[Diaphragm wall method]

- A method that builds underground concrete walls or soil cement walls (walls built by mixing cement and bentonite into local soil and stirring them).
- Several variations of these methods exist depending on how ground excavation or stirring is performed.

[Driving method]

- A method for building lining walls by driving in steel sheet piles, steel pipe sheet piles or synthetic resin boards into the ground.
- There are some methods for driving in sheet pile, such as vibration driving method, pressure infection method, auger-combined method, excavation build-up method, water jet method. Vibration driving method is used in general.

<Notes>

- It is a prerequisite condition to install drain facility suitably and reduce leachate quantity.

Appendix 10

Semi-aerobic Landfill System

1. Mechanism of Semi-aerobic Landfill System

Technical option for the introduction of landfill safe closure of this guideline is semi-aerobic landfill system. This system should basically be introduced for closure level C3 and C4.

The mechanism of semi-aerobic landfill is described as follows.

"In the semi-aerobic landfill, the leachate collection system consists of a central perforated pipe (main collection pipe) with perforated branch pipes on either side of it laid at a suitable interval. The pipes are embedded in graded boulders (5-15cm) and laid with adequate slope. The main collection pipe ends in an open leachate collection pond. The pipes are designed to be laid so that only one-third of the section is filled with flow. At each intersection of the main collection pipe with the branch pipes, and at the end of each branch pipe, vertical gas ventilation pipes enclosed in graded boulders packed inside a perforated used drum are erected. The heat generated by microbial activity in the semi-aerobic landfill causes the temperature difference between the landfill and the outside air makes it possible for air (oxygen) to enter the waste layers through the main collection pipe."**

A schematic view of semi-aerobic landfill is shown in **Figure A10-1**.

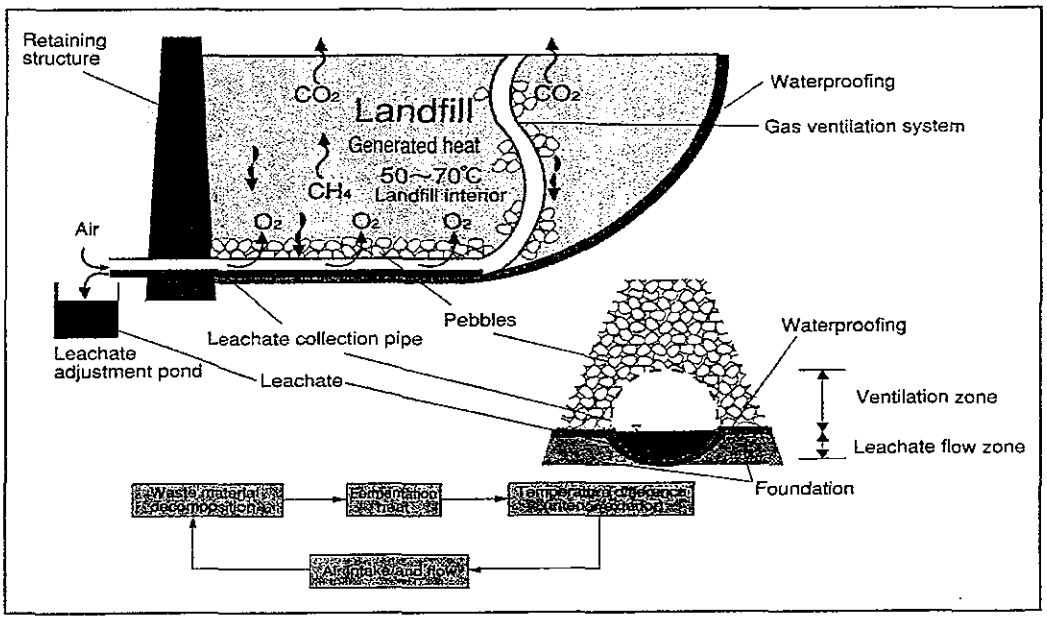


Figure A10-1 Schematic View of Semi-aerobic Landfill

** What is semi-aerobic landfill? Environmental Bureau, Fukuoka City

2. Acceleration of Stabilization by Semi-aerobic Landfill System

(1) Background

There are basically two types of biodegradations of organic matters observed in nature. The first is the "anaerobic" decomposition and another is the "aerobic" decomposition. The anaerobic decomposition is carried out by the anaerobic bacteria without oxygen. The aerobic decomposition is carried out by the aerobic bacteria with oxygen. Both kinds of bacteria are commonly found in nature. A fermentation process in the breweries is one of the most famous anaerobic decomposition processes. It is well known that the decomposition rate of the aerobic decomposition is much faster than that of the anaerobic decomposition process. Both processes have been applied to the wastewater treatment and selected according to the water quality and facilities' conditions for long time.

In a landfill, when the organic waste is dumped, aerobic decomposition process occurs at the initial period due to the rich in oxygen air supply. But as the waste is piled up, the oxygen consumption exceeds the oxygen supply available in the waste layers and the aerobic decomposition cannot be supported and the anaerobic decomposition takes place. Therefore, the waste degradation in the landfills is mostly by the anaerobic decomposition process.

(2) Semi-aerobic Landfill System

In order to decompose the organic waste rapidly, the aerobic decomposition process should be applied. The "composting" is the typical technique that uses the "aerobic" decomposition process for waste treatment. The aerobic decomposition process was not applied successfully at landfill sites until 1960s, even though there were several challenges like forced gas venting, etc. Based on the studies of landfill system carried out by the Fukuoka City, Japan, from 1960s, Dr. HANASHIMA of the Fukuoka University published the concept of "Semi-aerobic landfill system" in his study in the early 1970s.

Semi-aerobic landfill system enhances the air supply into the filled waste layers through the gas collection/ventilation pipes surrounded with gravels, which are also joined to the leachate collection/draining pipes. The leachate collection pipes are connected to the leachate pond with the discharge end open. The air will be able to flow into the waste layer through these pipes when the amount of leachate is lesser and leachate table inside the waste layer is low. Since the two piping systems are jointed, the air and landfill gas will flow through the leachate collection pipes and the gas ventilation pipes. This flow will enhance the intrusion of the air into the inner part of filled wastes occasionally. This is a reason why the process was called "Semi-aerobic".

Normally the temperature in the waste layer is higher than the atmospheric temperature due to the exothermic biodegradation of the waste. Since the hot air and gas inside the waste tends to rise and vented through the gas vents, thus generating a negative pressure siphoning effect that draws the air into the pipes.

In order to maintain the waste layer at an aerobic condition, more air should be injected into the filled waste by forced ventilation. This process is difficult to implement, it

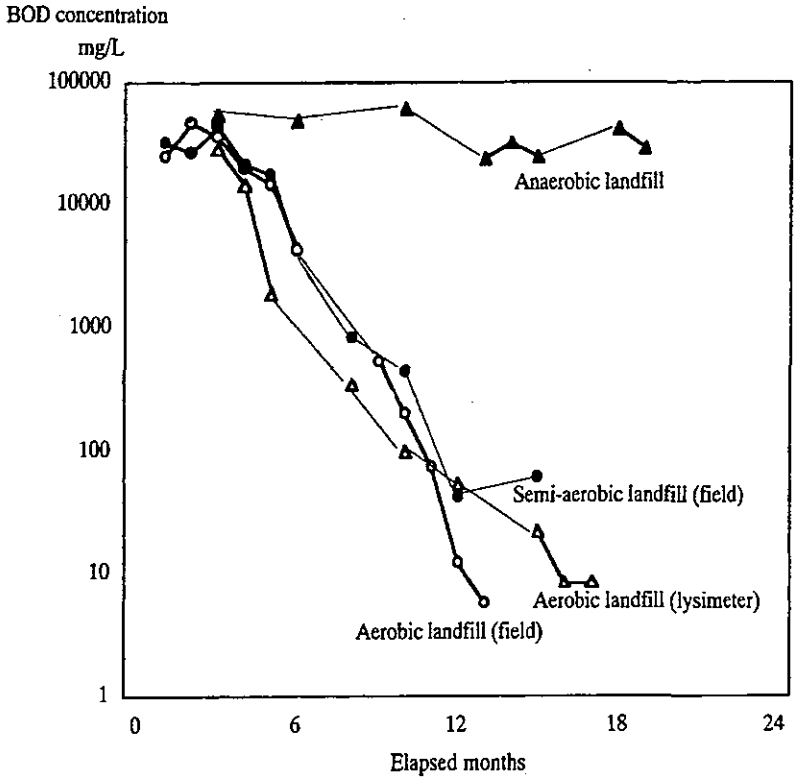
requires intensive power source and not particularly economical. However, the semi-aerobic landfill system does not require force ventilation.

Therefore, the semi-aerobic landfill system will be preferable to enhance the decomposition of organic matters of the waste, consequently also reduces the generation of methane and offensive odour, and the pollution load of leachate.

In order to verify the effects of semi-aerobic landfill system for waste decomposition, several study papers were reviewed, they are as follows.

1) Leachate

Dr. HANASHIMA, M et al. compared the change of concentration of BOD in leachate for different types of landfill systems (**Figure A10-2** and **Table A10-1**). The graph shows that the period for stabilisation of leachate of semi-aerobic landfill system is shorter than that of anaerobic landfill system.



Source: HANASHIMA, 1999

Figure A10-2 Changes of BOD Concentration in Leachate with Passage of Time for Several Landfill System

Table A9-1 Changes of Water Quality of Leachate

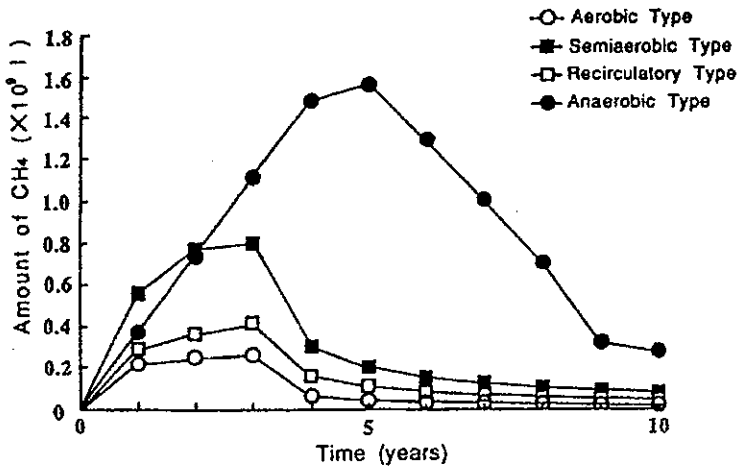
Landfill type	Water quality item	Continued landfilling	6 months after landfilling	One year after landfilling	Two years after landfilling
Anaerobic	BOD (mg/L)	40,000 - 50,000	40,000 - 50,000	30,000 - 40,000	10,000 - 20,000
	COD_{Mn} (mg/L)	40,000 - 50,000	40,000 - 50,000	30,000 - 40,000	20,000 - 30,000
	NH_3-N (mg/L)	800 - 1,000	1,000	800	600
	pH	About 6.0	About 6.0	About 6.0	About 6.0
	Transparency	0.9 - 1.0	1 - 2	2 - 3	2 - 3
Improved sanitary	BOD (mg/L)	40,000 - 50,000	7,000 - 8,000	300	200 - 300
	COD_{Mn}(mg/L)	40,000 - 50,000	10,000 - 20,000	1,000 - 2,000	1,000 - 2,000
	NH_3-N (mg/L)	800 - 1,000	800	500 - 600	500 - 600
	pH	About 6.0	About 7.0	7.0 - 7.5	7.0 - 7.5
	Transparency	0.9 - 1.0	1 - 2	1.5 - 2.0	1 - 2
Semi-aerobic	BOD (mg/L)	40,000 - 50,000	5,000 - 6,000	100 - 200	50
	COD_{Mn} (mg/L)	40,000 - 50,000	10,000	1,000 - 2,000	1,000
	NH_3-N (mg/L)	800 - 1,000	500	100 - 200	100
	pH	About 6.0	About 8.0	About 7.5	7.0 - 8.0
	Transparency	0.9 - 1.0	1 - 2	3 - 4	5 - 6
Aerobic	BOD (mg/L)	40,000 - 50,000	200 - 300	50	10
	COD_{Mn} (mg/L)	40,000 - 50,000	2,000	1,000	500
	NH_3-N (mg/L)	800 - 1,000	50	10	1 - 2
	pH	About 6.0	About 8.5	7 - 8	About 8.5
	Transparency	0.9 - 1.0	6 - 7	2 - 3	2 - 5

Source: HANASHIMA, 1999

Note: There are two analysis methods for COD as COD_{Mn} and COD_{Cr}. COD_{Mn} is applied in Japan and COD_{Cr} is applied in Malaysia, These two methods may show different figures.

2) Gas

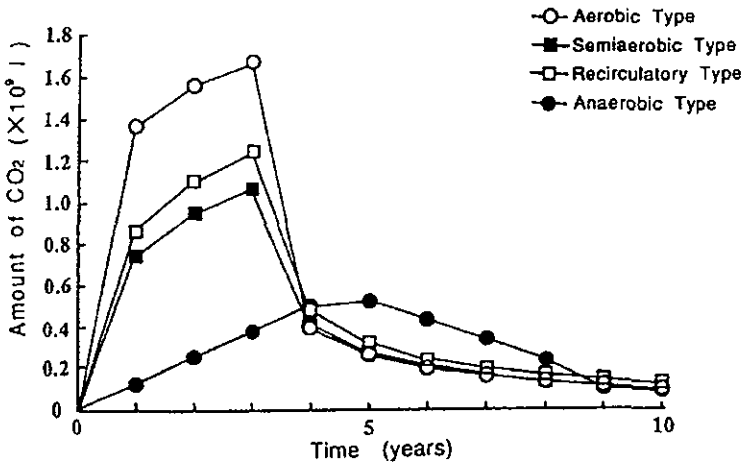
Dr. MATSUFUJI, Y et al. studied and compared the changes of gas generation for different types of landfill systems (**Figure A10-3** and **Figure A10-4**). **Figure A10-3** shows that both of the rate and the total amount of methane generation from semi-aerobic landfill system is lower than that of the anaerobic one.



Source: MATSUFUJI, 1993

Figure A10-3 Change of the Yearly Amount of CH_4 Generations from Different Types of Landfill Systems

Figure A10-4 shows that the rate of CO_2 generation from semi-aerobic system is increasing rapidly and ceasing in shorter time in comparison with the anaerobic system. These phenomena indicate that the period of biodegradation of semi-aerobic system will be shorter than that of the anaerobic system.



Source: MATSUFUJI, 1993

Figure A10-4 Changes of the Yearly Amount of CO_2 Generation from Different Types of Landfill System

3) Considerations for implementation of "Semi-aerobic" landfill system

The landfill system is not solely dependant on the installed facilities but also on the operation and maintenance activities. The "Semi-aerobic" landfill system requires appropriate operations in order to maintain the state of the filled waste layer in the semi-aerobic conditions. For example, the proper jointing and extension work for gas ventilation pipes surrounded with the gravels, and the designated and planned installation of gas collection system and leachate collection layer of gravels or other permeable materials at the intermediate layer are strongly recommended.

However, even if the landfill site has been provided with the suitable facilities designed for the semi-aerobic system, the air supply must always be allowed to flow into the waste layers. If the drainage of the leachate is insufficient and water table of the leachate is high, the air supply will be blocked and not able to flow through the pipes. Thus if the leachate is not controlled properly, the semi-aerobic conditions will revert to the anaerobic conditions rapidly.

In Malaysia, most of waste is disposed of in plastic bags and if the bags are not ripped open or broken, the wastes inside are not exposed to the air and kept in the anaerobic condition. Hence, in order to break the plastic bags at the landfill, bulldozers and landfill compactors should be used to compact the wastes properly after the daily filling work. It is recommended that the compactors should run over the dumped waste more than five times.

(3) Applicability of Semi-aerobic System for Post-closure Management (PCM)

Even though the waste filling work has completed, the biodegradation of the waste will continue and generate the landfill gas and leachate. In order to reduce the burdens of PCM for the site owners/operators, the public sector and the risks of environmental pollution, the PCM period should be minimised.

One of the ways to shorten the PCM period is by enhancing the decomposition of waste in the safe and proper manner. For the most economic means of enhancement of decomposition, it seemed that the preferred method is to promote the aerobic decomposition.

It may not be feasible and economical to install the gas ventilation pipe system and leachate collection system after the final soil cover work has been applied. If the connection of leachate collection system and gas collection/ventilation system have been provided during construction of the landfill, it will become easier to draw the air into the waste layer through the piping system, even though the site is operated under the anaerobic conditions.

The cost of providing the equipments at the initial stage will be cheaper than those that have to be provided after the closure. Therefore, it is highly recommended that application of the semi-aerobic system at closed landfill sites for shorten the PCM period, even though the site could be operated in anaerobic condition or aerobic condition.

In the case the landfill site is to be used for gas extraction (methane recovery) and operated in anaerobic condition, when the landfill gas generation has stop, the site can be change to the semi-aerobic system. When the ends of the pipes will be open to air, the piping system installed for gas extraction can be used for gas ventilation. Also the leachate table should be kept lower and the end of leachate collection pipes are occasionally open to air. It is recommended that re-circulation of leachate into the filled waste layer, using some of the gas extraction pipes. When the gas extraction pipes are used for leachate injection, the periodical usage, i.e. monthly change of injecting points, is recommended.

If the site is operated in the semi-aerobic conditions properly, it does not need major modification in the operations. In the case the site was designed and constructed as a semi-aerobic landfill system, but has not been operated properly, it is strongly recommended that the operations should carried out properly for the semi-aerobic landfill system.

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[MATSUFUJI, 1993] Y. MATSUFUJI, M. HANASHIMA, S. NAGANO, A. TANAKA : Generation of greenhouse effect gases from different landfill types, Engineering Geology, Vol.34, pp.181-187 (1993)