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

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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.

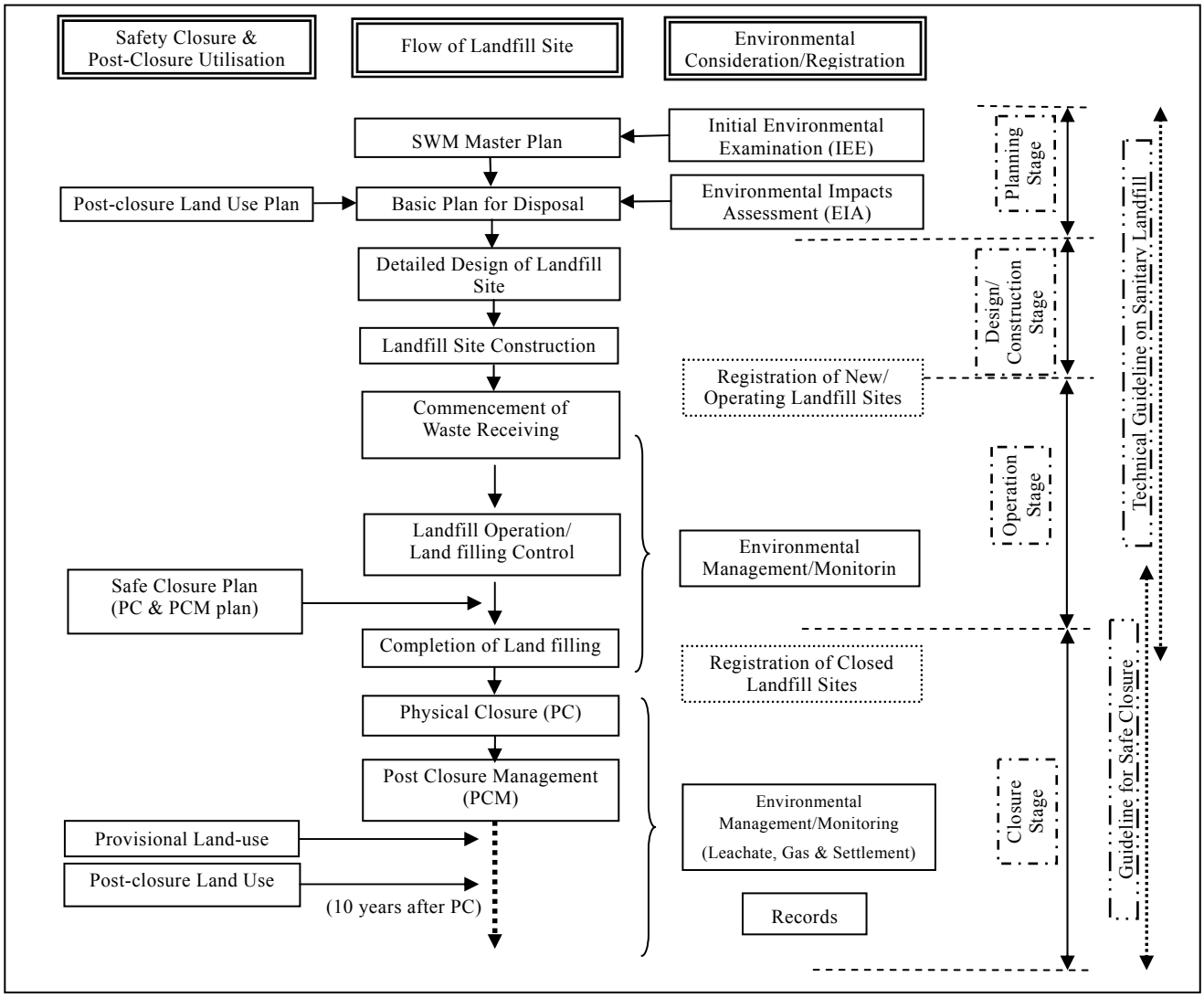


Figure A1-1 Flow chart on the Landfill Management Activities

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**.

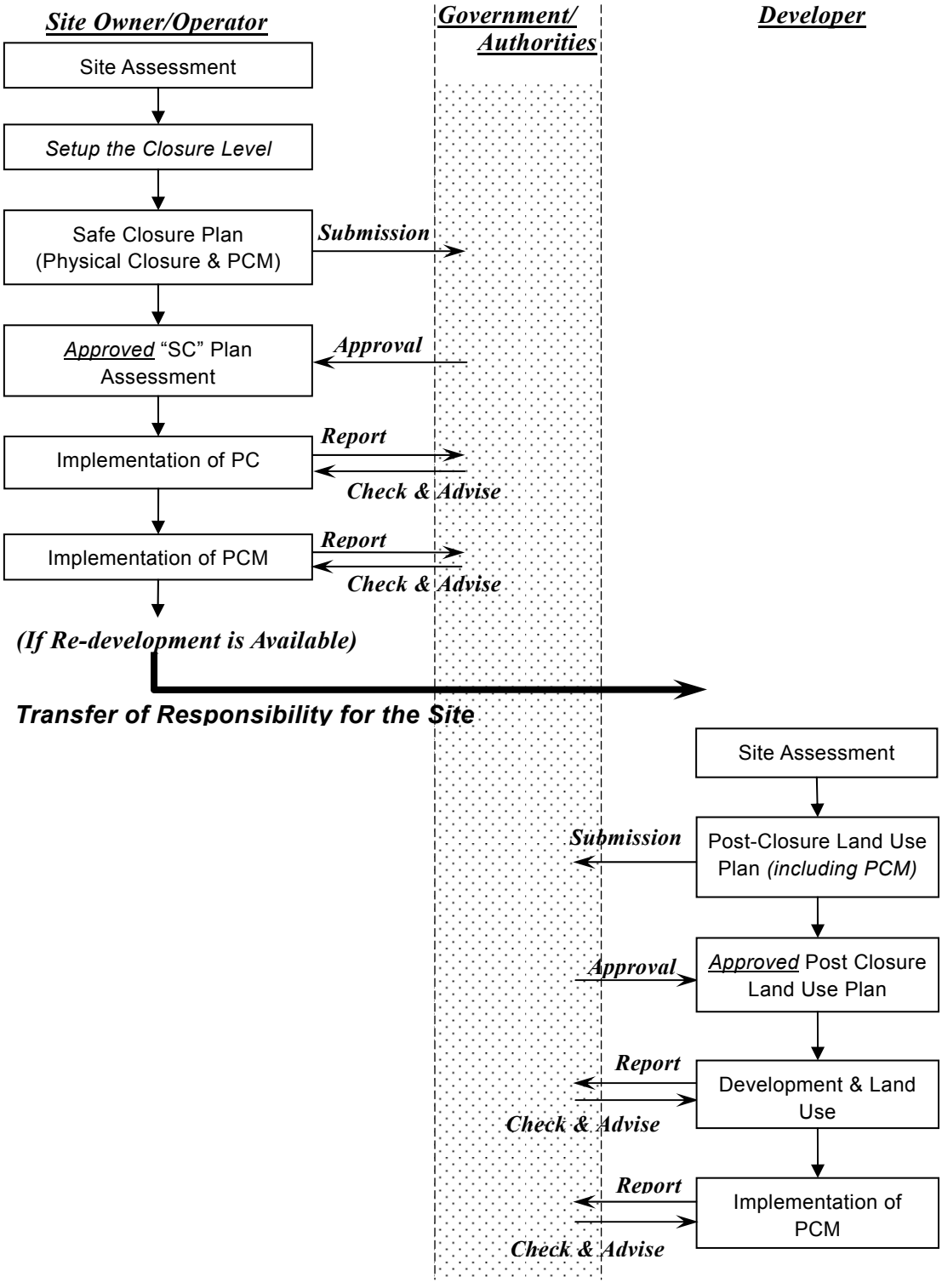


Figure A2-1 Process of Landfill Safe Closure

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**.

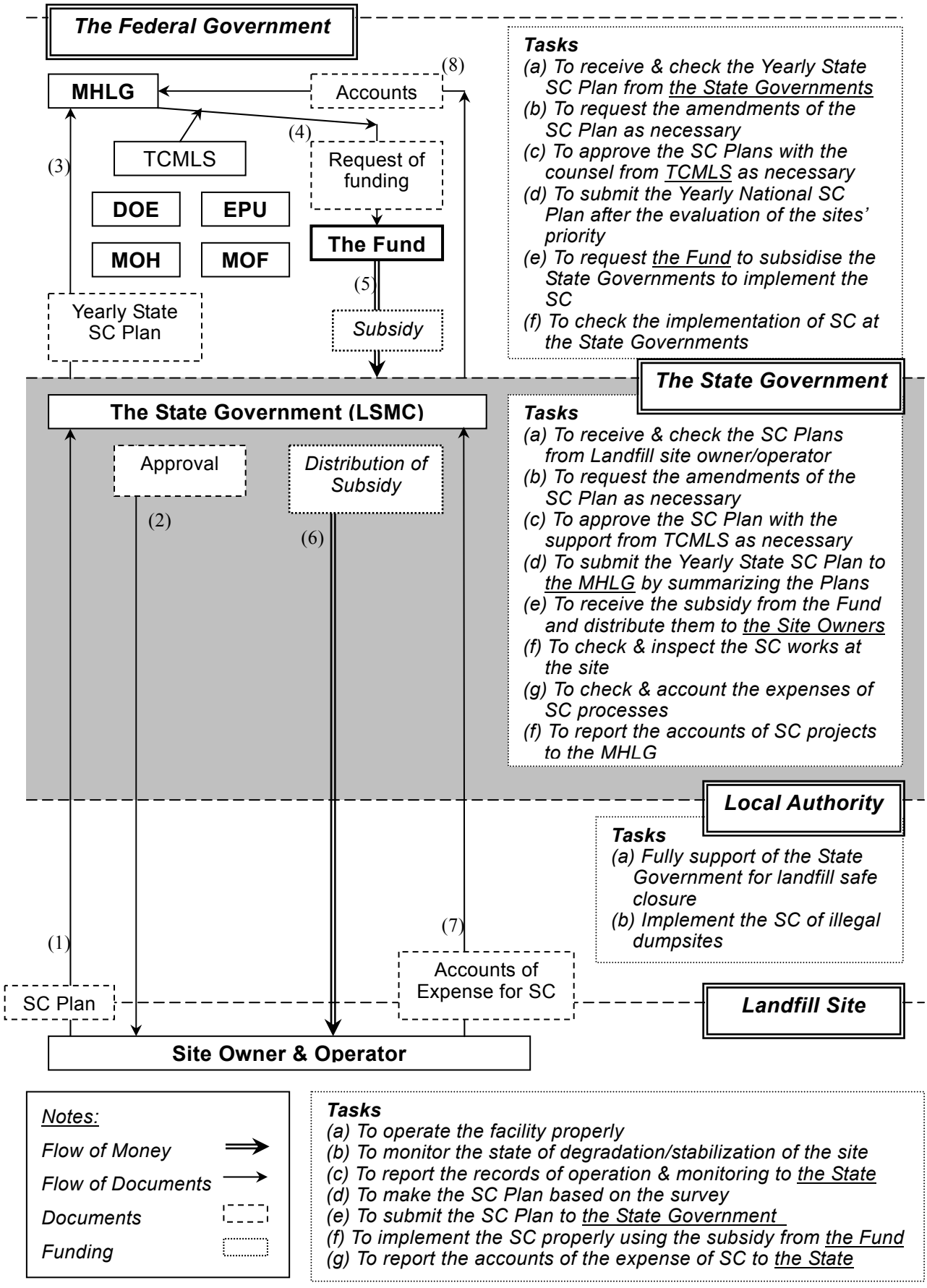


Figure A3-1 Roles of the Stakeholders for the Landfill Safe Closure

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.

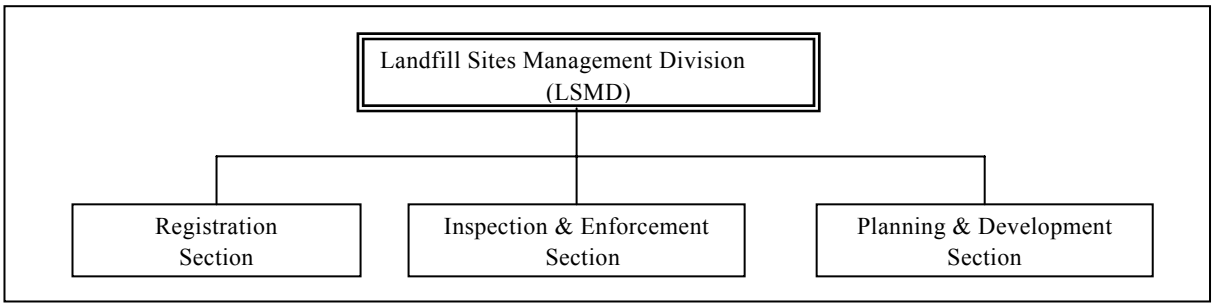


Figure A4-1 Organizational Structure of the LSMD

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.

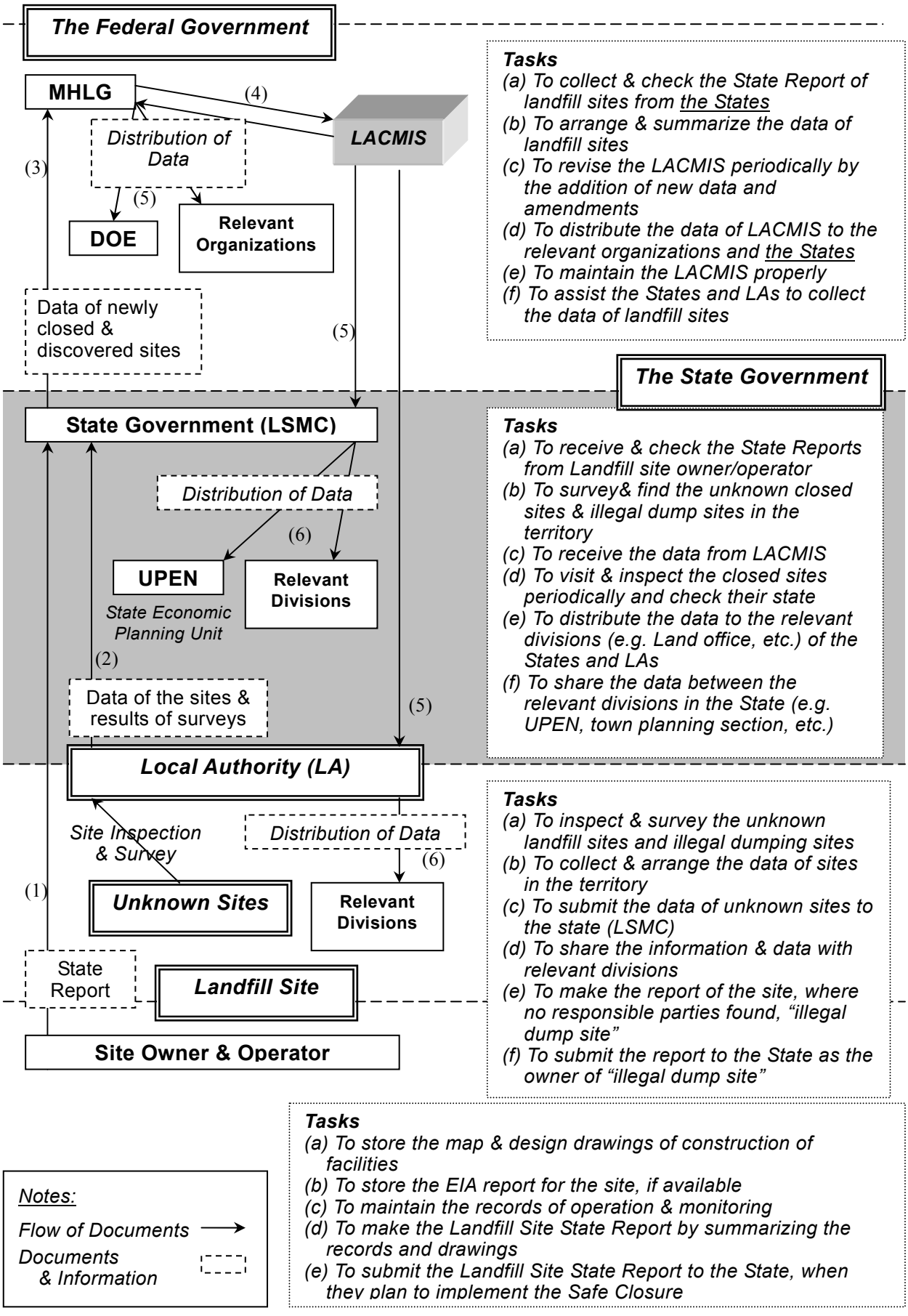


Figure A5-1 Roles of the Stakeholders for Management of the LACMIS (Landfill Closure Management Information System)

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**.

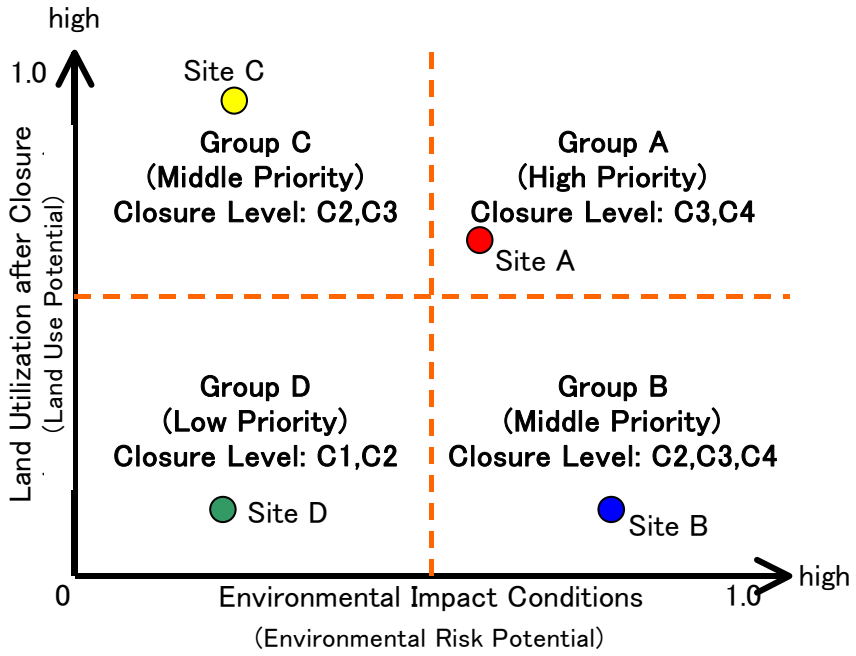


Figure A7-1 Concept of the Grouping of the Priority

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											++	++	+	

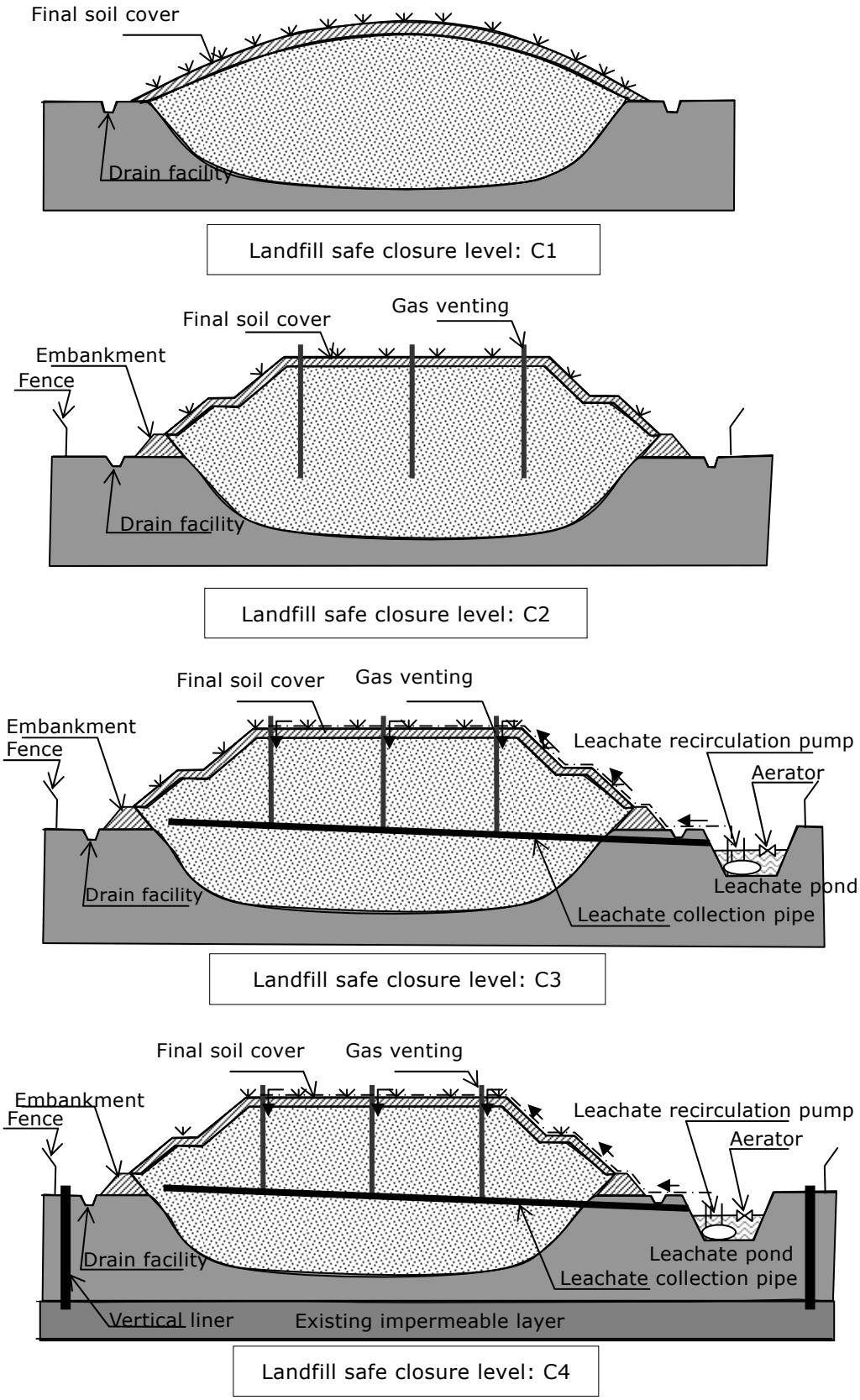
Note: * "Public Complaint" is equally divided to C1-C4

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.

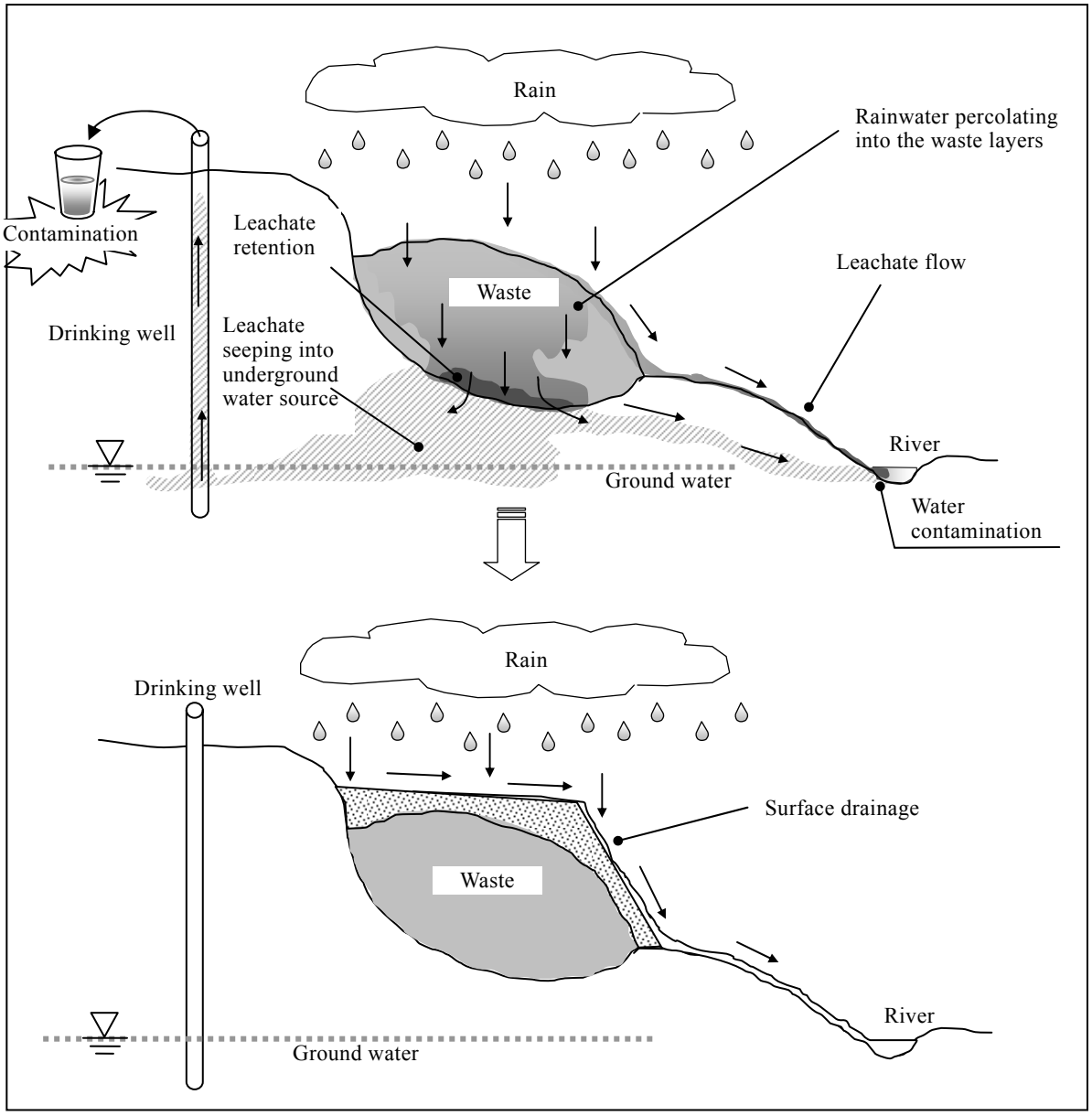


Figure A9-2 Purpose of Final Cover

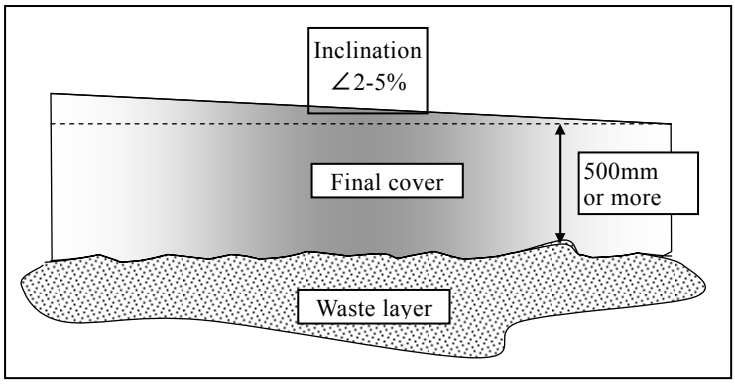


Figure A9-3 Final Cover Specifications

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

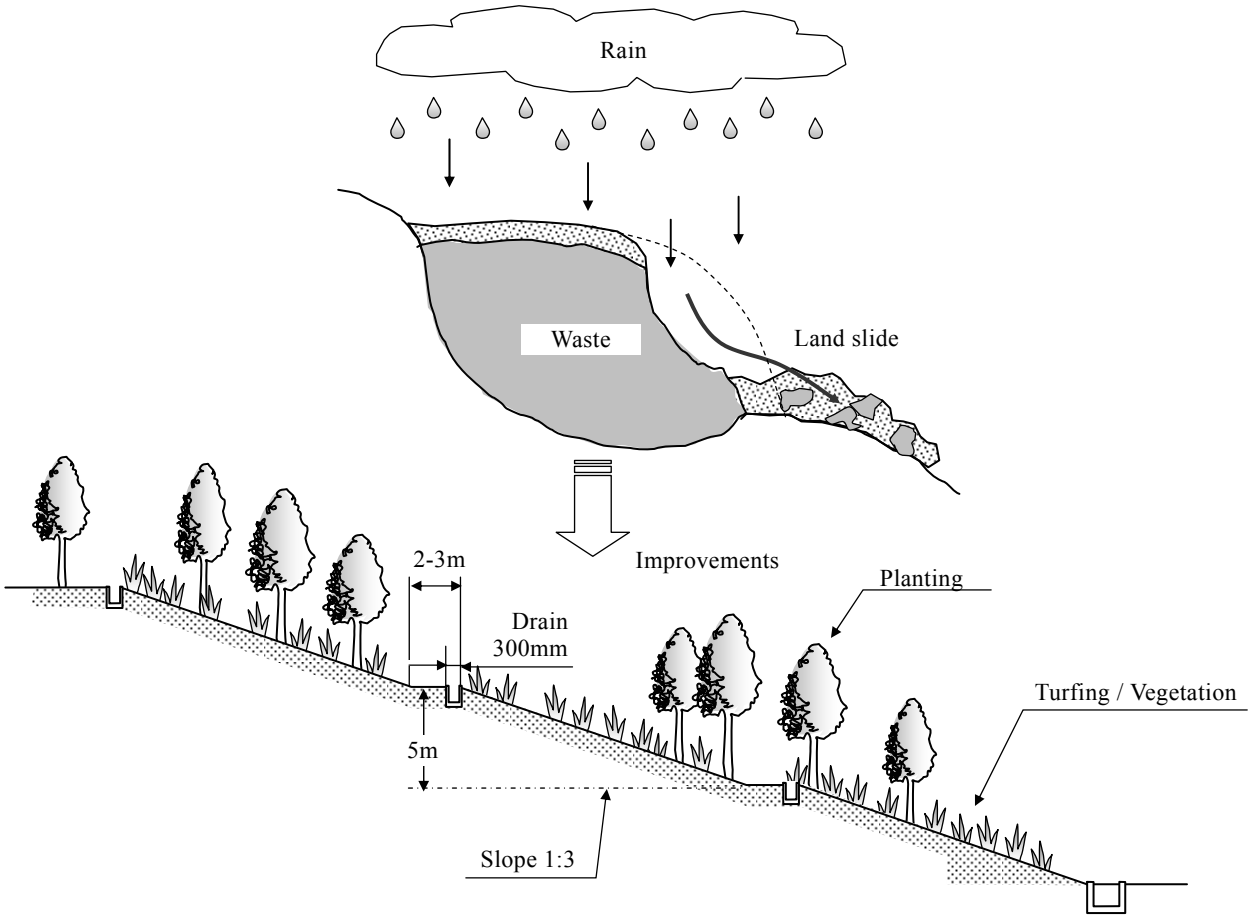


Figure A9-3 Slope Improvement

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)

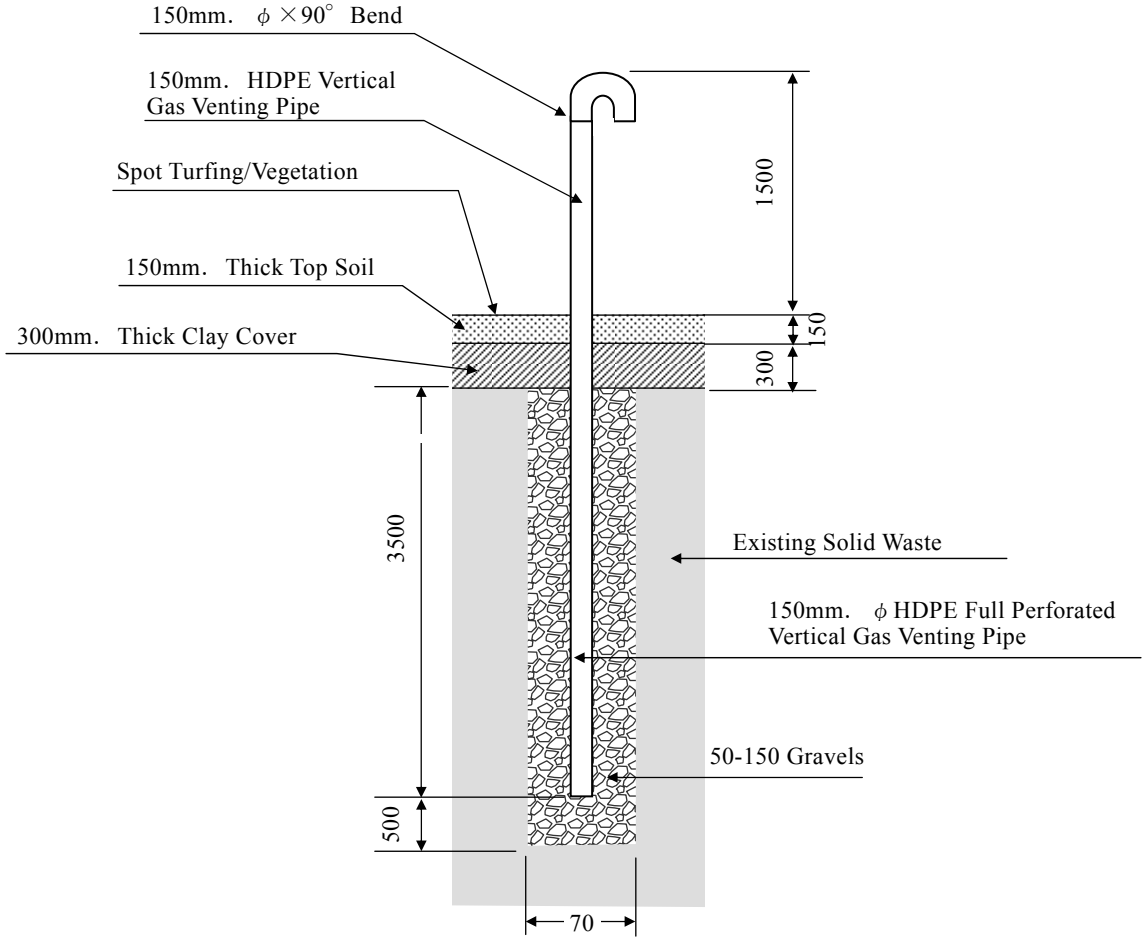


Figure A9-4 Typical 150mm. ϕ Vertical Gas Venting Pipe Detail

(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

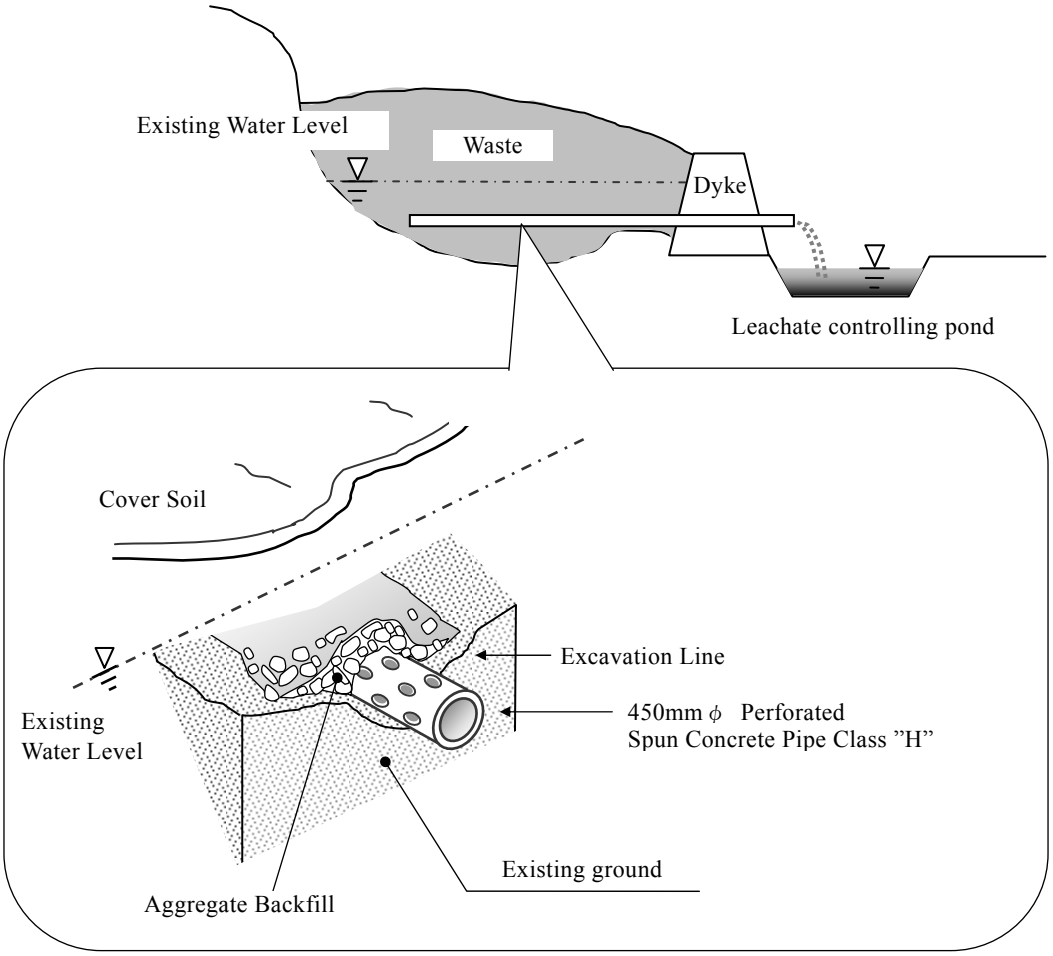
  Width: 3 or more times of diameter

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.

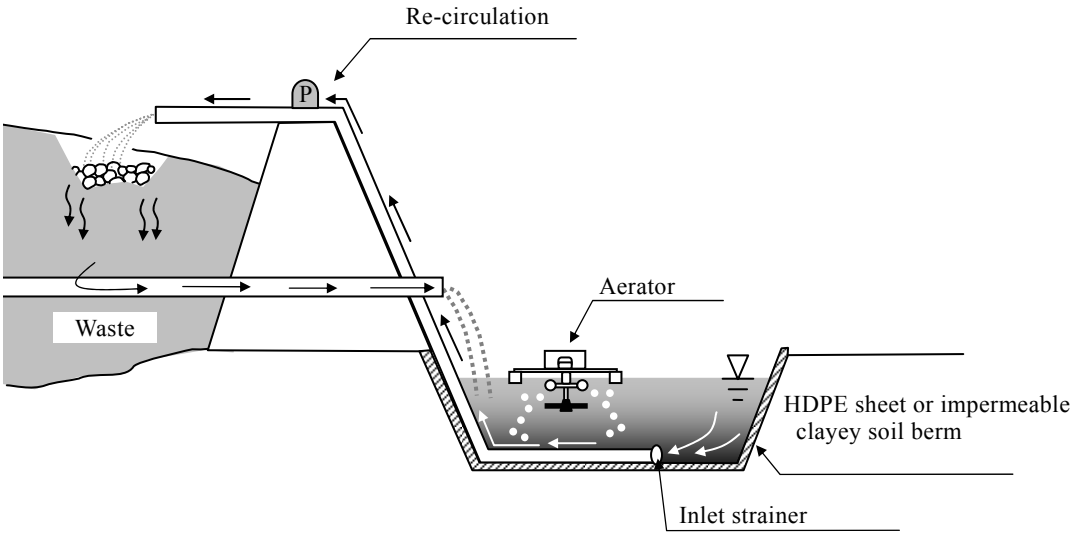


Figure A9-6 Typical Image of Leachate Re-circulation System

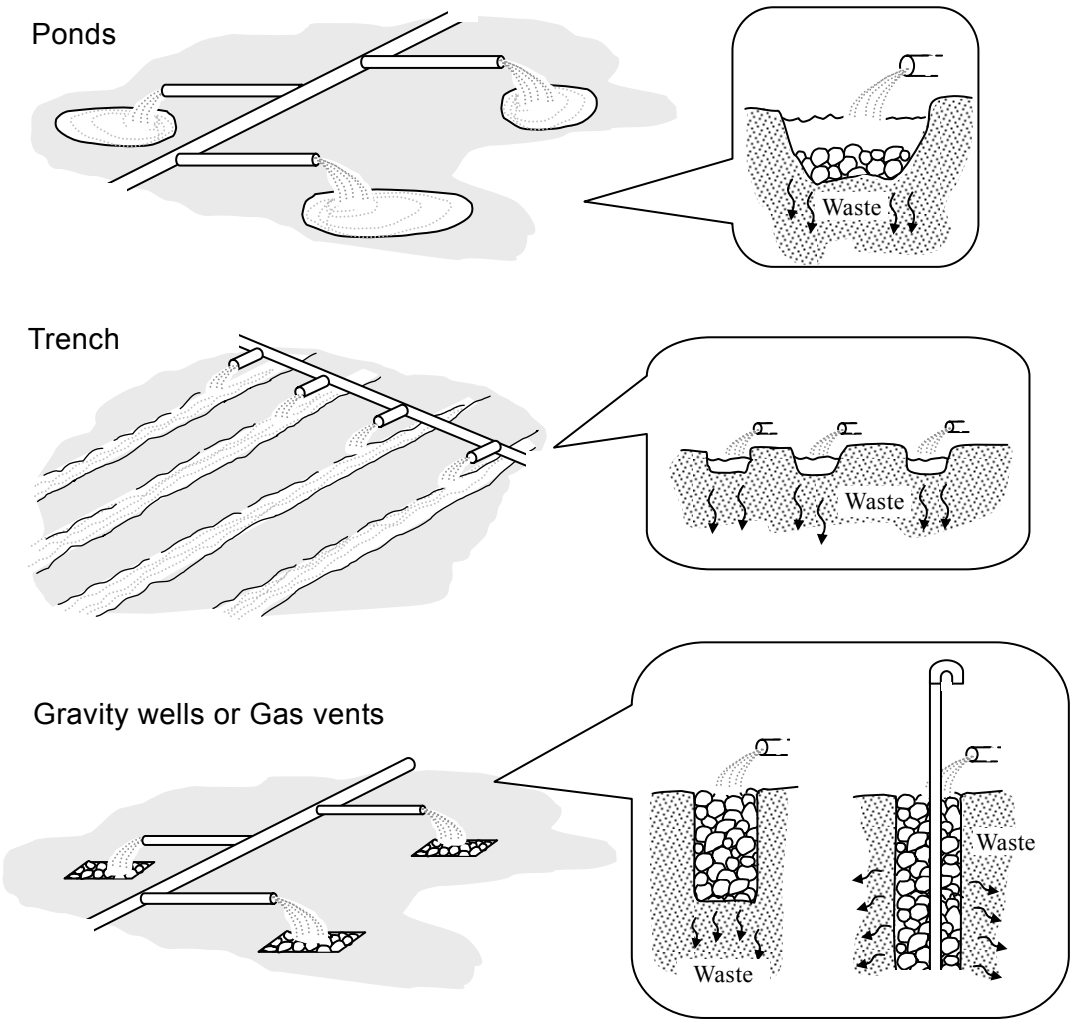


Figure A9-7 Type of the Infiltration Equipment

(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**.

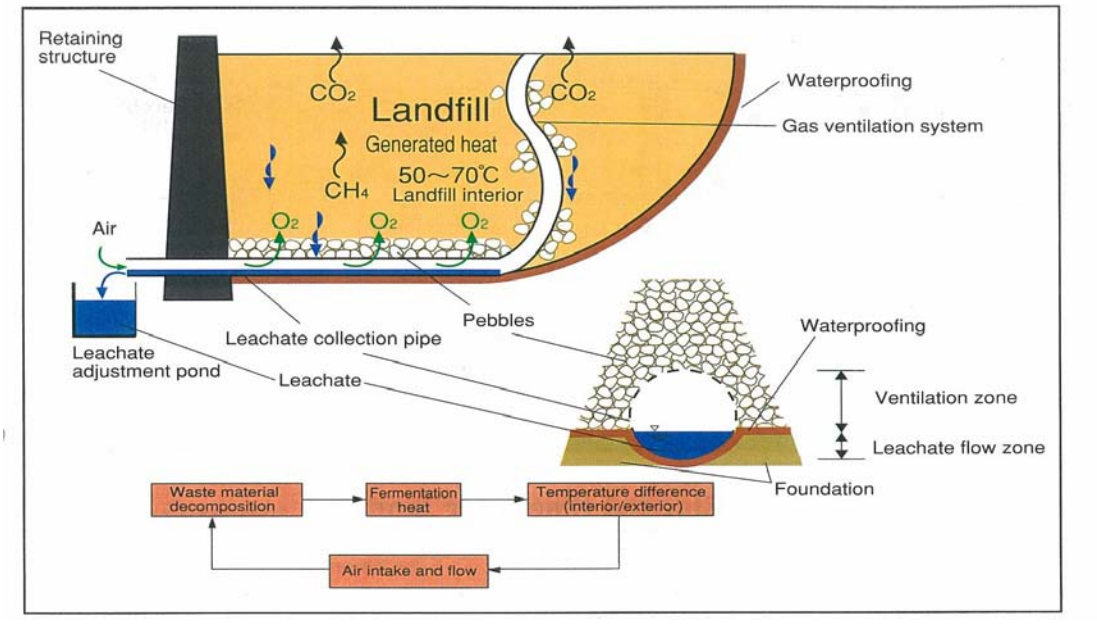


Figure A10-1 Schematic View of Semi-aerobic Landfill

** 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

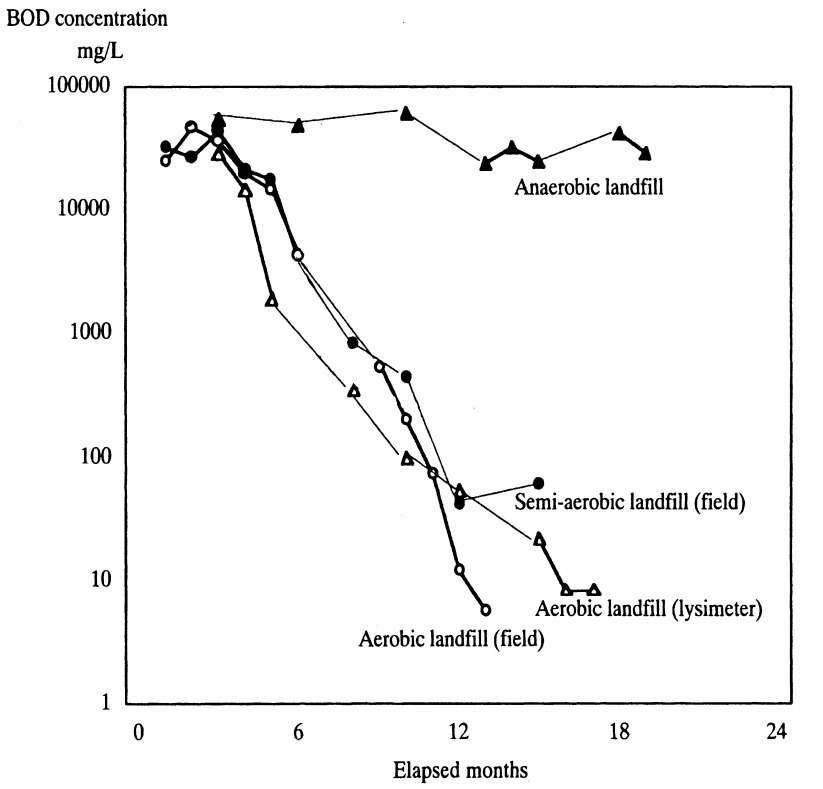
requires intensive power source and not particularly economical. However, the semi-aerobic landfill system does not require force ventilation.

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

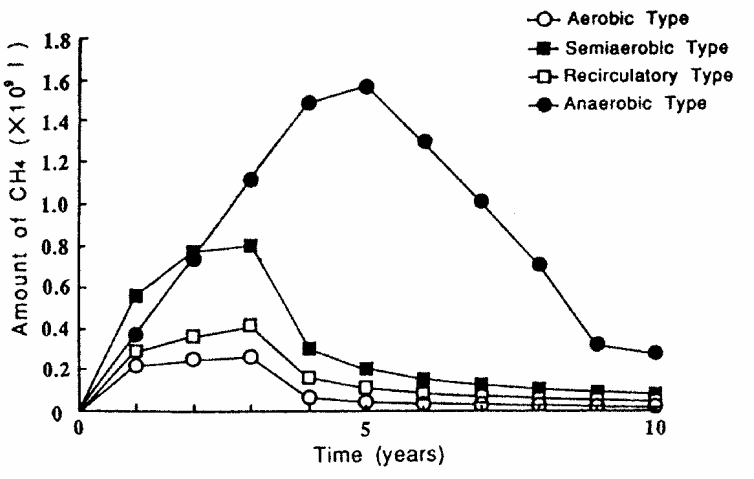
Landfill type	Water quality item	Continued landfilling	6 months after landfilling	One year after landfilling	Two years after landfilling
Anaerobic	BOD (mg/L)	40,000 - 50,000	40,000 - 50,000	30,000 - 40,000	10,000 - 20,000
	COD_{Mn} (mg/L)	40,000 - 50,000	40,000 - 50,000	30,000 - 40,000	20,000 - 30,000
	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

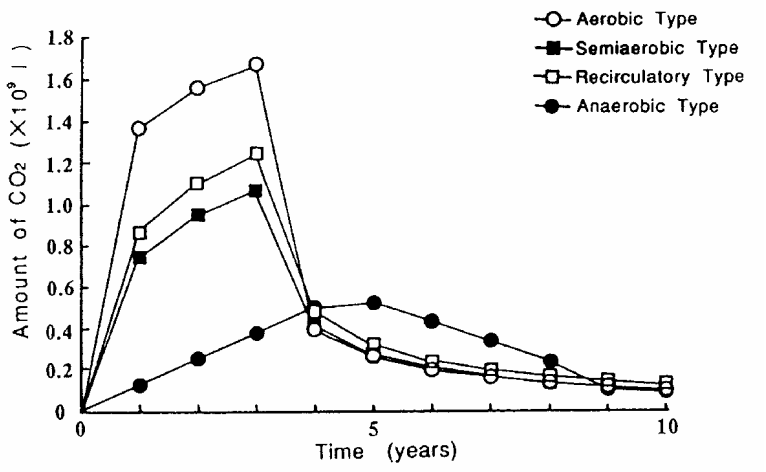
Dr. MATSUFUJI, Y et al. studied and compared the changes of gas generation for different types of landfill systems (**Figure A10-3** and **Figure A10-4**). **Figure A10-3** shows that both of the rate and the total amount of methane generation from semi-aerobic landfill system is lower than that of the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

References

[HANASHIMA, 1999] M. HANASHIMA: Pollution of Control and Stabilization Process by Semi-aerobic Landfill Type: The Fukuoka Method, Proceedings of Sardinia 99, Seventh International Waste Management and Landfill Symposium, Volume I, pp.337-344 (1999)

[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)

Appendix 11

Indicators for The Stability of Closed Landfill Sites

(1) Physical Conditions

a) Rate of subsidence

The rate of subsidence for the stabilized landfill should be less than 20mm per year.

The subsidence rate should be monitored regularly and the level survey should be carried annually. Benchmarks should be installed at suitable locations on the surface of the top coil soil. The minimum recommended number of benchmarks is two (2), or one (1) for each hectare of the site. The subsidence should be monitored and observed for more than two years.

b) Top covers

The top cover should not exhibit any surface cracks, pools or signs of soil erosion. The soil cover should be of sufficient thickness to protect the filled waste layer. The recommended thickness is more than 750mm and should be well compacted. The top cover should be planted with scrubs, vegetation or grass to prevent dust and soil erosion. Especially the thickness is recommended to be more than 1500mm for planting trees.

(2) Chemical Conditions

a) Quality of the raw leachate

The sites have reached stability when the quality of the untreated raw leachate discharged from the landfill has maintained constant for at least two years and is within the approved limits and complies with the relevant effluent discharge standards. If the effluent discharge does not meet with the standards, then the leachate treatment facility should continue to be operated.

b) Quality of landfill gas

The concentrations of landfill gas should satisfy the following conditions.

(i) Not volatile and explosive: The methane levels should be less than 5% (by volume)

(ii) Not cause suffocation: The oxygen levels should be higher than 18% (by volume)

The landfill gas should be monitored at the ventilation pipes a least twice a year after the filling works has completed. The concentration of the gas could become higher during low atmospheric pressure conditions. It is recommended that the frequency and number of gas monitoring activities during such low pressure conditions be increased to be more twice the frequency of the normal monitoring activities.

c) Quality of groundwater around the site

No pollution to the groundwater around the site should be observed. The number of the monitoring wells is one for upstream (as for background monitoring well) and two for downstream (as for detection well).

d) Temperature of the waste layers

There should be no significant increase in the temperature detected in the waste layers. The temperature in the waste layers should be monitored by using the gas ventilation pipe or by installing special temperature monitoring wells. The subsurface temperature 5m below the surface should be between 25° C to 30° C. If the temperature of the waste layers is higher than 30° C, then the waste degradation process is still active and the stabilization has not been reached.

Appendix 12

Stabilization Process of Landfill Site (Old sites in Japan)

(1) OUTLINE OF INVESTIGATION SITE

Investigation of the landfill site at the Tokyo harbour in Japan was implemented from 1981 about four sites (The No.8 site, The No.14 site, The No.15 site, The Inner central-breakwater landfill site). In these four sites, the observation base is installed. The outline of landfill sites for investigation is as follows.

Table A12-1 Outline of Investigation Site

	Term of landfill works	Landfill area	Amount of waste disposal	Thickness of landfill layer
The No.8 site	1927-1962	36.4 ha	3,710,000 t	14 m
The No.14 site	1957-1967	45 ha	10,340,000 t	14 m
The No.15 site	1965-1974	71.2 ha	18,440,000 t	14-20 m
The Inner central-breakwater landfill site	1973-1987	78 ha	12,300,000 t	30-32 m

Most of the waste filled in these sites was raw MSW and some incineration residues filled in the fourth site, because the sites were operating more than 20 years ago. The characteristics of these wastes may not be much different from the waste generated in Malaysia at present time.

(2) SUBSIDENCE OF LANDFILL SITE

In the case of the inner central-breakwater landfill site, the amount of subsidence has occurred about 40mm per year in early stages of the landfill when the decomposition of waste is active. The amount of subsidence decreases slowly over time.

When 20-25 years pass after landfilling was completed, the amount of annual subsidence per 10m of waste layers is about 10mm or less. In the result which analyzed the observation result by regression analysis, the amount of subsidence of a landfill site tends to become small according to the hyperbola.

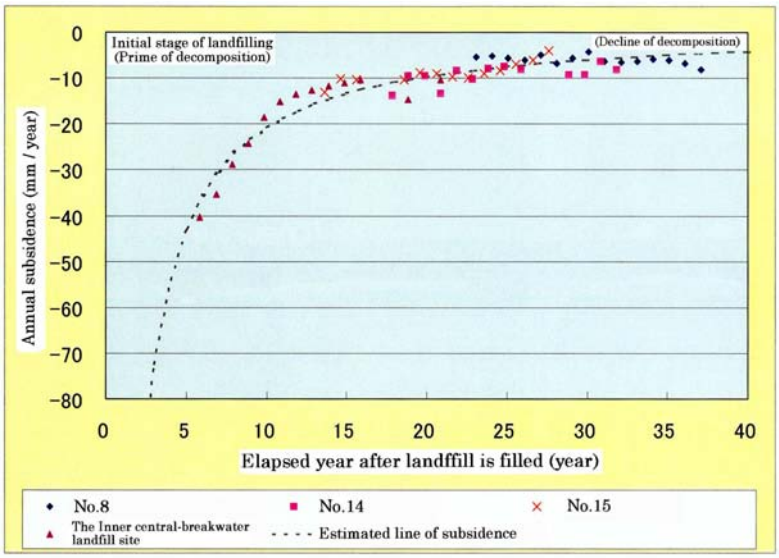


Figure A12-1 Change of Annual Subsidence

(3) CHANGE OF TEMPERATURE INSIDE LANDFILL

The distribution of temperature inside landfill site changes as decomposition of landfilled waste,

In early stages of the landfill, there are about a maximum of 70 degrees of temperature.

When decomposition is completed at the most part, temperature will become 20 degrees or less like the natural ground which is deeper than a landfill layer.

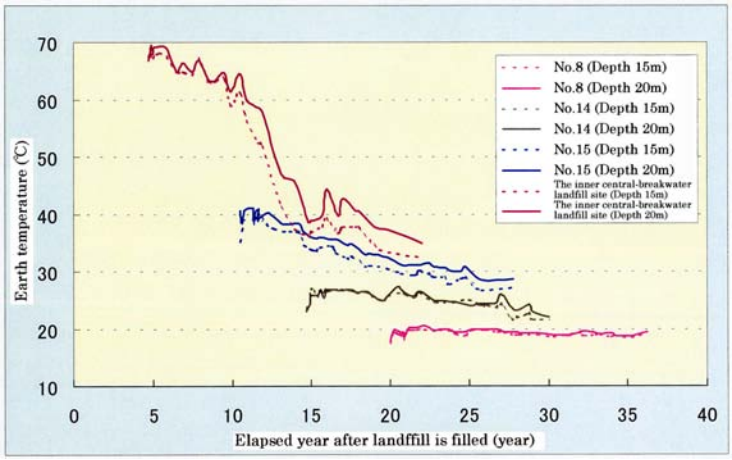


Figure A12-2 Change of Temperature Inside Landfill

(4) CHANGE OF GAS GENERATION

In early stages of landfilling (prime of decomposition), the amount of gas generation is 70-90 L/min. The amount of gas generation changes as decomposition of landfilled waste, it becomes almost 0 L/min in last stage of decomposition.

As for the concentration of the various gas components which constitute landfill gas, methane and carbon dioxide occupy the great portion of generating gas in early stages of landfilling. In last stage of decomposition, the concentration of methane becomes about 5% and the concentration of carbon dioxide becomes about 10%.

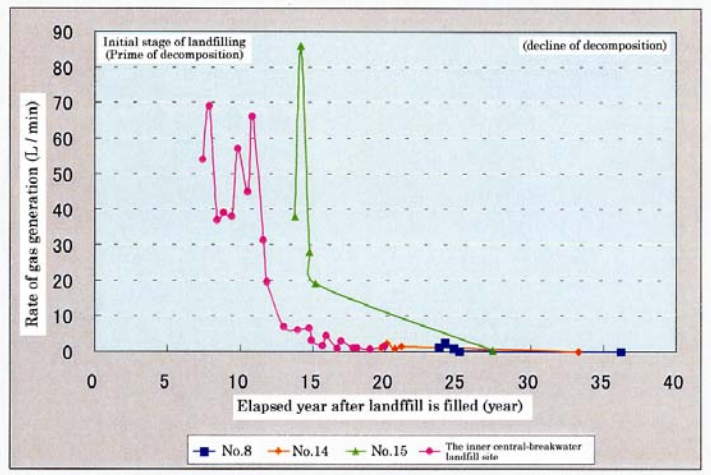


Figure A12-3 Change of Gas Generation Rate

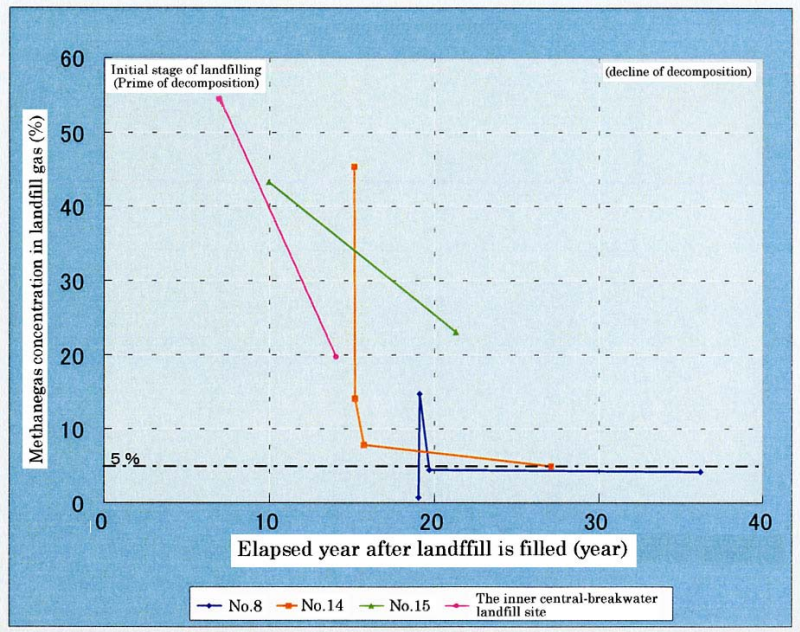


Figure A12-4 Change of Methane Gas Concentration

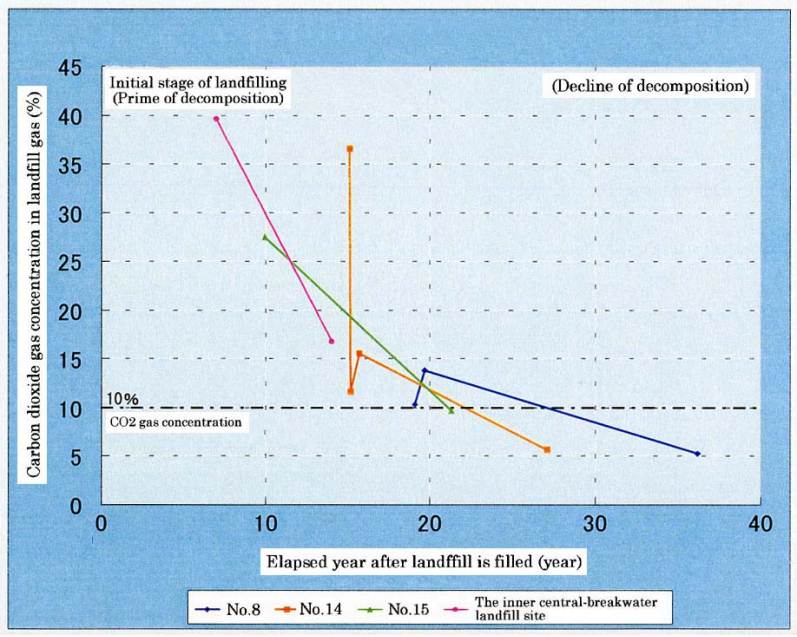


Figure A12-5 Change of Carbon Dioxide Gas Concentration

Appendix 13

Maintenance of Landfill Facilities

(1) TOP COVER & DYKES

Since damage of top cover or a storage structure causes the following troubles, maintenance of the top cover and dykes is needed.

- Scattering or outflow of waste
- Occurrence of offensive odour or vectors
- Disaster which has direct influences in the life of the person such as the collapse of the landfilled waste
- Obstruction for the post-closure land use by the erosion of ground
- Destruction of the landscape
- Increase of the leachate quantity by the increase of the soaking of the rain water into landfilled layer

As the inspection of top cover and dykes, visual inspection to the portion which has appeared on the ground shall be performed about the following items. Frequency of regular inspection shall be decided in view of the condition of these facilities. In addition, extra inspection shall be performed in case the heavy rain took place. Areas where stress is concentrated for structural reasons shall be designed in advance as areas requiring inspection.

- Leakage from dykes
- Cracks in the top cover and dykes
- Subsidence of the top cover and dykes
- Erosion of the top cover and dykes
- Swelling of the slope
- Collapse or slip down of slope
- Dead of vegetation on the top cover and dykes

When damaging is confirmed, repair shall be performed.

If a crack and corrosion are left, corrosion will be accelerated by rain and repair will become difficult. Therefore, brisk check and quick repair are important. The frequent check and the quick repair are necessary.

(2) SURFACE DRAINAGE ON THE TOP COVER

Surface drainage is damaged by the subsidence of the landfill site which is caused by the stabilization of the landfilled waste.

The damage of surface drainage causes the damage of a top cover and a retaining structure by rain water and causes the increase of leachate by the soaking of the rain water into landfilled layer.

As the inspection of the surface drainage, visual inspection shall be performed about the following items.

- Damage of the surface drainage
- Existence of differential subsidence
- Deposition situation of waste or earth and sand
- Existence and its situation of overflow point or stagnant water point

Frequency of regular inspection shall be decided in view of the condition of surface drainage. In addition, extra inspection shall be performed in case the heavy rain took place.

(3) CUT-OFF DRAINAGE AROUND THE SITE

When the fault occurs to the function of the cut-off drainage with the blockade by the discharged earth and sand and so on, it is caused the increase of the leachate quantity by the soaking of the rain water into landfilled layer.

As the inspection of the cut-off drainage, visual inspection shall be performed about the following items.

- Damage of cut-off drainage
- Deposition situation of waste or earth and sand
- Existence and its situation of overflow point or stagnant water point
- Inflow situation of rain water and the earth and sand from the surrounding area

Frequency of regular inspection shall be decided in view of the condition of cut-off drainage. In addition, extra inspection shall be performed in case the heavy rain took place.

Management roads shall be built and measures for improving access to other cut-off drainage shall be taken as required so that maintenance work, such as removal of earth and sand that accumulated in the cut-off drainage can be performed promptly.

(4) GAS VENTILATION PIPES

Gas ventilation pipes are damaged by the subsidence of the landfill site which is caused by the stabilization of the landfilled waste, and is clogged by the discharged earth and sand and so on. When the damage or clog of gas ventilation pipes occurs, it becomes difficult to vent the landfill gas properly and becomes the factor which discourages stabilization of landfill site.

About gas ventilation pipes exposed from the landfill surface, the following item shall be checked by visual inspection.

・Transformation and damage of gas ventilation pipes exposed from the landfill surface

About gas ventilation pipes located below the landfill surface, since it is difficult to perform the visual inspection, it shall be judged synthetically from the following item.

・Change of the amount of gas generation and concentration of landfill gas from gas ventilation pipes
・Gush of gas from the landfill surface except the gas ventilation pipes
・Change of the leachate quality

(5) LEACHATE COLLECTION PIPES

When the damage or clog of leachate collection/drainage pipes occurs, it becomes difficult to manage and treat the leachate properly. Moreover since the groundwater level inside the landfill rise up, infiltrating risk of leachate into underground becomes higher, and the water pressure which is bigger than designed pressure is put on retaining facilities.

About leachate collection/drainage pipes exposed from the ground, the following item shall be checked by visual inspection.

・Crack and hole of pipes
・Scale deposit inside pipes
・Leakage from the joint of the pipes
・Clogging of the pipes (Check inside the pipe from end of pipe)

Since the most part of the leachate collection/drainage pipes is buried underground, it shall be judged synthetically from the following item.

・Leachate quantity at the end of leachate collection/drainage pipe
・Groundwater level inside the landfill
・Crack and subsidence of the landfill surface

・Clogging of the pipes (Check inside the pipe from end of pipe)

(6) LEACHATE TREATMENT FACILITY

When the leachate treatment facilities is not functioning appropriately, it is difficult to perform sable treatment of the leachate which satisfies designed treated water quality and it causes water pollution at the downstream region.

As the inspection of the leachate treatment facility, it shall be performed about the following items.

・Quantity and quality of raw leachate
・Quantity and quality of treated water
・Water level of leachate controlling facility
・Setting of operating conditions and adjustment based on water quality and operation data (pH, DO, ORP, MLSS, etc.)
・Moisture content of dehydrated cake, SS of squeezed water, operating conditions of equipments (in case of installing sludge treatment facility)
・Check of chemicals, lubricants and fuel
・Check, adjustment and repair of each equipment and machines

(7) MONITORING FACILITY

When the damage or failure of groundwater monitoring well or other monitoring facilities occurs, it becomes impossible to understand appropriately the condition inside landfill or influence to the surrounding environment, and it tends to cause the misjudgement about maintenance of landfill site.

As the inspection of the groundwater monitoring well, it shall be performed about the following items.

・Existence of damage or failure
・The inflow situation of the rain water from the opening mouth of groundwater monitoring well

As the inspection of the monitoring facilities, it shall be performed about the following items.

・Existence of damage or failure of equipments
・Calibration of equipments
・Existence of damage or failure of sensing element
・Replacement of sensing element

Appendix 14

Environmental Monitoring

GENERAL OBJECTIVE AND METHODOLOGY OF ENVIRONMENTAL MONITORING

1. Role of Monitoring

Role of monitoring for landfill sites can be categorized based on the purposes. While environmental impact monitoring is primary objective, monitoring for safety of the site at operational phase and monitoring of stabilization process at closure phase are also important. Practical monitoring parameters, however, may be overlapped for different purposes. For example, leachate monitoring is required both for environmental impact monitoring as well as for stabilization process monitoring. **Figure A14-1** shows the concept of role of monitoring.

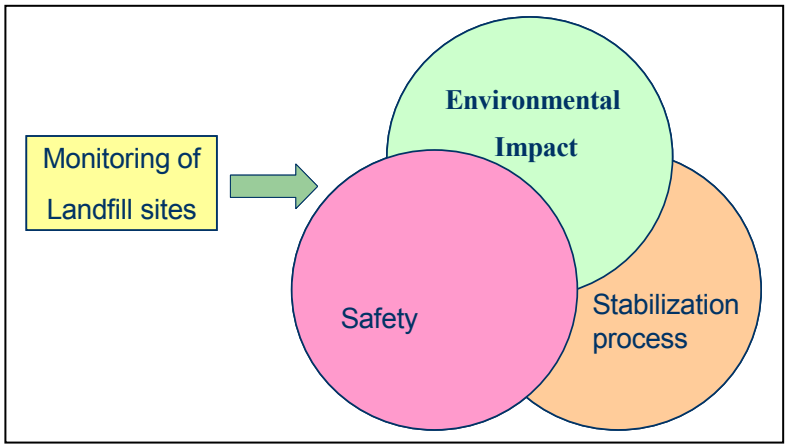


Figure A14-1 Concept of Role of Monitoring

Table A14-1 is the summary of each monitoring parameter related to the purposes.

Table A14-1 Summary of Each Monitoring Parameter related to Purpose

Monitoring media/parameters	Environmental impact	Safety	Stabilization process
Preliminary Site inspection	+	+	++
Leachate	++		++
Landfill gas	+	++	++
Soil subsidence		+	++
Groundwater	++		
Surface water	++		
Subsurface temperature			++

Note : + : magnitude of relation (+ : related, ++ : primarily related)

2. Monitoring Parameters and Frequency

Following table summaries recommended monitoring parameters and frequency for the above noted media.

Table A14-2 Recommended Monitoring Parameters and Frequency for Medias

Monitoring media/parameters	Item and parameters	Frequency	Location
Preliminary Site inspection	Surrounding environment Facility condition Nuisance condition	Once before monitoring	-
Leachate	• pH • BOD • COD • Nitrogen (Ammonia, Nitrate, Nitrite) • ORP • EC • TOC	4 times / year	1 point / leachate pond
Landfill gas	• Oxygen (O_2) • Nitrogen (N_2) • Methane (CH_4) • Carbon Dioxide (CO_2) • Hydrogen Sulphide • Temperature	2 times/ year	2 points / site
Land subsidence	Topographic height of the top of landfill	Once / year	1 point / landfill block
Groundwater	Groundwater benchmark parameters	Once / year	3 points / site
Surface water	Effluent standard parameters	Once /year	2 points / stream

Groundwater benchmark and Effluent standard parameters are shown in **Table A14-3**.

Table A14-3 National Guideline for Drinking Water Quality applied for Groundwater

No	Parameters	Unit	Benchmark value
1	Sulphate	mg/l	400
2	Hardness	mg/l	500
3	Nitrate	mg/l	10
4	Coliform	MPN	10
5	Manganese (Mn)	mg/l	0.2
6	Chromium, hexavalnet(Cr^{+6})	mg/l	0.05
7	Zinc (Zn)	mg/l	1.5
8	Arsenic (As)	mg/l	0.05
9	Selenium (Se)	mg/l	0.01
10	Chloride (Cl)	mg/l	250
11	Phenols	mg/l	0.002
12	TDS	mg/l	1,500
13	Iron (Fe)	mg/l	1
14	Copper (Cu)	mg/l	1
15	Lead (Pb)	mg/l	0.1
16	Cadmium (Cd)	mg/l	0.005
17	Mercury (Hg)	mg/l	0.001

Table A14-4 Parameter Limits of Effluent of Standard A and B

No.	Parameters	Unit	Standard A	Standard B
1	Temperature	Degree C	40	40
2	pH value		6.0-9.0	5.5-9.0
3	BOD at 20 degree C	mg/l	20	50
4	COD	mg/l	50	100
5	Suspended Solids (SS)	mg/l	50	100
6	Mercury (Hg)	mg/l	0.005	0.05
7	Cadmium (Cd)	mg/l	0.01	0.02
8	Chromium, hexavalent (Cr^{+6})	mg/l	0.05	0.05
9	Arsenic (As)	mg/l	0.05	0.1
10	Cyanide	mg/l	0.05	01
11	Lead (Pb)	mg/l	0.10	0.5
12	Chromium, trivalnet (Cr^{+3})	mg/l	0.20	1.0
13	Copper (Cu)	mg/l	0.20	1.0
14	Manganese (Mn)	mg/l	0.20	1.0
15	Nickel (Ni)	mg/l	0.20	1.0
16	Tin (Sn)	mg/l	0.20	1.0
17	Zinc (Zn)	mg/l	2.0	2.0
18	Boron (B)	mg/l	1.0	4.0
19	Iron (Fe)	mg/l	1.0	5.0
20	Phenol	mg/l	0.001	1.0
21	Chloride ion	mg/l	1.0	2.0
22	Sulphide	mg/l	0.50	0.5
23	Oil and Grease	mg/l	Not Detectable	10.0

3. Preliminary Site Inspection

Prior to prepare the monitoring plan, site visit to inspect to followings are recommended.

(1) Surrounding Environment

Site's specific condition around the landfill site shall be clarified firsthand as specified followings.

Topography and geology provides basis for evaluating potential propagation of environmental risk. Residence and workers are potential receptor of environmental pollution. Likewise these points are fundamental to evaluating and planning environmental monitoring.

- Topography and geology (near-surface soil profile)
- Residence and community nearby (how close and how many?)
- Workers for landfill operation
- Surface river and ponds (location, water quantity, water quality)
- Water intake point (as used for water supply)
- Groundwater well (other than monitoring well of the site)
- Public complaints (yes/no and contents of complaints)
- Vegetation condition (if affected by the gas or discharged water from the sites)

(2) Facility Condition

Condition of the landfill site facility has to be inspected to evaluate the environmental risk and to prepare the monitoring plan. Without expensive chemical measurement and analysis, many issues could be identified and recognized for proper countermeasure. Also such inspection will ensure the proper monitoring plan for maximum effectiveness. For example, leachate treatment facility and its discharge point to surface river will indicate where and how surface water monitoring should be done. Condition of band structure as well as landfill slope will provide base to evaluate the risk of waste collapse and outflow of the waste to outside. In this view, following points shall be inspected.

- Waste top cover
- Surface drainage
- Cut-off drainage around the site
- Leachate collection system
- Leachate treatment facility
- Gas vent
- Monitoring well
- Landfill slope and band structure

(3) Nuisance Condition

Apart from facility condition, nuisance condition as noted below also shall be checked.

- Odour
- Vector
- Land subsidence
- Leachate discharge
- Land fill gas
- Fire and smoke
- Slope collapse

Based on the result of the site inspection, monitoring plan shall be developed, focusing on the important risk issues of the site. Monitoring plan shall include sampling location, sampling schedule for each media/parameters as well as management action required (See **Figure A14-2**).

Quality control is an important aspect of the monitoring activity. Plan for quality control shall be included. This includes, but not limited to, field sampling and laboratory management. Detail explanation of each monitoring medium will be given in the following section.

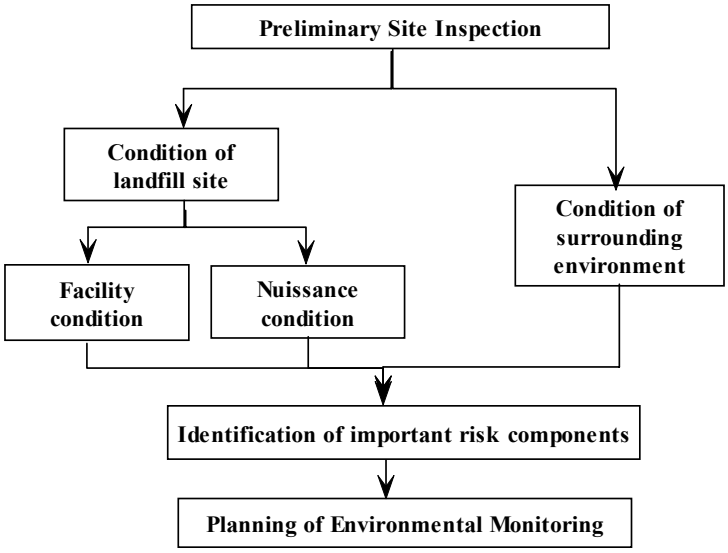


Figure A14-2 Schematic Diagram of Monitoring Plan

4. Leachate

(1) Objective

Rainwater penetrated into the landfill site is contaminated with the leaching substances from the waste materials and then effuses from the pore of the landfill. Therefore such contaminated water shall be treated before discharge into the public water body to prevent environmental contamination. Water quality of leachate varies by the nature of waste materials, structure of the landfill, metrological condition as well as the period elapsed after landfill. For example, at the landfill site on land, leachate quality in the early stage is at high concentration and contaminated, while in the later stage is at less concentration. Therefore leachate shall be monitored not only for environmental impact but also for stabilization process.

(2) Methodology

Leachate shall be sampled from the inlet point to the leachate treatment facility or directly from the monitoring well installed within the waste layer. It should be noted that sample taken from the re-circulation pond or aeration pond might have different water quality from the fresh leachate.

The most important monitoring parameters for leachate are 1) pH, 2) BOD, 3) COD and 4) Ammonium (NH_3-N). Other priority parameters include ORP, EC, TOC and total nitrogen. Other water quality parameters regulated by the Environmental Quality Act shall be also monitored. Depending on the parameters, sample taken shall be preserved properly at the site. Refer to the Effluent standard parameters shown in the previous table.

(3) Evaluation/Remarks

Followings are the meaning of important parameters and reason for monitoring.

1) pH

pH is the most basic water quality parameter and will provide the indication of generation of organic acid from the waste decomposition. It is also an important control factor of anaerobic methane generation process.

2) BOD (Biological Oxygen Demand)

It is an important parameter for understanding the quantity of biologically decomposable organic material in the original waste and leachate.

3) COD (Chemical Oxygen Demand)

It is an important parameter for understanding the quantity of chemically decomposable organic material in the original waste and leachate.

4) NH_3-N

Ammonia is generated from the decomposition of the waste. It can be used to evaluate the stage of decomposition of landfill waste, as Ammonia is high concentration at early stage, but gradually decreased.

5) ORP (Oxidation Reduction Potential)

ORP provide indication if the inside of the landfill site is aerobic or anaerobic condition.

6) EC (Electric Conductivity)

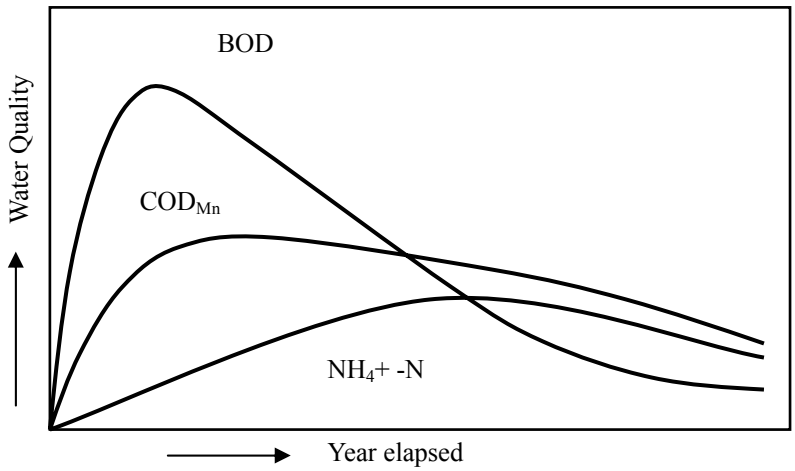
EC provide indication of the quantity of dissolved substances (ion) in the solution.

7) TOC (Total Organic Carbon)

TOC provide quantity of total organic in leachate. It includes both biologically degradable organic substance and humic substances which is difficult for degradation. Ratio of TOC and BOD can provide indication of quantity for biodegradation inside the landfill.

8) Nitrogen

Nitrogen controls the biological metabolism. Organic quantity and Ammonia are related to the stabilization process of the landfill site.



Source: Guideline for final waste disposal site, Ministry of Public Health, Japan 1989

Figure A14-3 Conceptual Graph Showing Change in Water Quality

5. Landfill Gas

(1) Objectives

Organic decomposition at the landfill generates carbon dioxide under aerobic condition and methane under anaerobic condition. Trace of hydrogen sulphide and ammonium are also generated. Volume of the gas generation will decrease while decomposition proceeds and remaining organic decreases. Therefore landfill gas measurement can provide qualitative indication of the stabilization of landfill in terms of organic decomposition of waste.

Methane is explosive gas and should be monitored for safety reason. Lower concentration limit of explosion for Methane – Air mixture at 20 degree C is approx. 5%. Hydrogen sulphide is also hazardous and gives offensive odour even at the low concentration at 1-2ppm. Therefore it should be monitored for safety and environmental reason.

(2) Methodology

Gas sampling shall be done using gas vent pipe. Gas sample can be colleted in sampling container or can be directly measured for the composition by the multi-sensor unit. Gas to be monitored includes methane, carbon dioxide, nitrogen, hydrogen sulphide and ammonium. Also gas volume can be estimated by measuring pressure. Twice a year monitoring is recommended. More landfill gas emitted from the boundary section of the landfill as well as the upper edge of leachate accumulation within the waste.

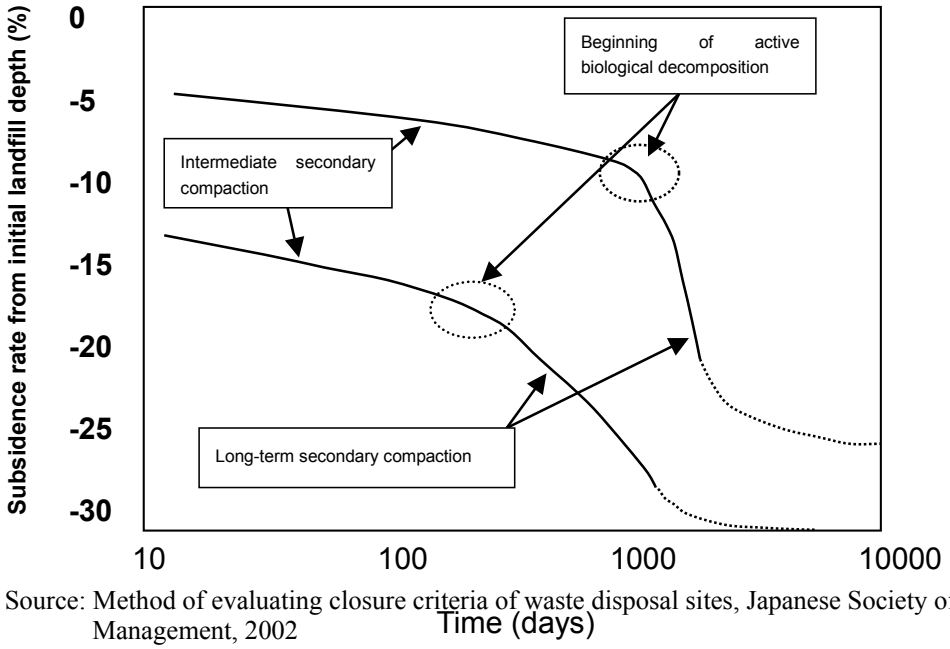
(3) Evaluation/Remarks

The most important issues are to avoid the explosive incidents from the methane. To avoid the explosive limit of methane, 5% of methane in the gas is an indication of safe criteria.

6. Land Subsidence

To prevent the problem in post closure land use, subsidence of the landfill site shall be monitored. Subsidence is caused by the compaction due to the weight and by the decomposition the waste as shown in the following figure.

For monitoring of the site, measuring base point shall be set on top of the landfill as well as at the original ground surface. Such base point shall be set at least one per each landfill zone/ phase. Levelling survey shall be done to measure the subsidence. After the closure, survey shall be done once a year.



Source: Method of evaluating closure criteria of waste disposal sites, Japanese Society of Waste Management, 2002

Figure A14-4 General Pattern of Land Subsidence at Landfill Sites

Above figure illustrates the general pattern of land subsidence at the landfill sites. Two line indicates the different landfill cases with varies compaction rate, but with similar pattern in terms of presence of rapid compaction phase initiated by active biological degradation.

7. Surface Water

(1) Objective

Surface water is the most visible environmental parameters. Leachate from the landfill site has potential to contaminate the river and/or pond water. Therefore surface water has to be monitored for such potential contamination by the landfill sites.

(2) Methodology

DOE set a standard for effluent discharged to public waterways. Monitoring parameters shall be basically those set in the standard.

Location of sampling shall be primarily at the downstream of the discharge point of effluent from the site. Water quality at the upstream also shall be monitored to evaluate the impact of effluent from the site. Usual practice applied for general water quality sampling such as preparation of preservative, cleaning of bottles, storage of sample in cold place, on-site calibration and measurement of pH, ORP, EC, DO and so on shall be applied. Analysis of the samples shall be according to official method at the accredited laboratory. QC/QA plan shall be integrated in the analytical plan.

(3) Evaluation/Remarks

Potential influence of the surface water contamination is through drinking water. Therefore presence of water intake point is primary importance to evaluate the impact of the contamination. DOE has separate effluents standard if water intake is at the down stream.

Also, especially in northern part of peninsula Malaysia, there are various fish/shrimp farming along the major rivers. As they introduce the river water into the farm pond, hazardous chemicals in the water may be bio-accumulated within the fish and shrimp. Therefore if such farming is near the site, it is also important.

8. Groundwater

(1) Objectives

Groundwater pollution may be the most serious problem caused by the landfill sites in terms of difficulty in remedy and long duration of the contamination. Also as groundwater is not easily seen, problem often is neglected or ignored.

In Malaysia, unlike many other countries, dependence on groundwater for drinking purpose is very low. In one sense, it makes lesser problem. On the other hand, it means there are less need for monitoring and hence lack of monitoring. Nevertheless, groundwater is the very important water resources because of its relatively good quality regardless of current use. It is strongly recommended that groundwater shall be properly monitored around the landfill sites

(2) Methodology

Groundwater shall be sampled from the monitoring well. Proper planning for the installation of monitoring well is of critical importance. Inadequate wells can not be used for groundwater monitoring. There are several important issues. This includes depth, location and structure of the monitoring well.

1) Depth:

Groundwater flows in aquifer (sand and gravel layer which is permeable). There is groundwater present in silt and clay layer which is less permeable, but such groundwater hardly flows. Therefore groundwater well should be drilled and placed at

the depth of aquifer. Aquifer is not a single layer at the given location. In many cases, there are multiple aquifers at different depth each separated by the silt and clay layer.

Information on the approximate depth of aquifer can be found in previous geological record and literature elsewhere. (Library of Mineral and Geo-science Department is one of the good sources of information). During the drilling of the well, core sample should be examined and geological log shall be prepared to confirm the depth of aquifer where the screen of the well should be placed.

The shallowest aquifer is the most vulnerable to the contamination caused by the landfill site, and in most cases it will be the priority for monitoring. When the shallowest aquifer was already contaminated by other reasons and source, and is not adequate for drinking purpose, the next aquifer may be the target for the monitoring. Also, if there is a groundwater well used for drinking purpose near the site, the aquifer of the well may be the priority for monitoring. It is not unusual to set multiple monitoring wells for different aquifers.

2) Location:

Monitoring wells shall be constructed at both upstream and downstream of the groundwater flow. Monitoring data of the upstream provide the baseline of the groundwater quality. Groundwater flow in the shallow aquifer is generally parallel to the topography of the surface. The depth of water table of three wells can measure accurate direction and gradient of groundwater flow. Topographic survey to determine the elevation of the platform of the well is required prior to the water table measurement. However, in the absence of the existing wells to confirm the flow direction, topography and general geological setting are the basis to plan the location of the monitoring wells.

When there is production well(s) near the site, water table may be influenced by the extraction from the well and may not be same as natural condition.

In case of topographically flat sites such as swamp area, groundwater flow may be estimated by larger regional topographic pattern.

3) Structure of the well:

"GUIDELINES FOR WELL DRILLING, GROUNDWATER ABSTRACTION and MONITORING" by the Department of Mineral and Geo-Science (2002) provides the general information and requirement for the monitoring well.

In order to use submergible pump during the sampling work, casing pipe diameter shall be larger than 2 inch or 50mm at minimum case, and is better if larger than.75mm.

Also it is important to seal the gap between borehole and casing pipe properly at the silt/clay layer so that any contamination in the shallow section will not migrate to the screen section through this gap.

4) Pumping test:

At the completion of the monitoring well, pumping test has to be done to obtain permeability or hydraulic conductivity of the aquifer. Hydraulic conductivity is

expressed as m/sec. This is the distance of groundwater flow at the given hydraulic gradient of 1:1. (1m-height difference at 1m separated point). This test is important in evaluating how fast groundwater contamination spread.

5) Sampling and analysis:

An important note on sampling of groundwater from monitoring wells is prior replacement of the stagnant water in the pipe of the well. As the water in the pipe stayed long time in contact with the headspace air, some chemical composition may have changed and thus it can not represent the original water quality in the aquifer.

For example, some groundwater in aquifer is at reducing condition where Fe is in the form of dissolved Fe^{2+} ion. Once water is in contact with oxygen in air, Fe^{2+} ion is quickly oxidized to form $Fe(OH)_2$ precipitation. In this process, some other metal element may co-precipitate and removed from the water. Obviously, there may be significant change in chemical composition. Another example is volatile organic compounds in water. These compounds may escape from the water quickly once they are equilibrium with air.

In order to replace the stagnant water in the pipe, it is recommended to pump up three times the volume of the water in the pipe. Many cases, this is quite hard work if one has to do only with bailer. Therefore submergible pump is recommended.

Proper preservation for the sample is also required as noted for surface water sampling.

(3) Evaluation/Remarks

When groundwater contamination is detected in the monitoring well, necessary management action shall be taken. First step of the action is assessment of urgency of the problem. Urgency depends on 1) how fast the groundwater flow is, and 2) if any well is used at the downstream, and if so, how quick the contamination reaches the point of the well.

The assessment of groundwater flow is straight forward, if hydraulic gradient and conductivity are taken at the field monitoring. For example, if hydraulic gradient is 1/100 (= 1m difference in water table height between wells of 100m distance) and hydraulic conductivity is 10^{-3} m/sec, then flow velocity (per year) will be as follows; (assuming effective porosity as 20%)

$$1/100 \times 10^{-3} \text{ m/sec} \times 1/0.2 \times 60 \times 60 \times 24 \times 365 = 1{,}575 \text{ m/year}$$

Therefore groundwater contamination moves and spread at the speed of approx. 1,575m/year. If the well is 1km downstream of the site, the contamination will reach there within a year. If the hydraulic gradient is 1/500, the hydraulic conductivity is 10^{-4} m/sec, then;

$$1/500 \times 10^{-4} \text{ m/sec} \times 1/0.2 \times 60 \times 60 \times 24 \times 365 = 31.5 \text{ m/year}$$

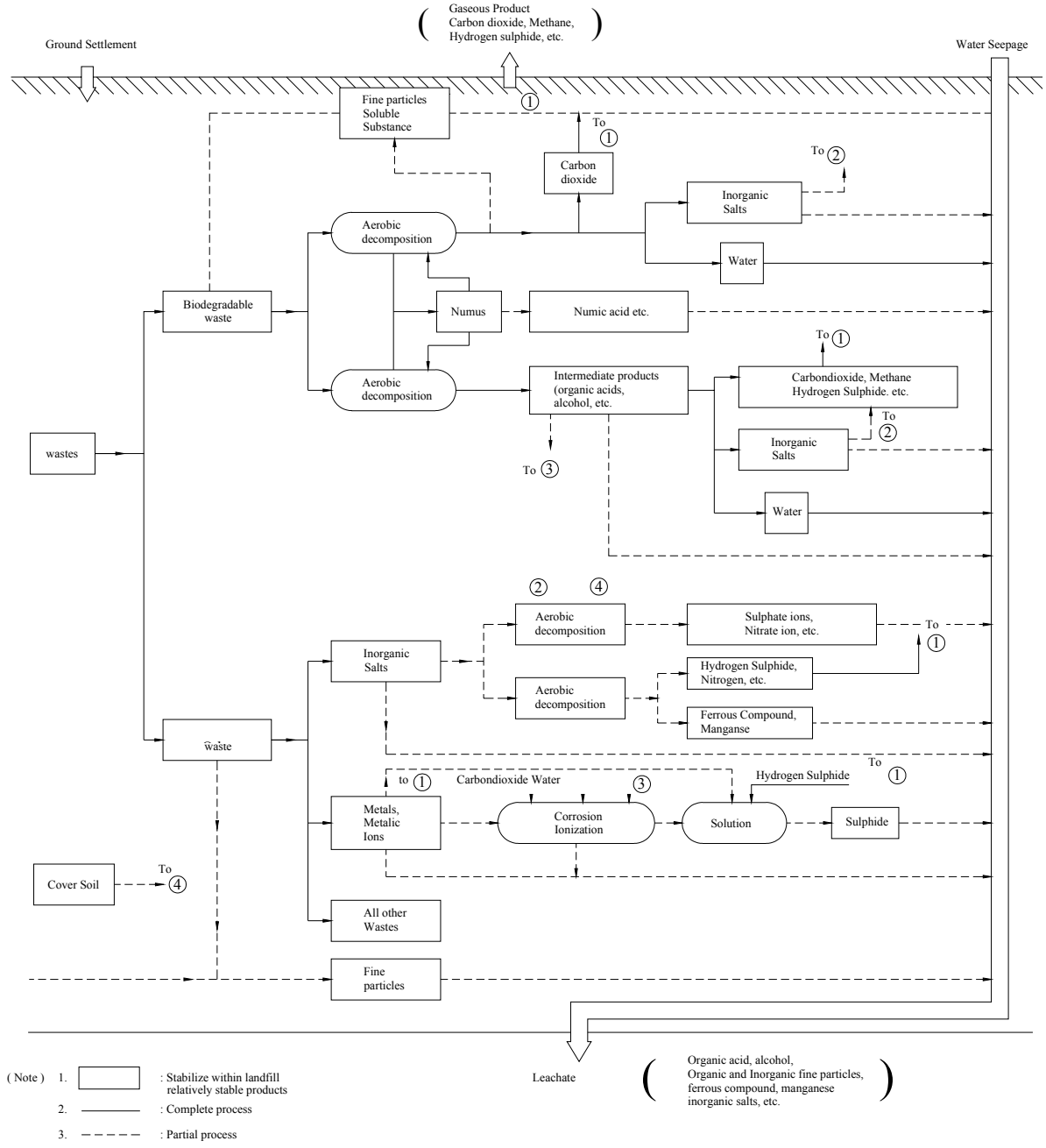
In this case, contamination will reach the well only after 30 years or so. Clearly the urgency to take actions is very different.

Precise assessment is more complex as other parameters such as retardation by soil, natural degradation of contaminant, dispersion have to be considered. However, to assess the urgency of the problem, the simple approach noted above will be sufficient.

Depending on the urgency, water intake from the well shall be stopped and alternative water supply shall be provided. Protection measure such as installation of vertical liner, hydro-geological barrier well system, which best suites the site specific condition should be planned and implemented.

9. Waste Decomposition and Stabilization Process

General understanding for the process of waste decomposition and stabilization process is required for the management and monitoring of the landfill sites. **Figure A14-5** summarizes the waste decomposition and stabilization process.



Source: Research Report on Management Technology for Landfill Site, Ministry of Public Health, Japan, 2000

Figure A14-5 Waste Decomposition and Stabilization Process

Appendix 15

Indicators for Risk of Post-closure Land Use

(1) Risk of landslide or collapse

The developer/designer shall design the shape of site as it can stand by itself. During the planning of the redevelopment of the site, the designer should consider the weight of the traffic, buildings, etc. of future use. Weight balance and physical stability of the slope shall be checked.

The Stability factor shall be more than 3.0 (including the safe factor).

If there is some risk of landslide or collapse by the new buildings, etc., the designer should modify the future land use plan or take the improvement measures, for example, the geological anchor system, soil improvement of the dikes and their bottoms, surplus fill at the dike, and etc. The authority should check the adequacy of these measures.

(2) Risk of subsidence

The subsidence at the site is always heterogeneous. Therefore, there will be some differences of subsidence between the points of landfill surface. For the buildings and basements, these differences cause the serious stress on the building material. Sometimes there will be the cracks on the wall or pipes. Especially, the damages on the pipes of water supply, sewage, electricity, etc. are serious problems for the residents and users.

a. *If the yearly subsidence rate is more than 20cm/year, there will be serious hollows and cracks.*
b. *If the yearly subsidence rate is more than 10cm/year, the building structure will be seriously damaged.*
c. *If the yearly subsidence rate is less than 3cm/year, there may not be serious damage on the building structure.*
d. *If the yearly subsidence rate is less than 1cm.year, there may not be serious damage on any structures.*

The developer/landowner should not use the site for houses or buildings while the site still has the significant subsidence.

(3) Risk of groundwater pollution

The developer/ designer shall design the post closure land use with careful prevention system against the groundwater pollution. The common measures of landfill for groundwater pollution control are bottom liners and leachate collection systems. The developer of the site should maintain these two facilities even after the post closure land use.

Construction of the foundation piles, which break the bottom liner (synthetic and/or natural ones), shall be strongly prohibited, if the degradation of waste is still going.

(4) Risk of leachate

After the completion of filling work, there will be leachate production by the percolated water and degradation of wastes. Leachate has many and heavy pollutants at initial period of the site operation, but they will be decreased as the waste will be degraded. The quality of leachate will be stabilized as times goes by. Therefore, the developer/owner should certify the followings.

(a) Quality of effluent of leachate will not cause the surface water pollution.

(b) Quality of leachate may not change to worse again.

It is very common the leachate inside the waste layer still has high concentration of pollutants, although the quality of effluent of leachate is stabilized and low. The quality of effluent will change to high concentration of pollutants, if there is some disturbing works on the site, just like excavation, drilling, etc.

Therefore, (a) and (b) shall be certified under the special condition of no disturbing works in the waste layer. That is special cares will be needed when disturb the waste layer like excavation, drilling, etc. These cares will be noted at the PCM plans for post-closure landfill site.

If the effluent water at the border of landfill site cannot meet the water standard or may cause serious damage on the surface water body, the leachate treatment facility shall be operated.

(5) Risks of gas explosion and fires

The landfill gas contains the explosive and combustible matter; i.e. methane (CH_4), hydrosulphide (H_2S), hydrogen (H_2), and so on. These gases go out to the air through the ventilation pipes mainly and through the cover soil slightly. A main dangerous gas is methane. The methane is explosive at the concentration from 5 to 15 %(v/v) in normal air, and is combustible when it is over 15 %.

Therefore, the developer/owner shall certify the concentration of methane gas at the ventilation pipe is below the 5%. The concentration of methane and another dangerous gas will decrease as time goes by in accordance with the degradation of waste. It is similar to the effluent of leachate.

a. If there is no gas ventilation and gas collection system, the public access and the construction works which use fires shall be prohibited strictly.
b. If the combustible content of gas in the ventilation pipe indicates more than 15%, the public access shall be prohibited.
c. If the combustible content of gas below the cover soil is more than 5%, the gas collection and ventilation system shall be installed.
d. Even though the combustible content of gas below the cover soil is less than 5%, the landfill gas could be accumulated and the concentration will get higher.
e. The combustible content of gas in the space below floor shall be less than 1.5%. If not so, the landfill gas collection and ventilation system shall be installed under the building.

Therefore, the developer/owner should certify the followings:

(a) Quality of landfill gas will not cause the explosion and fire

(b) Quality of landfill gas may not change to worse again

(6) Damages of the plants on the site and surroundings

It was commonly observed that some plants on the landfill site did not grow up well and the plants near the site were damaged or died sometime. Main reasons of these phenomena seem to be caused by landfill gas and soil contamination.

The landfill gas contains some phylotoxic matters, ethylene, acetylene, hydrosulphide, etc. These chemicals will prevent the germination, growth of roots, etc.

The soil contamination will also prevent the growth of plants. The famous metals to prevent the growth are copper (Cu), cadmium (Cd), arsenic (As), selenium (Se), etc. If these metals were observed at high concentration, the plants will not grow up well.

a. For the vegetation, the characteristics of landfill gas and soil shall be checked in advance.
b. In order to prevent the contacts of roots to the filled waste, the top cover shall have sufficient thickness.

(7) Risk of corrosion for construction materials and basement

During the degradation of waste, the many by-products are produced. Some of them have risks to cause the corrosion on the construction materials like mortar, steel and so on. Hydrogen Sulphide (H_2S) is well known for their corrosiveness on cement and steel.

The building materials faced the landfill gas, waste, and leachate may have a risk of corrosion. Acidity and H_2S could be good indicators.

(8) Temperature inside the waste layer

Most of the degradation process of waste is heat production reaction. Therefore, the heat production is high inside the waste layer, when the degradation process is active. Sometime the temperatures inside the waste layer reach to 80^{o}C. In case the degradation reaction calms down, the temperatures inside the waste layer decrease.

The temperature inside the waste layer is a good indicator to evaluate the progress of degradation of waste. Therefore, the temperature inside the waste layer using the gas ventilation pipes or another observation wells in the site. The temperature of leachate is also helpful.

If the temperature inside the waste body is higher than 50 ^{o}C, the degradation rate may be still high and is not suitable for re-development work.

Sometime the unexpected increase of temperature is observed during the re-development work. This phenomenon is often occurred at the waste excavation stage, because the excavation will induce the fresh air into the waste and promote the degradation rapidly. Therefore, the careful monitoring should be also required during the construction works.

(9) Accidental chemical reaction

The waste layer contains many kinds of chemicals. While during a re-developing and/or rehabilitation of landfill site, its construction works use some chemicals, such as lime, steel, concrete, etc. There is some risk of chemical reaction between construction work materials and chemicals in waste.

One of famous accidental reaction is ammonia stripping. When the waste have so much of ammonium ion in liquid phase, if someone adds an strong alkali matters, like lime and concrete, into the waste, ammonium ion becomes ammonia in gaseous phase. Accordingly, ammonia rich gas, which is very irritating and dangerous, comes from the waste. Another one is hydrogen generation by the reaction of metals and acids in waste. Sometimes there is much hydrogen gas comes from waste.

Therefore, these accidental reactions shall be checked beforehand by laboratory test, when they try to use some chemicals or matters as additives for waste layer or basements. Most common test method is head-space test in flask. In this test, researcher shall take a small amount of samples of waste and other chemicals/matters into flask and mix them in flask. Then the researcher shall observe the phenomenon inside the flask. For example, changes of colour, bubbles on a surface of waste, and etc. After 10 to 30 minutes passed, the gas inside the flask shall be sampled and checked.

The materials, which plan to be use for the development works of the landfill sites, shall be checked and possible chemical reaction between the materials and waste/leachate shall be verified, in order to prevent the accidental chemical reaction cause new pollution and hazards.

(10) Change of surface covers

Even after the physical closure of landfill site, there still might have gas generation from waste layer. If there is cover soil on the top of waste layer, the gas migrates through the cover soil. On the other hands, the air goes into the waste layer through the cover soil. Therefore, if the top of waste layer is covered with impermeable matters, like concrete or asphalt pavement for re-development, the gas try to go through the permeable parts of surface, like the vegetation fields, flower garden, etc. If the landfill gas comes to a small area at high concentration, it will damage the plants and etc. Some time it causes the fires and/or explosion.

Therefore, in some cases, change the characteristic of surface covers shall be considered. If there is very limited permeable area, they should install the gas ventilation/collection system.

If the surface of top cover will be occupied with the impermeable matters like buildings and pavements, the gas collection and ventilation system shall be installed as a substitution of gas migration through the occupied area.

Appendix 16

Type of Development for Post-closure Land Use

There are several patterns of development of closed landfill sites. The level of necessary countermeasures depends on the site condition and the patterns of post closure land use.

(1) Classification of Post-closure Land use

Post-closure land use patterns can be classified into two aspects as follows.

a. Public access and time of exposure

(i) Levels of public access

Few:	Very limited people will enter into the area like an agricultural field.
	It is easy to inform the risks relevant to their use.
Controlled:	Some people will enter into the area under the control like a warehouse.
	It is possible to inform the risks relevant to their use.
Open:	Everybody can enter into the area like a park and a shopping market
	It is difficult to inform the risks and control the entrance.

(ii) Times of exposure

Short:	People spend very limited time at the site like car parking
Controlled:	The hours to stay at the site are controlled like a visitor to the park and/or shop
Full time:	People spend most of the daily hours on the site like a resident

The most risky case will be “Open access” and “Full time exposure”; however, this combination may not be realized. The second risky case will be “Controlled access” and “Full time exposure”. This combination will be observed at the residential use of closed site.

b. Engineering work effect (depth of engineering work)

(i) Surface layer use:	Only the surface of top cover of the site is used without excavation
(ii) Middle layer use:	“Surface layer use” and excavation work of cover soil and waste layer
(iii) Bottom layer use:	Bottom of the filled waste layer will be affected.

(2) Examples and Probable Problems

It should be noted that special caution and/or measures shall be taken in case the middle and bottom layer use. The typical problems and/or issues, which may occur from the post-closure land use, are summarized as follows.

a. Agriculture: Limited accessed and little engineering works

   Probable incident is damage of plants caused by the landfill gas

b. Park: Open access and little engineering works

   Probable incidents are accidental fires, unpredictable offensive odour, etc.

c. Motor park/Roads: Open access and some engineering works

   The subsidence will cause the damage on the surface drainage system and casual fires may occur.

   The weight and vibration of the traffic will affect the slope stability.

d. Low Story Houses: Limited person for long time and Medium Engineering Work

   The subsidence will cause the damage on building, pipeline, etc. There might be a possible damage on the human's health via inhalation of landfill gas.

e. Commercial/Industrial Facility: Many persons access for long-time and more engineering works

   There will be many problems as stated above.

Appendix 17

Receptor of Landfill Closure for Social Consideration

(1) Possible Receptors

Possible receptors to be impacted by closures of landfill sites shall be identified by the State/LAs in advance of the closures. The following should be referred for considering of the identification.

- Possible receptors to be impacted by closures of landfills are principally summarized in **Table A17-1**.

Table A17-1 Possible Receptors Impacted by Closures of Landfill Sites

Item	Possible Receptors
At Landfill Sites	- Authorized Workers (Operators of Heavy Equipment, Drivers of Collection Vehicles, Recyclers, Scrap Dealers and so on) - Scavengers
Vicinities of Landfill Sites	- Residential Households

Source: The JICA Study Team

- As for authorized workers, it can be generally considered that they could be appropriately evacuated and re-employed by any legal programs or schemes if authorities close landfills.
- Thus, in this guideline, scavengers working at landfill sites and households located around those sites are assumed as the possible receptors.

(2) Who are the Scavengers?

a. Definition

There is no official definition of scavengers in Malaysia at present. Therefore, in order to make sure who are considered as scavengers, the definition of the scavengers shall be considered and be temporally defined by authorities concerned for the closures in accordance with circumstances of landfills to be closed. The following should be referred for considering of the definition of scavenging and scavengers.*

- Scavenging refers to the informal practice of collecting saleable items from garbage at a waste disposal site and eventual reuse of the materials picked.
- Scavengers devote either part or most of their working time to foraging for saleable materials in the wastes.

* "Waste Recycling in Malaysia: Economics & Environmental Needs", Mohd Nasir Hassan et al. Universiti Putra Malaysia

b. Law and Regulation

According to the following circumstances on law and regulation related, scavenging at landfill sites is prohibited and is regarded as an illegal action in Malaysia.

- "Local Government Act 1976 (Act 171) regulates local government activities in Malaysia.
- In accordance with the act 171, every municipal council respectively enacts a "By Law" by which collection, transportation and disposal of municipal solid waste is regulated.
- Namely municipalities have a responsibility for municipal solid waste management (MSWM) in each administrative boundary.
- Those "By Laws" enacted by municipality councils regulate activities on MSWM, one of which includes prohibition of entering landfill sites without permission.

In spite of the illegal action of scavenging, however, from humanity's point of view, the authorities involved shall appropriately evacuate scavengers from landfills to be closed.

Appendix 18

Questionnaire on the Landfill Condition

Lampiran 1

BORANG RINGKASAN SOAL SELIDIK KAJIAN TAPAK PELUPUSAN DI PIHAK BERKUASA TEMPATAN
(Summary of Qestionnaire on the landfill condition in Local Authorities)

1. Nama PBT/Nama of LA: _____

2. Jumlah tapak pelupusan yang (no. of landfills that):

   a. Telah ditutup (have been closed): _____

   b. Masih beroperasi (in operation): _____

3. Tarikh borang di isi: _____
   (Date the form is filled)

4. Jumlah lawatan yang dibuat oleh pegawani PBT ke tapak pelupusan
   (No. of visit made by the LA personnel to the landfill site)

   a. Tapak yang telah dututup: _____ kali/tahun
   (Closed landfills) (times/year)
   b. Tapak yang sedang beroperasi: _____ kali/tahun
   (Landfils in operation) (times/year)

5. Pegawai yang mengisikan borang (Officer who filled up the questionnaire):

   Nama (Name): _____

   Jawatan (Position): _____

   No Telefon (Tel No.): _____

6. Jumlah Borang Inventori tapak pelupusan yang dikembalikan: _____
   (No. of Questionnaire returned)

7. Pelan lokasi tapak pelupusan disertakan: Ya (Yes) _____ Tidak (No) _____
   (Location plan submitted)

8. Pelan Susunatur tapak pelupusan disertakan: Ya (Yes) _____ Tidak (No) _____
   (Layout plan submitted)

9. Gambar tapak pelupusan disertakan: Ya (Yes) _____ Tidak (No) _____
   (Photos attached)

Nota: Setiap maklumat tapak pelupusan sama ada yang telah tidutup atau pun yang masih beroperasi hendaklah di isi dengan menggunakan Borang Inventori yang berasingan. Bagi setiap maklumat untuk 1 tapak pelupusan di isi dengan menggunakan 1 Borang Inventori.

Note: Separate forms are to be used for every landfill that are either already closed or are still in operation; 1 landfill for 1 inventory form.

INVENTORY TAPAK PELUPUSAN (LANDFILL INVENTORY)

Satu borang untuk satu tapak pelupusan (One form for one landfill)

A. Matlumat Asas *(Basic Information)*

1.Nama Tapak (Name of Site) _____

2. Alamat tapak *(Address of Site)* _____

3. Pelan tapak disertakan *(Layout site attached)* — ya *(yes)* ☐ tidak *(no)* ☐

4. Kategori *(Category)*
Sedang beroperasi *(in operation)* ☐ Telah ditutup *(Closed)* ☐
Sekiranya sedang beroperasi, berapa lama lagikah jangka hayat yang tinggal: _____ tahun
(If still in operational, what is the remaining life span)

5. Diuruskan oleh: *(Managed by)* — PBT *(Local Authority)* ☐ Lain-Lain *(Others)* ☐ Nyatakan(*specify*) _____

6. Pemilik Tanah *(Land ownership)* — Kerajaan *(government)* ☐ Persendirian *(Private)* ☐

7.Adakah tapak digazet *(Is the site gazetted as landfill)* — Ya *(yes)* ☐ Tidak *(no)* ☐

8. Operasi pelupusan *(Disposal Operation)* — Tahun bermula _____ *(Year start)* Tahun berakhir: _____ *(Year end)*

9. Keluasan *(area)* _____hektar

10. Jumlah sisa dilupus sehari _____ ton *(Waste disposed daily)* Total amount of waste disposal of _____ ton

11. Sebab tapak ditutup *(Reason for Closure)*
Telah sampai jangka hayat *(Reach the life span)* ☐ Arahan JAS *DOE Directive* ☐
Aduan orang ramai *(Public Complaint)* ☐ Pembangunan berdekatan *(development at adjacent area)* ☐
Berpindah ke tapak yg lebih baik *(Move to a new improved site)* ☐ Lain-lain sebab, sila nyatakan *(Other reason, pls specify)* ☐

B. Kesan Terhadap Alamsekitar (Environmental Impact Conditions)

Tarikh Kajian (*Date of Survey*)

1. Tahap Tapak Pelupusan *(Landfill Facility Level)*
pelupusan terbuka *(open dumping)* ☐ Tahap 3 *(level 3)* ☐
Tahap 1 *(Level 1)* ☐ Tahap 4 *(level 4)* ☐
Tahap 2 *(level 2)* ☐

2. Keadaan tapak *(Site Condition)*
tanah rata *(flatland)* ☐ tapak kuari *(ex quarry, mines)* ☐
berbukit *(hilly)* ☐ kawasan paya *(swampy area)* ☐
lain-lain, sila nyatakan *(others, please specify)* ☐

3. Sampah ditutup*(Waste Covered)* — Ya *(Yes)* ☐ tidak *(No)* ☐
Jika ya, nyatakan kekerapan sisa ditutup *(If yes, state the frequency of cover material applied)*
setiap hari *(daily)* ☐
seminggu sekali *(weekly)* ☐
sebulan sekali *(monthly)* ☐
setahun sekali *(annually)* ☐
lain-lain, sila nyatakan *(others please specify)* ☐
Catitan *(Remarks)* : _____
(Note: including daily operation)

4. Terdapat tumbuh-tumbuhan *(Vegetation Condition)*
pokok *(Trees)* ☐
an semak-samun*(grasses and bushes)* ☐
tiada tumbuhan *(no vegetation)* ☐
Catitan *(Remarks)*: _____

5.Tanah Runtuh *(Landslide)*
rekahan tanah ketara *(Noticeable)* ☐
rekahan tanah sedikit *(Medium)* ☐
Tiada *(no)* ☐
Catitan *(Remarks)*: _____
Nyatakan tinggi dan kecuraman *(state the height and slope)*

6. Pemendapan Tanah *(Soil Subsidence)*
a. Nampak jelas*(Noticeable)* ☐
b. Nampak sedikit *(medium)* ☐
c. tiada *(not noticeable)* ☐
Catitan *(Remarks)*: _____

7. Vektor dan binatang liar *(Vector and wild animals)*
Nampak jelas*(Noticeable)* ☐
Nampak sedikit *(medium)* ☐
tiada *(not noticeable)* ☐
Catitan *(Remarks)*: _____

8. Bau, gas dan asap *(Odour, landfill gas and smoke)*	Terasa jelas *(noticeable)* ☐ Terasa sedikit *(medium)* ☐ tiada *(not noticeable)* ☐	Catitan *(Remarks)*: _____	
9. Kuantiti 'leachate' *(Leachate Quantity)*	jelas kelihatan*(Noticeable)* ☐ sedikit kelihatan *(medium)* ☐ tiada *(not noticeable)* ☐	Catitan *(Remarks)*: _____	
10. Lokasi 'intake' air *(Location of water intake)*	di kawasan ulu *(upstream)* ☐ di hilir tapak *(downstream)* ☐ tiada *(No intake point)* ☐	jarak *(distance)* _____km jarak *(distance)* _____km Catitan *(Remarks)*: _____	
(Note: No limited stance for down stream within 2km for upstream)			
11. Lokasi perigi untuk air minuman *(Location of Drinking Water Well)*	Kurang dari 500m *(<500m)* ☐ Lebih dari 500m *(>500m)* ☐ Tiada *(no)* ☐	Catitan *(Remarks)*: _____	
(Note: within 2km)			
12. Keadaan Geologi *(Geological Condition)*	Batu kapor *(limestones)* ☐ Tanah liat *(alluvial)* ☐ lain-lain (others) ☐	Sila nyatakan *(specify)*: _____	
13. Adakah terdapat aduan orang ı *(Ae there any Public Complaint)*	Ya *(yes)* ☐	Tidak *(no)* ☐	
	Jika ada, nyatakan jumlah aduan dalam setahun : _____ *(If yes, state the no of complaints per year)*		
14. Jarak dari kawasan kediaman *(Distance to the residential area)*	Kurang dari 500m *(<500m)* ☐ Lebih dari 500m *(>500m)* ☐ Tiada *(no)* ☐	Catitan *(Remarks)*: _____	
C. PENGGUNAAN TAPAK PELUPUSAN SELEPAS DITUTUP (Land Utilisation after closure)			
1. Kegunaan tanah Sediada *(Existing Land Utilisation)*	kosong *(vacant)* ☐ pertanian*(agriculture)* ☐ industri/perniagaan*(industry/commerce)* ☐	perumahan *(housing)* ☐ rekreasi*(recreation)* ☐ lain-lain *(others)* ☐ nyatakan:_____	
2. Kawasan sekeliling *(Surrounding area)*	kosong *(vacant)* ☐ pertanian*(agriculture)* ☐ industri/perniagaan*(industry/commerce)* ☐	perumahan *(housing)* ☐ rekreasi*(recreation)* ☐ lain-lain *(others)* ☐ nyatakan:_____	
3.Penggunaan Tapak dimasa hadapan *(Ultimate land use)*	ya *(yes)* ☐	tiada *(no)* ☐	
Jika ya. aktiviti yang dirancangkan akan mempunyai penghuni/pengunjung yang: *(If yes, will the proposed activities will be heavily used)*		ramai*(high use)* ☐ sederhana*(medium)* ☐ pengunjung sedikit *(low use)* ☐	
4. Adakah tapak ini termasuk dalam Pelan Pembangunan Tempatan *(Is the disposal site is included the Local Development Plan)* Catitan *(Remarks)*: _____		ya *(yes)* ☐ tidak *(no)* ☐ berdekatan *(adjacent)* ☐	
5. Adakah tapak ini berkemungkinan akan dibangunkan *(Is the site is to be probably developed)* Catitan (Remarks); _____		Berkemungkinan besar *(most probably)* ☐ Kurang berkemungkinan *(less probably)* ☐	
6. Jarak dari pusat bandar *(distance from town centre)* Catitan (Remarks); _____		kurang dari 5 km *(less than 5 km)* ☐ diantara 5km hingga 10km *(between 5km to 10km)* ☐ lebih dari 10 km *(more than 10 km)* ☐	

* - sila lihat nota *(refer to the notes)*

Appendix 19

List of Landfill Sites Covered by the JICA Study

List of landfill sites covered by the JICA Study is shown in **Table A19-1**. It is noted that the listed landfill sites does not cover all the landfill sites in Malaysia. Remaining landfills which are not listed in the table shall be registered by the concerned authorities and the LACMIS (landfill closure management information system) shall be updated based on the information of remaining landfill sites.

Table A19-1 List of Landfill Sites

ID	State	No.	Name of LA	Name of Site	Landfill Level	Category	Year Start	Year End	Area (ha)	Environ-mental Risk	Value of Land Utilization	The necessity of the safe closure				Group	Closure Level
												C1	C2	C3	C4		
1	Selangor	SL-01	MP Petaling Jaya	Kelana Jaya	Level 1	Closed	1990	1996	8.1	0.28	0.80	0.46				CL-C	C2
2	Selangor	SL-02	MP Klang	Telok Kapas	Level 1	Operation	2000	2003	32.4	0.40	0.28	0.44	0.55	0.43		OP-D	C2
3	Selangor	SL-03	MP Kajang	Sungai Kenbong	Open Dump	Operation	1996	2008	16.2	0.64	0.29	0.76	0.63	1.00		OP-B	C3
4	Selangor	SL-04	MP Selayang	Kundang	Level 1	Operation	1996	2005	32.4	0.34	0.00	0.44	0.48	0.43		OP-D	C2
5	DBKL	DB-01	DB Kuala Lumpur	Taman Beringin	Level 2	Operation	1996	2004	12.0	0.43	0.52	0.54	0.63	0.47		OP-A	C3
6	N.Sembilan	NS-01	MP Nilai	Pajam	Level 1	Operation	1996	2018	27.9	0.23	0.28	0.42				OP-D	C1
7	N.Sembilan	NS-02	MP Nilai	Kuala Sawah	Level 1	Closed	1998	2003	10.1	0.53	0.11	0.58	0.63	1.00		CL-B	C3
8	N.Sembilan	NS-03	MP Seremban	Sikamat	Level 1	Operation	1986	2003	5.3	0.39	0.58	0.68	0.45	0.25		OP-C	C3
9	N.Sembilan	NS-04	MP Port Dickson	Quarters MPPD	Open Dump	Closed	1950	1960	0.4	0.24	0.23	0.22				CL-D	C1
10	N.Sembilan	NS-05	MP Port Dickson	Bukit Palung	Open Dump	Operation	1975	2013	25.0	0.41	0.22	0.78	0.33	0.25		OP-B	C3
11	N.Sembilan	NS-06	MP Port Dickson	Pengkalan Kempas	Open Dump	Closed	1990	2002	1.2	0.28	0.33	0.25		0.21		CL-D	C2
12	N.Sembilan	NS-07	MP Port Dickson	Sua Betong	Open Dump	Operation	1998	2008	3.2	0.47	0.06	0.78	0.52	0.47		OP-B	C3
13	Melaka	ML-01	MD Alor Gajah	Air Molek	Open Dump	Operation	1970	2013	2.4	0.35	0.19	0.78				OP-D	C1
14	Melaka	ML-02	MD Alor Gajah	Pulau Sebang	Open Dump	Closed	1960	2002	0.8	0.45	0.13	0.69	0.63			CL-B	C2
15	Melaka	ML-03	MB Melaka	Krubong	Level 2	Operation	1994	2005	27.7	0.45	0.28	0.78	0.52	0.47		OP-B	C3
16	Melaka	ML-04	MB Melaka	Krubong A	Open Dump	Closed	1974	1994		0.32	0.72	0.34				CL-C	C2
17	Melaka	ML-05	MB Melaka	Kota Laksamana	Open Dump	Closed	1950	1973		0.30	0.71	0.35				CL-C	C2
18	Melaka	ML-06	MD Jasin	Lipat Kajang	Level 1	Closed	1967	2000	3.2	0.43	0.42	0.31		0.57		CL-B	C3
19	Melaka	ML-07	MD Jasin	Batang Melaka	Open Dump	Closed	1970	2001	1.5	0.28	0.42	0.39				CL-D	C1
20	Melaka	ML-08	MD Jasin	Kesang Pajak	Open Dump	Closed	2001	2002	9.2	0.59	0.52	0.40	0.26	0.70	0.43	CL-A	C4
21	Johor	JH-01	MD Tangkak	Chohong	Open Dump	Closed	1970	2000	1.0	0.58	0.38	0.34	0.29	0.57	0.43	CL-B	C4
22	Johor	JH-02	MP Muar	Bakri	Level 1	Operation	1993	2005	14.6	0.32	0.46	0.31	0.37	0.21		OP-C	C3
23	Johor	JH-03	MP JB Tengah	Ulu Tiram	Level 2	Operation	1997	2003	17.4	0.46	0.18	0.95	0.75	0.47		OP-B	C3
24	Johor	JH-04	MP JB Tengah	Lima Kedai	Open Dump	Closed	1992	1997	2.5	0.22	0.14	0.27				CL-D	C1
25	Johor	JH-05	MP JB Tengah	Kempas	Open Dump	Closed	1988	1997	0.9	0.27	0.42	0.34				CL-D	C1
26	Johor	JH-06	MP JB Tengah	Taman Mega Ria	Open Dump	Closed	1988	1997	6.5	0.37	0.45	0.27	0.40	0.47		CL-D	C2
27	Johor	JH-07	MD Kota Tinggi	Batu Empat	Open Dump	Operation	1988	2004	6.0	0.69	0.09	1.00	0.63	1.00		OP-B	C3

ID	State	No.	Name of LA	Name of Site	Landfill Level	Category	Year Start	Year End	Area (ha)	Environ-mental Risk	Value of Land Utilization	The necessity of the safe closure				Group	Closure Level
												C1	C2	C3	C4		
28	Johor	JH-08	MD Kota Tinggi	Sungai Rengit	Open Dump	Operation	1998	2008		0.36	0.10	0.95	0.23			OP-D	C2
29	Johor	JH-09	MD Kota Tinggi	Bandar Kota Tinggi	Open Dump	Closed		1988	1.6	0.44	0.68	0.34		0.53		CL-A	C3
30	Johor	JH-10	MD Mersing	Jemaluang	Open Dump	Operation	1993	2013	4.0	0.27	0.07	0.47				OP-D	C1
31	Johor	JH-11	MD Mersing	Endau	Open Dump	Operation	1993	2013	4.9	0.27	0.20	0.47				OP-D	C1
32	Johor	JH-12	MD Mersing	Sri Pantai	Open Dump	Operation	1993	2013	4.0	0.38	0.36	0.86	0.26			OP-D	C2
33	Pahang	PH-01	MD Rompin	Kampong Feri	Level 1	Operation	1983	2020	5.0	0.26	0.50	0.59				OP-C	C2
34	Pahang	PH-02	MD Pekan	Pekan Nenasi	Level 2	Operation	1988	2023	22.7	0.26	0.22	0.49	0.30	0.21		OP-D	C2
35	Pahang	PH-03	MP Kuantan	Taman Bandar	Open Dump	Closed	1983	1986	2.0	0.24	0.58	0.20				CL-C	C2
36	Pahang	PH-04	MP Kuantan	Gambang	Open Dump	Closed	1965	2001	2.0	0.28	0.18	0.53				CL-D	C1
37	Pahang	PH-05	MP Kuantan	Indera Mahkota	Level 1	Closed	1985	1993	50.0	0.26	0.55					CL-C	-
38	Pahang	PH-06	MP Kuantan	Jabor Jerangau	Level 2	Operation	1993	2018	55.0	0.30	0.18	0.36	0.55	0.43		OP-D	C2
39	Terengganu	TR-01	MP Kemaman	Fikri	Open Dump	Closed	1976	1985	2.0	0.26	1.00	0.22				CL-C	C2
40	Terengganu	TR-02	MP Kemaman	Gelugor	Open Dump	Closed	1981	1992	1.2	0.22	0.40	0.22				CL-D	C1
41	Terengganu	TR-03	MP Kemaman	Gelugor	Open Dump	Operation	1993	2006	10.0	0.32	0.50	0.59				OP-C	C2
42	Terengganu	TR-04	MP Kemaman	Mak Cili Paya	Open Dump	Operation	1985	2006	5.0	0.28	0.46	0.54				OP-C	C2
43	Terengganu	TR-05	MP K.Terengganu	Tok Jembal	Open Dump	Closed	1985	1994	8.1	0.28	0.55	0.22				CL-C	C2
44	Terengganu	TR-06	MP K.Terengganu	Wakaf Tok Keh	Open Dump	Closed	1975	1985	4.0	0.29	0.68	0.29				CL-C	C2
45	Terengganu	TR-07	MP K.Terengganu	Kubang Ikan	Open Dump	Operation	1998	2004	13.3	0.53	0.49	1.00	0.63	0.47		OP-A	C3
46	Kelantan	KL-01	MP Kota Baru	Panji	Open Dump	Closed	1961	1987	4.0	0.26	0.80	0.22				CL-C	C2
47	Kelantan	KL-02	MP Kota Baru	Tebing Tinggi	Open Dump	Operation	1987	2003	19.0	0.55	0.20	0.81	0.70	0.47		OP-B	C3
48	Kelantan	KL-03	MD K.Krai Selatan	Sungai Sam	Open Dump	Closed	1984	2000	0.3	0.32	0.00	0.46	0.29			CL-D	C2
49	Kelantan	KL-04	MD K.Krai Selatan	Bukit Tembeling	Open Dump	Operation	2000	2013	4.0	0.39	0.00	0.90	0.34			OP-D	C2
50	Perak	PR-01	MD Kinta Selatan	Sg. Siput Selatan	Level 2	Operation	1990	2028	26.7	0.20	0.46	0.41				OP-C	C2
51	Perak	PR-02	MD Kinta Selatan	Kg. Batu Putih (Kg. Tersusun)	Open Dump	Closed	1980		2.0	0.26	1.00	0.22				CL-C	C2
52	Perak	PR-03	MD Kinta Selatan	Taman Sri Kampar	Open Dump	Closed	1960	1970	4.0	0.49	0.40	0.44	0.40	0.30	0.30	CL-B	C4
53	Perak	PR-04	MB Ipoh	Bercham	Level 1	Operation	1986	2007	50.0	0.49	0.57	0.80	0.63	0.47		OP-A	C3
54	Perak	PR-05	MB Ipoh	Buntong	Open Dump	Closed	1970	1986	20.0	0.28	0.96	0.22				CL-C	C2
55	Perak	PR-06	MB Taiping	Jebong	Open Dump	Operation	2000	2008	20.0	0.70	0.48	0.85	0.75	0.47	0.81	OP-A	C4
56	Perak	PR-07	MB Taiping	Tekkah Jaya	Open Dump	Closed	1980	1999	40.0	0.39	0.67	0.59			0.37	CL-C	C3
57	Perak	PR-08	MD Tapah	Pekan Getah	Level 1	Operation	1985	2004	21.5	0.52	0.62	0.95	0.63	0.47		OP-A	C3
58	Perak	PR-09	MD Tapah	Bidor	Level 1	Operation	1980	2013	2.1	0.60	0.38	0.95	0.86	0.47		OP-B	C3
59	Penang	PP-01	MP Pulau Pinang	Jeti Jelutong	Level 1	Operation	1980	2001	20.0	0.53	0.62	0.73	0.82	0.47		OP-A	C3
60	Penang	PP-02	MP Seberang Perai	Ampang Jajar	Level 3	Operation	1980	2003	17.0	0.32	0.50	0.68	0.60	0.43		OP-C	C3
61	Penang	PP-03	MP Seberang Perai	Pulau Burong	Level 3	Operation	1980	2009	64.0	0.28	0.09	0.44	0.48	0.43		OP-D	C2
62	Kedah	KD-01	MP Kulim Kedah	Padang Cina	Open Dump	Operation	1996	2023	56.0	0.57	0.05	0.88	0.82	0.47		OP-B	C3
63	Kedah	KD-02	MD Baling	Pulai	Level 3	Operation	2001	2018	6.8	0.65	0.09	0.44	0.59	1.00	0.81	OP-B	C4

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												C1	C2	C3	C4		
64	Kedah	KD-03	MD Baling	Kuala Pegang	Open Dump	Closed	1989	2002	11.0	0.35	0.12	0.63				CL-D	C1
65	Kedah	KD-04	MP Sungai Petani	Semeling	Level 1	Operation	1989	2013	51.0	0.45	0.23	0.80	0.63	0.47		OP-B	C3
66	Kedah	KD-05	MP Sungai Petani	Jeniang	Open Dump	Closed	1985	2001	1.5	0.23	0.12	0.22				CL-D	C1
67	Kedah	KD-06	MP Kota Setar	Bukit Tok Bertandok	Level 2	Operation	1983	2009	9.7	0.61	0.35	0.58	0.78	0.96		OP-B	C3
68	Kedah	KD-07	MD Kubang Pasu	Paya Kemunting	Level 2	Operation	1974	2005	5.0	0.41	0.23	0.90	0.60	0.43		OP-B	C3
69	Perlis	PL-01	MP Kangar	Kuala Perlis	Open Dump	Operation	1983	2003	8.0	0.52	0.70	0.95	0.52	0.25		OP-A	C3
70	Kelantan	KL-05	MD K.Krai Selatan	Dabong	Open Dump	Operation	1996	2006	0.2	0.34	0.24	0.49				OP-D	C1
71	Pahang	PH-07	MP Kuantan	Atabara	Open Dump	Closed	1984	1985	20.0	0.26	0.46					CL-D	-
72	Pahang	PH-08	MD Bentong	Sungai Sematut	Level 1	Closed			2.0	0.41	0.30	0.45	0.23	0.36	0.36	CL-B	C4
73	Pahang	PH-09	MD Bentong	Chamang	Open Dump	Operation	1995	2006	3.0	0.46	0.30	0.43	0.23	0.36	0.36	OP-B	C4
74	Pahang	PH-10	MP Temerloh	Ulu Tualang	Level 3	Operation	1998	2006	7.3	0.20	0.54	0.26				OP-C	C2
75	Pahang	PH-11	MD Cameron Highlands	Tapak Pelupusan Sisa Pepejal MDCH (Simpang Pulai)	Open Dump	Operation	2001	2008	0.4	0.40	0.30	0.24	0.26	0.30	0.21	OP-B	C4
76	Pahang	PH-12	MD Cameron Highlands	Tapak Pelupusan Sisa Pepejal MDCH (Cameron Highlands)	Open Dump	Closed	1990	2001	0.4	0.34	0.62	0.51				CL-C	C2
77	Selangor	SL-05	MD Kuala Langat	Tapak Pelupusan Sampah	Open Dump	Operation		2007	6.1	0.47	0.35	0.53		0.64		OP-B	C3
78	Selangor	SL-06	MD Kuala Langat	Tapak Pelupusan Tanjung Sepat	Open Dump	Closed	1985	1995	1.0	0.23	0.41					CL-D	-
79	Selangor	SL-07	MD Kuala Langat	Tapak Pelupusan Banting	Open Dump	Closed	1985	1998	3.0	0.48	0.76	0.47	0.36	0.36	0.32	CL-A	C4
80	Pahang	PH-13	MD Jerantut	Kg.Mat Lilau	Level 2	Operation	1997	2005	4.4	0.68	0.18	0.65	0.94	1.00		OP-B	C3
81	Pahang	PH-14	MD Jerantut	Batu 57	Open Dump	Closed	1984	1996	2.0	0.32	0.76	0.33				CL-C	C2
82	Pahang	PH-15	MD Maran	Tapak Sampah Maran	Level 2	Operation	1988	2013	4.0	0.30	0.24	0.47	0.36	0.26		OP-D	C2
83	Pahang	PH-16	MD Maran	Tapak Sampah Jengka 10	Level 1	Operation	1997	2030	8.0	0.42	0.24		0.22	0.90		OP-B	C3
84	Pahang	PH-17	MD Raub	Sg.Ruan	Level 3	Operation	1997		3.4	0.22	0.40	0.43			0.21	OP-D	C2
85	Pahang	PH-18	MD Raub	Cheroh	Level 3	Operation	1991	2008	4.9	0.30	0.54	0.43	0.31	0.30	0.21	OP-C	C3
86	Perak	PR-10	MD Hilir Perak	MDHP (Teluk Intan)	Open Dump	Operation	1993	2008	20.3	0.35	0.35	0.55				OP-D	C1
87	Perak	PR-11	MD Hilir Perak	Tapak Sampah MDHP (Kaw. Pekan Jenderata)	Open Dump	Operation	1979	2006	0.4	0.35	0.22	0.55				OP-D	C1
88	Perak	PR-12	MD Hilir Perak	Tapak Sampah MDHP (Kaw. Bagan Datoh)	Open Dump	Operation	1979	2006	1.2	0.39	0.32	0.51				OP-D	C1
89	Perak	PR-13	MD Kuala Kangsar	MDKK	Open Dump	Operation	1986	2006	13.4	0.48	0.30	0.57	0.23	0.36	0.36	OP-B	C4
90	Perak	PR-14	MD Lenggong	Air Kala	Open Dump	Operation	1989	2008	1.5	0.34	0.30	0.53				OP-D	C1
91	Perak	PR-15	MD Lenggong	Kuak	Open Dump	Closed	1979	1999	1.2	0.31	0.29	0.33				CL-D	C1
92	Kelantan	KL-06	MD Jeli	MD Jeli (Bato 'O')	Open Dump	Closed	1990	2000	0.4	0.36	0.33	0.57				CL-D	C1
93	Kelantan	KL-07	MD Jeli	MD Jeli (Kg.Sg.Mengkong)	Open Dump	Operation	2000	2015	2.4	0.42	0.05	0.61	0.36	0.26		OP-B	C3
94	Perak	PR-16	MD Pengkalan Hulu	Tapak Pelupusan Sisa Pepejal	Open Dump	Operation	1993	2009	8.4	0.52	0.30	0.45	0.44	0.26	0.61	OP-B	C4
95	Perak	PR-17	MD Selama	Tapak Pelupusan MDS	Open Dump	Operation	1991	2008	4.0	0.44	0.58	0.65	0.22			OP-A	C3
96	Perak	PR-18	MD Tanjong Malim	Panderas	Open Dump	Operation	1980	2010	2.5	0.73	0.60	0.87	0.54	0.69		OP-A	C3
97	Selangor	SL-08	MB Shah Alam	MPSA	Open Dump	Closed		1996	12.0	0.26	0.12					CL-D	-
98	Selangor	SL-09	MP Subang Jaya	Worldwide Landfills Sdn Bhd	Level 4	Operation	1995	2015	43.0	0.35	0.63	0.22	0.48	0.56	0.21	OP-C	C3
99	Selangor	SL-10	MD Kuala Selangor	Kubang Badak B.Berjuntai		Operation	1984		20.0	0.38	0.31	0.65	0.39	0.39		OP-D	C2

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												C1	C2	C3	C4		
100	Selangor	SL-11	MD Sabak Bernam	Jalan Panchang Bedena	Level 3	Operation	1984	2006	4.0	0.18	0.30		0.22	0.26		OP-D	C2
101	Perak	PR-19	MD Kerian	Jalan Dnnistown Parit Buntar	Open Dump	Operation	1979	2003	0.8	0.64	0.60	0.69	0.79	0.56	0.21	OP-A	C4
102	Perak	PR-20	MD Kerian	Pematang Pasir Alor Pongsu (Beriah) Bagan Serai.	Open Dump	Operation	1983	2005	2.4	0.64	0.60	0.69	0.79	0.56	0.21	OP-A	C4
103	Terengganu	TR-08	MD Besut	Landfield (Sistem Tambus)	Open Dump	Operation	1993	2010	4.6	0.32	0.20	0.45				OP-D	C1
104	Terengganu	TR-09	MD Hulu Terengganu	Tapak Pelupusan MDHT	Open Dump	Operation	1982	2013	9.5	0.30	0.52				0.30	OP-C	C3
105	Terengganu	TR-10	MD Marang	MDM	Open Dump	Operation	1986	2004	2.5	0.29	0.04	0.39				OP-D	C1
106	Johor	JH-13	MD Labis	Pusat Membuang Sampah Jalan Temayar	Open Dump	Operation		2005		0.40	0.35	0.67	0.30	0.26		OP-D	C2
107	Johor	JH-14	MD Labis	Pusat Membuang Sampah Jalan Maskil	Open Dump	Operation	2003	2013		0.40	0.35	0.67	0.30	0.26		OP-D	C2
108	Johor	JH-15	MD Pontian	Tapak Pelupusan Jalan Sawah, Pekan Nenas	Open Dump	Operation	1998	2008	12.0	0.40	0.13	0.41	0.30	0.26		OP-D	C2
109	Johor	JH-16	MD Pontian	Tapak Pelupusan Rimba Terjun, Pontian	Open Dump	Operation	1980	2003	12.0	0.45	0.38	0.31	0.65	0.56		OP-B	C3
110	Johor	JH-17	MD Pontian	Tapak Pelupusan Sanglang, Ayer Baloi	Open Dump	Operation	1986	2006	1.2	0.55	0.14	0.55	0.21	0.24	0.51	OP-B	C4
111	Johor	JH-18	MD Segamat	Segamat Baru		Closed		2003	3.3	0.40	0.33	0.35	0.57	0.56	0.21	CL-D	C2
112	Johor	JH-19	MD Segamat	Jementah		Operation	1970	2023	10.0	0.27	0.20	0.41	0.30	0.26		OP-D	C2
113	Johor	JH-20	MD Segamat	Lebuh Raya Segamat / Kuantan		Operation	2003		90.0	0.36	0.29	0.39	0.57	0.56	0.21	OP-D	C2
114	Johor	JH-21	MD Tangkak	Simpang Bekoh	Open Dump	Operation	2000	2023	3.0	0.46	0.10	0.20	0.22	0.79		OP-B	C3
115	Johor	JH-22	MD Tangkak	Batu 16 Sengkang, Bukit Gambir	Open Dump	Operation	1970	2004	7.0	0.43	0.52	0.53	0.26	0.20		OP-A	C3
116	Johor	JH-23	MD Simpang Renggam	Simpang Renggam (Ladang Cep 1)	Open Dump	Operation	1996	2012	6.0	0.39	0.30	0.92	0.28			OP-D	C2
117	Johor	JH-24	MD Simpang Renggam	Machap	Open Dump	Closed	1986	1996	3.0	0.47	0.18	0.53	0.62	0.56		CL-B	C3
118	Johor	JH-25	MD Simpang Renggam	Renggam	Open Dump	Closed	1980	1984	2.0	0.34	0.22	0.33	0.22	0.26		CL-D	C2
119	Johor	JH-26	MD Simpang Renggam	Simpang Renggam (Jln Kulai Cina)	Open Dump	Closed	1990	1995	0.5	0.46	0.60	0.55	0.26	0.30		CL-A	C3
120	Johor	JH-27	MD Yong Peng	MDYP		Operation	1990		0.4	0.49	0.24	0.71	0.65	0.56	0.21	OP-B	C4
121	Kedah	KD-08	MP Langkawi	Tapak Pelupusan Sisa-Sisa Pepejal Majlis	Level 1	Operation	1988	2013	30.0	0.49	0.00	0.44	0.36	0.90		OP-B	C3
122	Kedah	KD-09	MD Padang Terap	MDPT	Open Dump	Operation	1988		2.0	0.53	0.42	0.83	0.57	0.56		OP-A	C3
123	Kelantan	KL-08	MD Bachok	Kg. Sungai Gali, Telong	Open Dump	Operation	1995	2009	10.0	0.40	0.30	0.65	0.27			OP-D	C2
124	Kelantan	KL-09	MD Bachok	Kg. Hujung Repek, Repek	Open Dump	Closed	1985	1995	2.5	0.49	0.52	0.51			0.59	CL-A	C4
125	Perak	PR-21	MD Gerik	MD Gerik (1)	Open Dump	Closed	1976	1997	1.8	0.28	0.10	0.24				CL-D	C1
126	Perak	PR-22	MD Gerik	MD Gerik (2)	Open Dump	Operation	1997	2032	2.0	0.49	0.18	0.47	0.48	0.56		OP-B	C3
127	Kelantan	KL-10	MD Machang	Air Berlaga	Open Dump	Operation	2002	2010	4.0	0.40	0.30	0.53	0.36	0.26		OP-B	C3
128	Kelantan	KL-11	MD Pasir Puteh	Tapak Pelupusan Bukit Gedombak	Open Dump	Operation	1982	2020	2.0	0.38	0.22	0.45	0.22			OP-D	C2
129	Kelantan	KL-12	MD Tumpat	Kok Bedollah	Level 1	Operation	1988		20.0	0.35	0.15	0.44	0.36	0.26		OP-D	C2
130	N.Sembilan	NS-08	MP Port Dickson	Bt.2, Jln Seremban		Closed		1972	2.0	0.22	0.27	0.37				CL-D	C1
131	N.Sembilan	NS-09	MD Jelebu	Pertang	Open Dump	Closed	1997	2002	2.4	0.33	0.17	0.41				CL-D	C1
132	N.Sembilan	NS-10	MD Jelebu	Sg.Muntuh	Open Dump	Operation	2002	2032	6.1	0.33	0.17	0.41				OP-D	C1
133	N.Sembilan	NS-11	MD Jempol	MD Jempol (Rompin)	Open Dump	Operation	1993		5.0	0.39	0.05	0.59				OP-D	C1
134	N.Sembilan	NS-12	MD Jempol	MD Jempol (Bahau)	Open Dump	Closed	1981	1993	1.2	0.26	0.38	0.28				CL-D	C1
135	N.Sembilan	NS-13	MD Rembau	Chembong	Open Dump	Operation	1982	2010	4.0	0.43	0.41	0.51	0.35	0.26		OP-A	C3

ID	State	No.	Name of LA	Name of Site	Landfill Level	Category	Year Start	Year End	Area (ha)	Environ-mental Risk	Value of Land Utilization	The necessity of the safe closure				Group	Closure Level
												C1	C2	C3	C4		
136	Kelantan	KL-13	MD Tanah Merah	KG.Cat Rimau	Open Dump	Closed	1981	1999		0.60	0.32	0.94	0.54	0.30	0.44	CL-B	C4
137	Perak	PR-23	MP Manjung	Sungai Wangi	Level 1	Operation	1980	2003	10.1	0.42	0.09	0.67	0.40	0.30	0.21	OP-B	C4
138	Perak	PR-24	MP Manjung	Tapak Pelupusan Teluk Cempedak	Level 1	Operation	1990	2005	2.0	0.34	0.44	0.47			0.21	OP-C	C3
139	Perak	PR-25	MP Manjung	Pantai Remis	Open Dump	Operation	1970		1.2	0.38	0.12	0.31	0.26	0.30	0.21	OP-D	C2
140	Perak	PR-26	MP Manjung	Beruas	Open Dump	Operation	1970		0.8	0.37	0.09	0.45	0.36	0.26		OP-D	C2
141	Selangor	SL-12		Ampang Jaya	Level 1	Closed	1980	1997	10.0	0.67	0.33	0.47	0.86	1.00		CL-B	C3
142	DBKL	DB-02	DB Kuala Lumpur	Jinjang Utara	Level 2	Operation	1979		10.0	0.52	0.59	0.69	0.76	0.30		OP-A	C3
143	DBKL	DB-03	DB Kuala Lumpur	Sri Petaling	Level 1	Closed	1979	1991	21.0	0.35	0.59	0.26	0.30	0.26		CL-C	C3
144	DBKL	DB-04	DB Kuala Lumpur	Sungai Bersi	Level 2	Closed	1989	1995	14.0	0.36	0.59	0.26	0.44	0.26		CL-C	C3
145	DBKL	DB-05	DB Kuala Lumpur	Paka 2	Level 2	Closed	1989	1994	6.5	0.37	0.59	0.63	0.36	0.26		CL-C	C3
146	DBKL	DB-06	DB Kuala Lumpur	Paka 1	Level 1	Closed	1989	1994	6.5	0.40	0.75	0.63	0.36	0.26		CL-A	C3
147	DBKL	DB-07	DB Kuala Lumpur	Kampung Semarak (Brickfield)	Open Dump	Closed				0.44	0.63	0.63	0.36	0.26		CL-A	C3

Safe closure level shall be determined taking into account the "necessity of the safe closure" described in the above **Table A19-1** and "priority for closure" stated in following **Table A19-2**. Relationship between landfill closure priority and safe closure level is shown below.

Table A19-2 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 20

Hazard Experience Caused by the Landfill Sites in Several Countries

Examples of hazardous incidents experiences in other countries are tabulated in **Table A20-1**.

Table A20-1 Hazard Experiences Caused by the Landfill Sites in Several Countries

No	Location	Year	Hazard Types	Outline of the Hazards
1	Kobe, Japan	1977	Gas explosion	2 gas explosions occurred in a school in Kobe. As a result of site investigation, the land was found to be an ex-landfill site. The school was closed for half a year to ensure the area was safe for the pupils to return.
2	Chiba, Japan	n.a.	Gas migration	A carrot farm situated next to the landfill was exposed to the escaping methane gas. The gas and also a rise in temperature caused some damage to the crops.
3	Fukuoka, Japan	1999	Gas breakout	3 workers were killed when they were exposed to a gust of hydrogen sulphide gas whilst carrying out some digging/boring work at the landfill site.
4	Okinawa, Japan	2002	Landfill fire	A fire occurred at a landfill site in Miyako Island which resulted in the release of several types of toxic gases. The local residence experienced and suffered irritations to their eyes and throat.
5	Selangor, Malaysia	1998	Landslide and fire	Landslide occurred at a landfill site in Ampang Jaya, Selangor. It was reported that two people were buried alive. After the incident, the site was immediately closed.
6	Atlanta, USA	1999	Gas explosion	A gas explosion caused an-8-year-old girl to suffer burns on her arms and legs while playing in a playground. The area was later discovered to be an illegal dumping ground many years ago.
7	North California, USA	1994	Gas explosion	A woman was seriously burned by a methane gas explosion while playing soccer in a park that was built over an old landfill site in Charlotte, North Carolina,.
8	Pittsburgh, USA	1987	Gas explosion	Off-site gas migration from the landfill caused an explosion in a housing area in Pittsburgh, Pennsylvania.
9	Ohio, USA	1984	Gas explosion	Off-site gas migration from the landfill caused an explosion and destroyed a house in Akron, Ohio.
10	Cincinnati, USA	1983	Gas explosion	Gas explosion caused by the landfill destroyed a house across the street from the site in Cincinnati, Ohio. Some injuries were reported.
11	Colorado, USA	1975	Gas explosion	In Sheridan, Colorado, a gas explosion occurred near the storm drain laid across the site. The explosive gasses accumulated in the drain pipe ignited when a group of children were playing and lighting candles near the drain. The children all suffered serious injuries.
12	North California, USA	1969	Gas explosion	Methane gas migrated from the adjacent landfill leaked into the basement of an armoury in Winston-Sakem, North Carolina. The gas ignited when a cigarette was lit thus killing three men and seriously injuring five others.

No	Location	Year	Hazard Types	Outline of the Hazards
13	New York, USA	n.a.	Health problem	On the request from the community near the landfill site, an American agency conducted a public health assessment of the area. The assessment report concluded that there is a potential health risk to the community and may of cause respiratory damage due to hydrogen sulphide gas emitting from the sites although Further study is required.
14	Philippine	2000	Landslide	Heavy rainfall triggered an avalanche at a waste dumping site in the suburb of Quezon City. At least 68 people died and 800 were evacuated to emergency shelters.
15	Nantygwyddon, UK	n.a.	Health problem	More than 120 residence living near Nantygwyddon landfill site suffered major health problems. At the court, the residence group won a major compensation claim.
16	Bogota, Colombia	1997	Landslide	It was reported that 80ha of avalanche at a waste dumping site occurred in Bogota.
17	Ghemme, Italy	1992	Gas explosion	Underground gas migration from the closed landfill site caused an explosion at the nearby industrial plant.
18	Carate-Brianza, Italy	1981	Gas migration	Gas migration from operating landfill sites seeping into nearby industrial facility was reported.
19	Casate, Switzerland	1981-	Gas migration	Gas migration from landfill seeping into a home was reported.
20	Sarajevo, Yugoslavia	1977	Landslide and gas explosion	About 200,000 m^3 of avalanche occurred at the landfill site due to stability failure and gas explosions. Horizontal movement was recorded to be over 1 km and a number of nearby houses were burnt.
21	S. Augustin, Germany	1981	Gas migration	Gas migration from nearby landfill site occurred in the subsoil layer resulting in the neighbouring houses had to be evacuated.
22	Biella, Italy	1981	Gas explosion	Gas migrated via the subsoil layer penetrated into the neighbouring house resulting in an explosion that caused the death of the resident.
23	Cavenago, Italy	1996	Gas migration	Landfill gas migrated over a distance of 1 km and caused damage to the vegetation in nearby area.
24	Los Angeles, USA	1982	Landslide	A residential area built on a closed landfill showed cracks on the ground and experienced land movement.
25	Sacramento, USA	2002	Landfill fire	A fire occurred at a landfill site in Sacramento.
26	West Valley, USA	2002	Landfill fire	A fire occurred at a landfill site. It is reported that the fire produced some toxic gases such as carbon monoxide.
27	Vancouver, Canada	2000	Landfill fire	A fire occurred in a landfill site in Vancouver. The total damages and loss by the fire was estimated to be about at $80,000.

Note: The above list is in random order.
Sources: Information retrieved and collected from the "Agency for Toxic Substances and Disease Registry (USA)", CNN, BBC, Encos SA (Switzerland), Fire Department in Sacrament & West Valley (USA), MP Ampang Jaya etc.

Appendix 21

Case Example of Landfill Safe Closure & Post Closure Land Use

(1) CASE EXAMPLE OF THE SAFE CLOSURE OF LANDFILL SITE

a. Outline of the case example of safe closure

For the purpose of surrounding environmental conservation, the seepage control work which surrounds a landfilled waste with the polyethylene sheet was introduced.

b. Outline of the landfill site

Term of landfill works: 1973-1986

Type of landfilled waste: incineration ash and separation residue of non-combustible refuse

Landfill area: 3,000m^2

Amount of waste disposal: 22,000m^3

Remarks: The conservation measures of groundwater contamination, such as seepage control works, are not performed at all.

c. The process which resulted in the safe closure

Since this landfill site was the open dumping landfill site where equipment of seepage control work etc. was not installed and an environmental conservation measure is inadequate, inhabitants at the downstream region were demanding the removal of the landfilled waste by the reason that there is a fear of the ground water pollution.

The cause of the problem was that the seepage control sheet was not installed in this landfill site.

As a result of the environmental investigation performed by specialists whom entrusted by city, the following proposals were made: "It isn't possible to declare that the influence of the pollutant from landfill site does not reach a down-stream region at all. For this reason, it is necessary to take countermeasures so that influence may not arise."

Therefore, it implemented safe closure measure according to the proposal of the professionals.

d. Countermeasure works

Seepage control walls for blocking the flow of the groundwater which flows into landfill was installed, and further, surface liner by cover soil was installed so that rain water might not soak into the landfilled waste from surface of the landfill. The cost of countermeasure works of about 200 million yen in total was paid by the city.

This post-closure landfill site was inherited from the developer by the city with 30,000m^2 including the surrounding area, and is used as a playground of the elementary school in a new urban residential area.

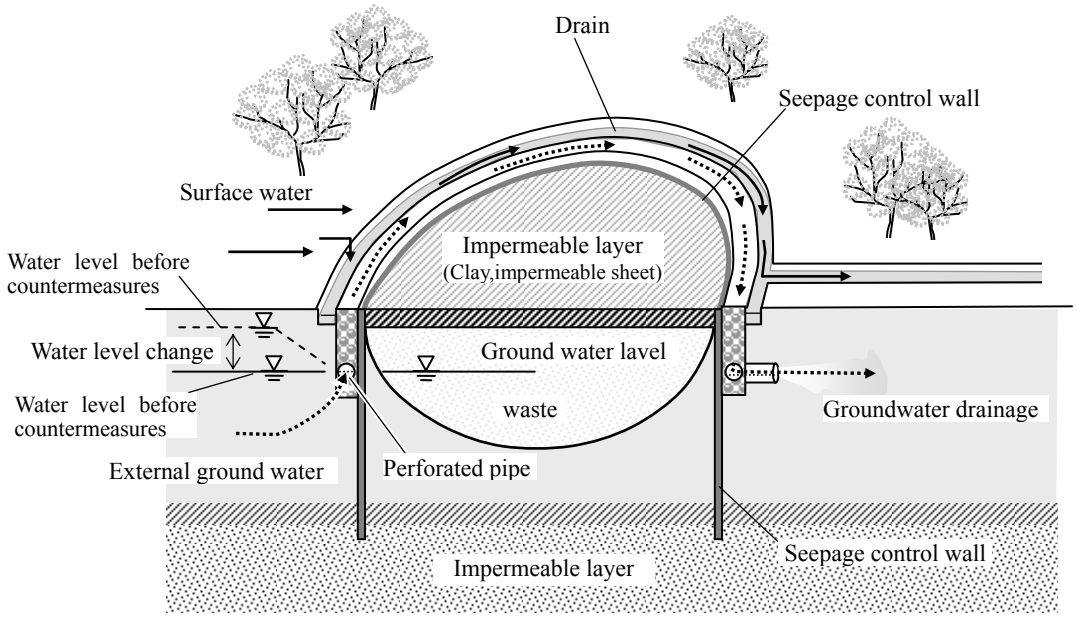

Figure A21-1 Image of the Safe Closure Measurement

(2) CASE EXAMPLE OF THE POST-CLOSURE LAND USE

1) Surface use

Case : Use for golf course

a. Outline of the case example of the post-closure landfill use

A post-closure landfill site for municipal waste of Tokyo metropolitan government was used as the park (Wakasu Sea-side Park) which the golf course is a main use.

Post-closure landfill use is jurisdiction of the bureau of port and harbour, Tokyo metropolitan government. Since it was necessary to make the facilities which the trouble by the sinking of the landfill doesn't occur, a golf course was adopted by the main use of the park.

Countermeasure work was started in 1988 and post-closure landfill use was started from December, 1990.

b. Outline of landfill site

Name of the landfill site: The No.15 site (Tokyo metropolitan government)

Term of landfill works: 1965-1974

Landfill area: 71.2ha

Amount of waste disposal: 10.34 million ton

Thickness of landfill layer: 14-20m

Landfill method: Sea area landfill (the method of dumping waste in the water from the landfill seawall constructed in the sea)

c. Countermeasure works

- Installing of gas ventilation pipes for countermeasure against landfill gas
- No smoking regulation on the golf course because of generating of methane gas
- Measure which prevents soaking of the rain water for decreasing the quantity of leachate
- Nothing particular measure for subsidence about the play ground of the golf course

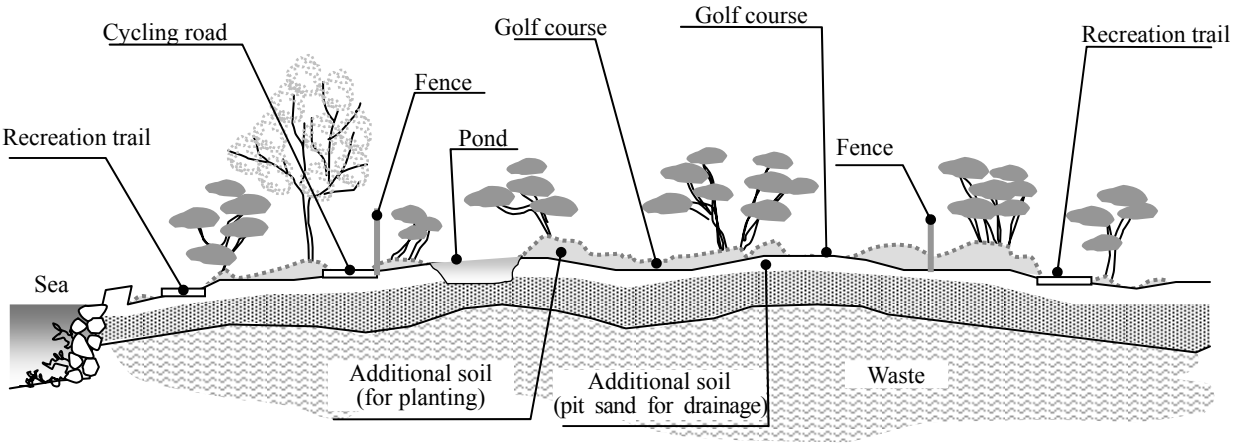

Figure A21-2 Standard Profiles of Wakasu Sea-side Park

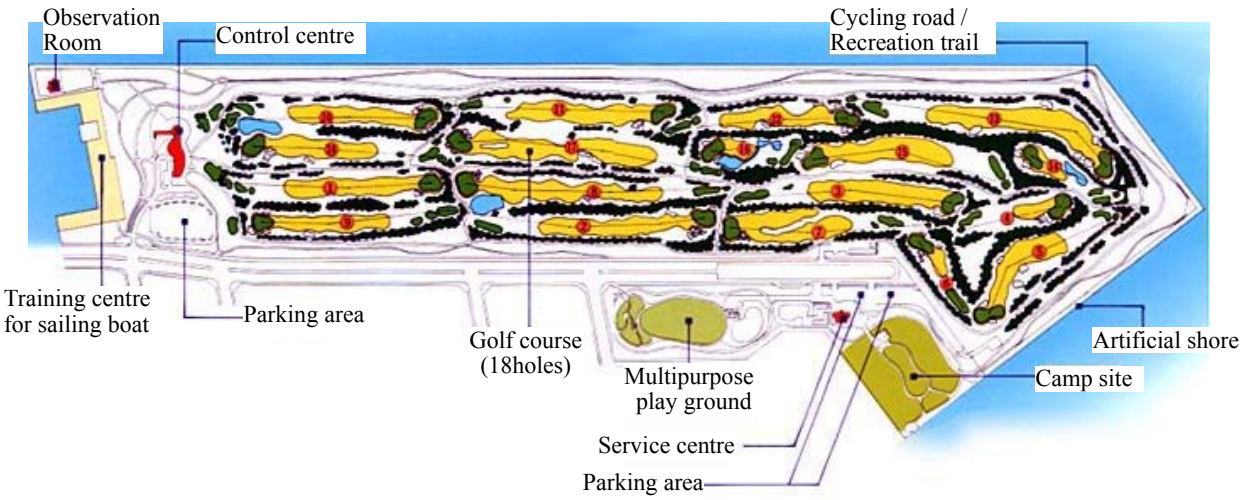

Figure A21-3 Top View of Wakasu Sea-side Park

Photo A21-1 Golf Course of Wakasu Sea-side Park

2) Medium layer use

Case: Use for distribution station

a. Outline of the case example of the post-closure landfill use

A post-closure landfill site for municipal waste was used as the distribution station (Fujimae distribution station) and residential district.

b. Outline of landfill site

Type of landfill site: municipal waste landfill site (80% is glass, pottery waste and incineration ashes and others are organic matter.)

Term of landfill works: 1968-1974

Landfill area: approximately 95ha

Amount of waste disposal: estimate 3.3 million ton or more

Thickness of landfill layer: 2-5m

Remarks: Before reclamation, it is the paddy field of 0 m sea level. Seepage control works was not installed.

c. Countermeasure works

- At the area used as common carriers, warehouses and wholesale trades, foundation improvement of the road part was performed by the percussion compaction method for the purpose of the early stability of the subsidence.
- At the other area, foundation improvement was performed by the surcharge method.
- Subsidence was accelerated an average of 1m or more and the amount of residual subsidence was decreased considerably. As for the manhole, the mesh-like hole was processed at the lid for gas ventilation.

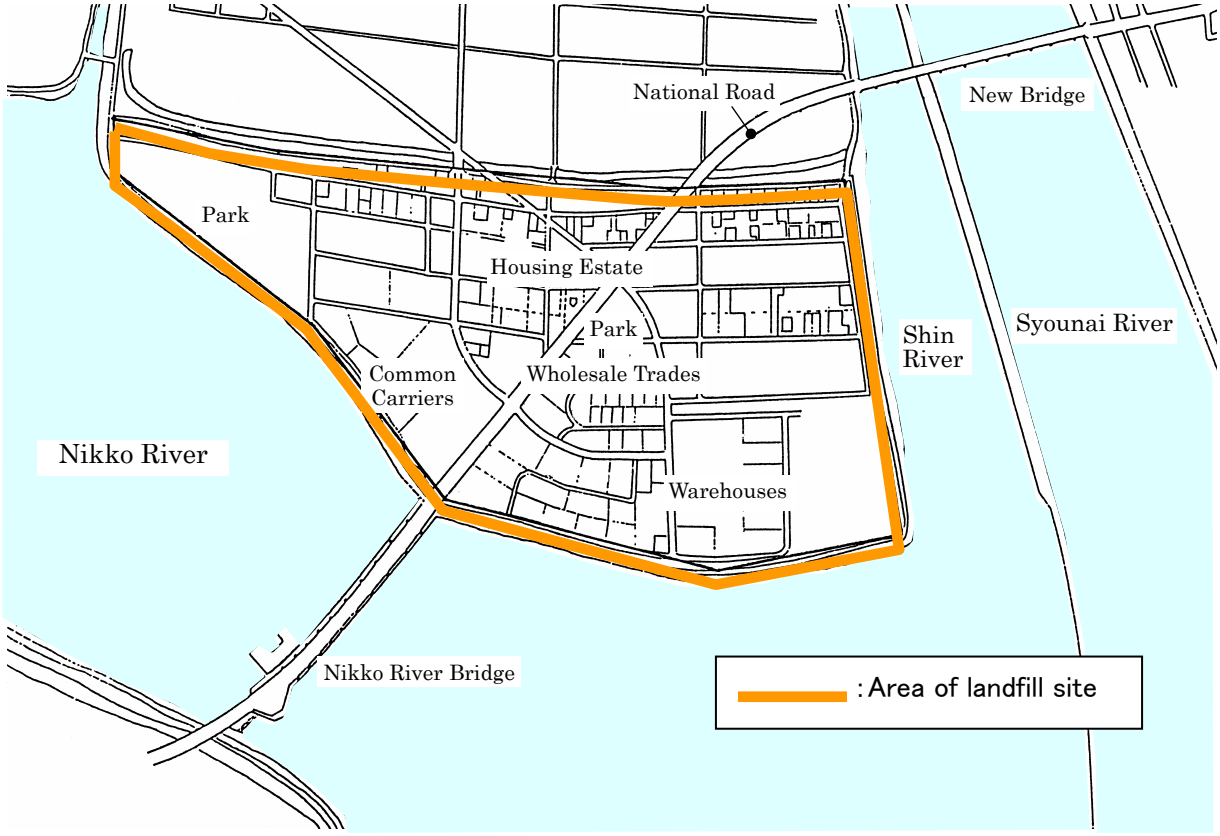

Figure A21-4 Top View of Post-closure Landfill Use

3) Bottom layer use

Case: Bridge pier construction of a highway interchange elevated bridge

a. Outline of the case example of the post-closure landfill use

A post-closure landfill site for industrial waste was used as the highway interchange of the 2nd Meishin super highway (under construction).

The Kuwana interchange is single trumpet type interchange. The highway main road and a ramp part are elevated structures, and seven bridge piers were constructed in the post-closure landfill.

b. Outline of landfill site

Type of landfill site: industrial waste landfill site

Landfill area: approximately 6.4ha

Amount of waste disposal: approximately 42,500 ton (sludge: 200,000m^3, glass and pottery waste: 60,000m^3, slag: 43,000m^3, organic sludge/animal and vegetable residue: 46,000m^3)

Thickness of landfill layer: 14-20m

Remarks: seepage control works by geomembrane lining sheet

Leachate inside the landfill was collected by the leachate collection pipes. It was pumped up and treated by the leachate treatment facility.

The landfill surface was covered by the cover soil of approximately 50cm thickness.

c. Countermeasure works

- Construction of the substructure pile (well foundation, steel pipe sheet pile) to the supporting layer near -45 m of GL
- Substructure construction :

  Displacement of industrial waste within the waste layer to 10m of underground

  Construction of steel pipe sheet pile

  Excavation of industrial waste inside the well curb

- Since the geomembrane lining sheet laid at the landfill bottom is damaged by the construction of steel pipe sheet pile, in order to prevent the outflow of the leachate to the surrounding area, seepage control work (sealing steel sheet pile) was installed to impermeable layer at the circumference of landfill.
- The measure performed with construction is as **Table A21-1**.

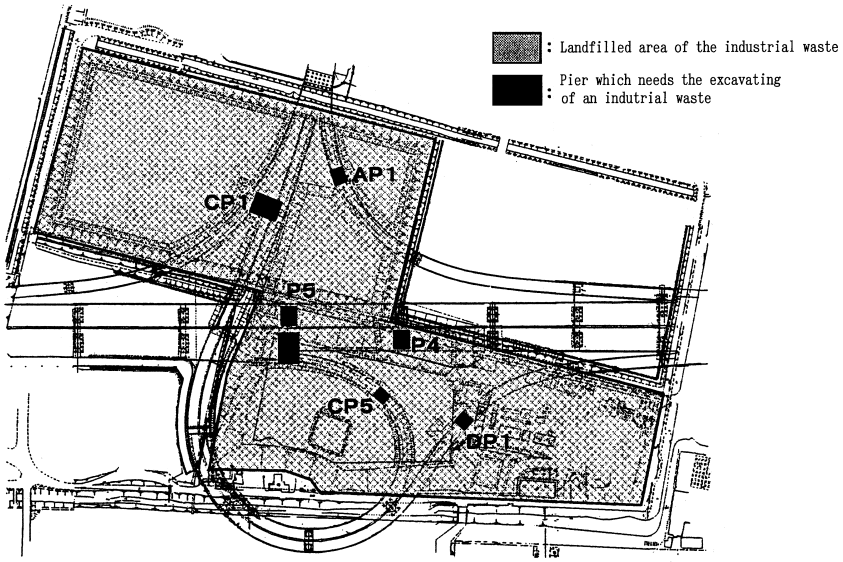

Figure A21-5 Top View of Post-closure Landfill Use at the Kuwana Interchange

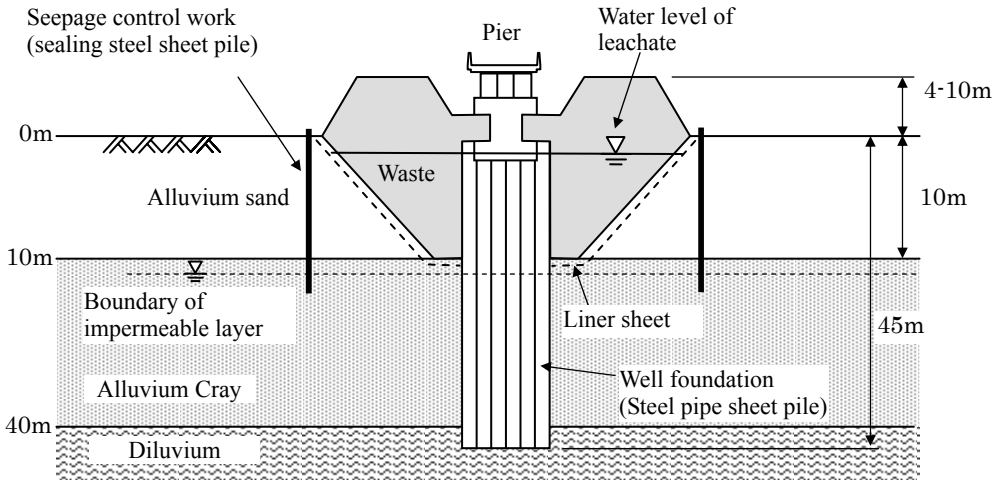

Figure A21-6 Image of Cross Section of the Pier

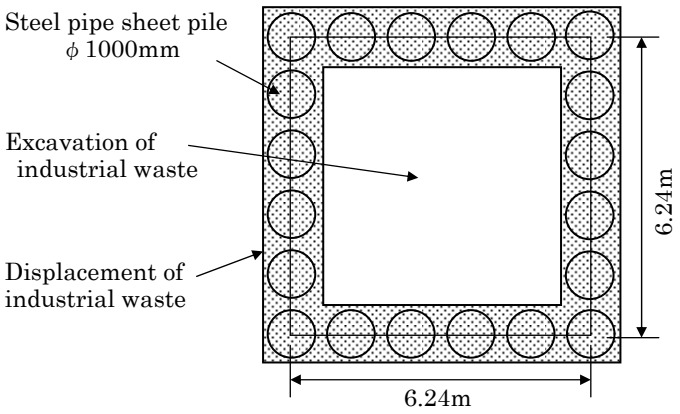

Figure A21-7 Top View of the Pier

Table A21-1 Measure Performed with Construction

Target of measures	Assumed accidents	Countermeasure	Details
Gas	Oxygen depletion Explosion of flammable gas Gas poisoning by hydrogen sulphide Gas poisoning by organic solvent	Gas ventilation in advance	In advance of excavating industrial waste, the retaining gas in the ground was sucked and exhausted compulsorily, and concentration of harmful gas was reduced.
		Automatic gas detecting system	Automatic measurement for every work site Remote central control
		Rescue, lifesaving, and fire-extinguishing equipment	Deployment of breathing apparatus, Emergency escape equipment, special fire extinguisher, etc.
Offensive odour	Odour trouble	Deodorization by soil deodorization equipment	Removal of the offensive odour in closing space
		Spraying of the deodorization material by special atomizer	Automatic spraying by the odour sensor
		Daily cover method	Containment of a odour by the self-hardening foam
Harmful substance (Leachate)	Outflow of pollutants to the surrounding area	Transfer to a neighbouring treatment facility	Installation of a piping system Installation of a leachate controlling facility
		Enclosure of the landfill site	Underground : Installation of sealing steel sheet pile to impermeable layer Ground : Installation of the lining sheet to dykes
		Environmental monitoring	Continuing monitoring of the water quality change etc. at the inside/outside of construction area
	Deterioration of structures	Electrical protection	Process to steel substructure piles etc.
		Corrosion protection of concrete	Surface protection of building frame by the polyurethane membrane
Disease	Infectious disease Contact with chemicals Disorder of respiratory function	Unattended works	Use of a radio-controlled heavy industrial machine in the pit or vertical shaft
		Vaccination Blood test	Prevention of hepatitis and tetanus
		Wear of protective equipment	Use of gas mask, goggle, etc.

Appendix 22

Case Example of Problems Associated with the Post-Closure Landfill Sites

< CASE 1 > EFFECTS OF HEAVY RAIN

1) Overview of the problems

- The landfilled waste was washed out by heavy rain.
- The nearby Cedar forest was damaged by the landfill gas. (refer to Case 4)
- There was an explosion during the construction of the drain pipe at the closed site.

Table A22-1 Basic Description of the Site

Operation start year	early 1970s
Type of waste	Municipal waste
Landfill area	Unknown
Topography	Mountain area
Facility (during operations)	Liner system was not installed. Gas vent pipes, leachate collection facility, and leachate treatment facility was installed.

2) Cause of the problems

- Part of the dyke collapsed by the heavy rain.
- Since the liner system was not installed, the landfill gas escaped to the adjacent land.
- The consideration for post closure development was insufficient.

3) Countermeasures

- The washed out waste was collected and removed back to the landfill and the dyke was repaired.
- Gas venting pipes were installed at the border to the adjacent land in order to prevent further gas migration and vent the collected gas to the air.
- Specific guideline for post-closure land use of the site was prepared.

< CASE 2 > DAMAGE TO THE UTILITY PIPELINES CAUSED BY SUBSIDENCE

1) Overview of the problems

The low-rise apartments constructed at the closed site were provided with precast concrete foundations. There was almost no subsidence to the building but the surrounding grounds of the building experienced heavy subsidence of more than 200mm and thus damaged the connecting pipes. Therefore, in order to avoid further

damage to the utilities such as water, sewage, gas and electricity, etc, special consideration were required.

Table A22-2 Basic Description of the Site

Operation start year	early 1970s
Type of waste	Municipal waste (mainly : incombustible waste)
Landfill area	Unknown
Topography	Mountain area
Facility (during operations)	Liner system, gas vent pipe, etc. were not provided.

2) Cause of the problems

The foundation of the building did not subside, however the surrounding area settled caused the buried pipes to subside and break at the interconnection points to the building. (Refer to **Figure A22-1**)

3) Countermeasures

- Flexible joints were used at the interconnections of the utilities to the building. This increased the flexibility of the pipelines and prevented them from breaking easily.
- In order to determine the future rate of subsidence, investigative study was carried out based on the waste characteristic analysis, the composition analysis and the rate of decomposition.

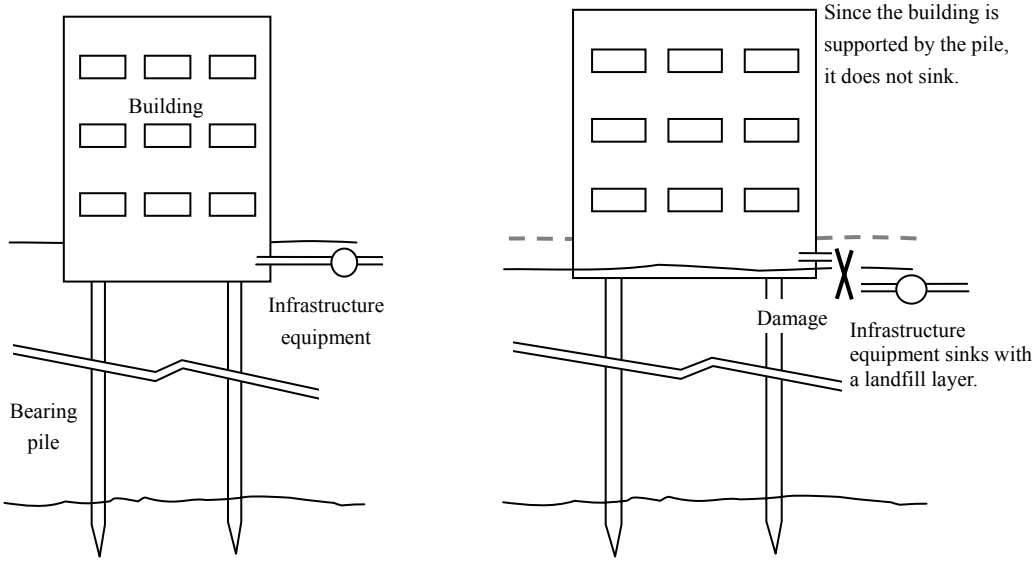

Figure A22-1 Damage Caused by Differential Subsidence

< CASE 3 > DAMAGE TO PADDY FIELD BY INSUFFICIENT LEACHATE TREATMENT

1) Overview of the problems

The rice of a paddy field withered owing to the salt of the leachate from a nearby closed landfill site.

Table A22-3 Basic Description of the Site

Operation start year	early 1970s
Type of waste	Municipal waste (mainly: Incinerator residue)
Landfill area	Unknown
Topography	Unknown
Facility	Unknown

2) Cause of the problems

- The site was mainly filled with the municipal waste the incineration residue. The salts contained in the incinerator residue were dissolved into leachate. The leachate was collected and treated. The effluent from leachate facility was discharged into the small drains. The discharge effluent from the site complied with the standards for the Water Pollution Control Law, however the standard for the salts was not defined.

3) Action against the trouble

- The effluent was diverted and discharged to the wider channel so that some dilution will occur, and the salt will not affect the crops so much.

< CASE 4 > CROP DAMAGED BY LANDFILL GAS

1) Overview of the problems

The crops died at the nearby field due to over exposure to the landfill gas.

Table A22-4 Basic Description of the Site

Operation start year	Unknown (late 1970s)
Type of waste	Inert Waste (mainly : Construction and demolition waste)
Landfill area	Unknown
Topography	Flatland
Facility	Liner system, gas vent pipe, etc. were not provided.

2) Cause of the problems

- At this landfill site, the disposal of only inert waste (i.e. plastics, rubber, metal, glass, ceramic, asphalt concrete and so on) was licensed, but during operations, organic waste was also disposed at the site. Hence, landfill gases were generated by the biodegradation of the organic matter.
- Since the liner system was not installed in this landfill site, the landfill gas migrated and escaped into the adjacent land through the ground. (refer to **Figure A22-2**)
- The landfill gases escaped to the atmosphere not only through the cover soil but also migrated to the adjacent land through the ground.

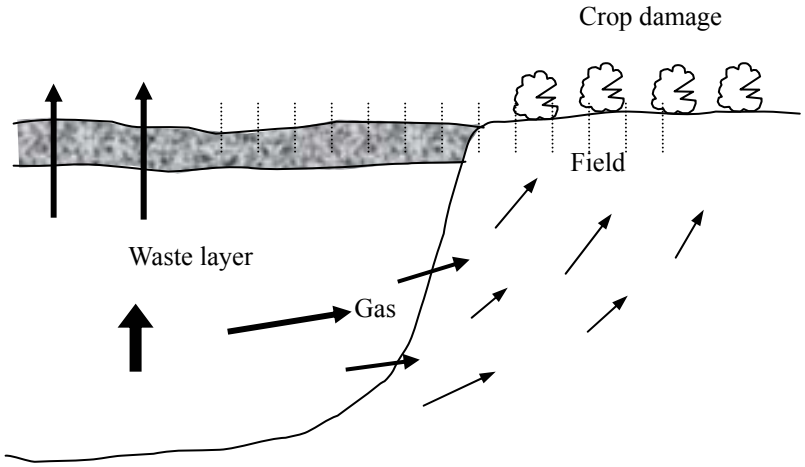

Figure A22-2 Migration of Landfill Gas to the Adjacent Land

3) Countermeasures

- In order to determine the cause of the problem, germination/sprouting tests were carried out.
- In order to prevent the gas migration to the adjacent land, barrier wells (vertical gas vent pipes) were installed at the boundary, as shown in **Figure A22-3**. The gases were intercepted and vented before reaching the crops.

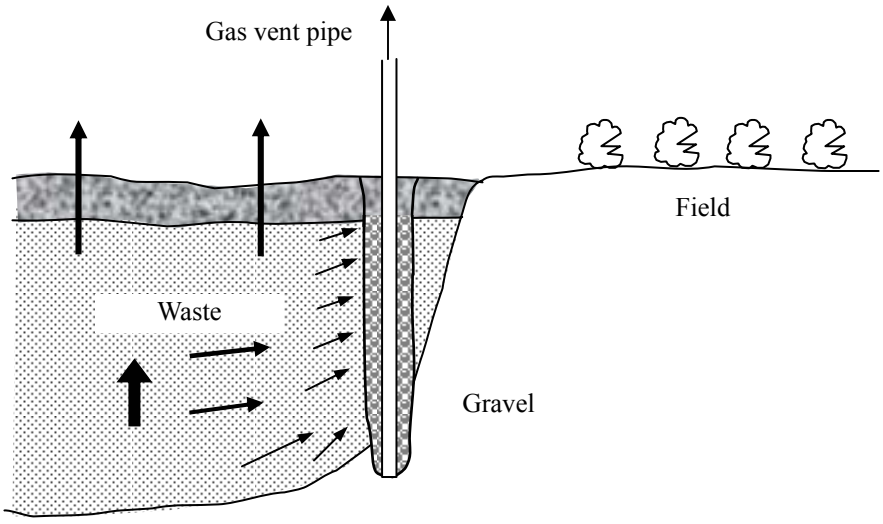

Figure A22-3 Control of Gas Migration by Gas Barrier Wells

< CASE 5 > FIRE CAUSED BY LANDFILL GAS

1) Overview of the problems

- At the residential area developed on the closed site, the residents burned their garden waste in their yard. The fire was extinguished eventually, but in the evenings, bluish flames have been discovered at the garden area. This was due to the landfill gas being burning. The flame of the burning landfill gas is difficult to see in the daylight but is highly visible at night.
- Subsequent investigation determined that the landfill gas was escaping from the ground and was ignited.

Table A22-5 Basic Description of the Site

Operation start year	early 1970s
Type of waste	Municipal waste (Raw garbage, etc.)
Landfill area	Unknown
Topography	Mountain Area
Facility (during operations)	Liner system, gas vent pipe were not provided.

2) Cause of the problem

- The landfill gas, which was generated by biodegradation of raw garbage, escaped into the yard.
- Since the residents were not aware of the presence of the landfill gas, the care for fire hazards and safety was insufficient.
- The housing developers did not give sufficient information or warning concerning the effects of the landfill gas to the residents

3) Countermeasures

- In order to prevent the landfill gas escaping into the yard, the gas collection and vent pipes, i.e. vertical and horizontal pipes, were installed throughout the development, and the gas was collected and vented.
- Gas monitoring, such as composition analysis, was carried out regularly in the outlet of the gas vent pipes.

< CASE 6 > GENERATING OF AMMONIA GAS BY SPREADING OF LIME

1) Overview of the problems

- The spreading of lime on the soil at the closed site was carried out in order to strengthen the bearing capacity of the ground for development purposes. Gaseous ammonia was generated as a result of the unintended chemical reaction between the lime and the chemicals present in the waste. The workers at the development complained about irritation to their eyes and to their respiratory organs.

Table A22-6 Basic Description of the Site

Operation start year	early 1960s
Type of waste	Mainly raw garbage , partly incinerator residue
Landfill area	Unknown
Topography	Flatland
Facility	Unknown

2) Cause of the problems

- Much concentration of ammonium ions were present in the waste layer in the liquid phase which were generated by the decomposition of the waste.
- Since lime, which is a strong alkali, was added to the waste layer, ammonia, "ammonia stripping" reaction will occur and librates the ammonium gas. "Ammonia stripping" is a well-known process to remove the ammonia from waste water into the air by adding the strong alkali.

3) Countermeasures

- The construction of applying lime to the ground was stopped. The post-closure land use plan was revised.
- Composition analysis and a dissolution test for the landfilled waste were carried out.
- The laboratory scale ammonia generating reaction test was carried out.

Appendix 23

Sanitary Landfill System and Levels

1 Integrated Landfill Facilities

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

A typical sanitary landfill system must be provided with all the necessary facilities as shown in **Figure A23-1**. Generally the sanitary landfill system comprise of the core facilities, such as the waste retaining facility, leachate collection piping facility, gas vents, access roads, drainage system, fencing etc; and the supporting facilities, such as the leachate treatment facility, administrative facility, machineries etc.

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

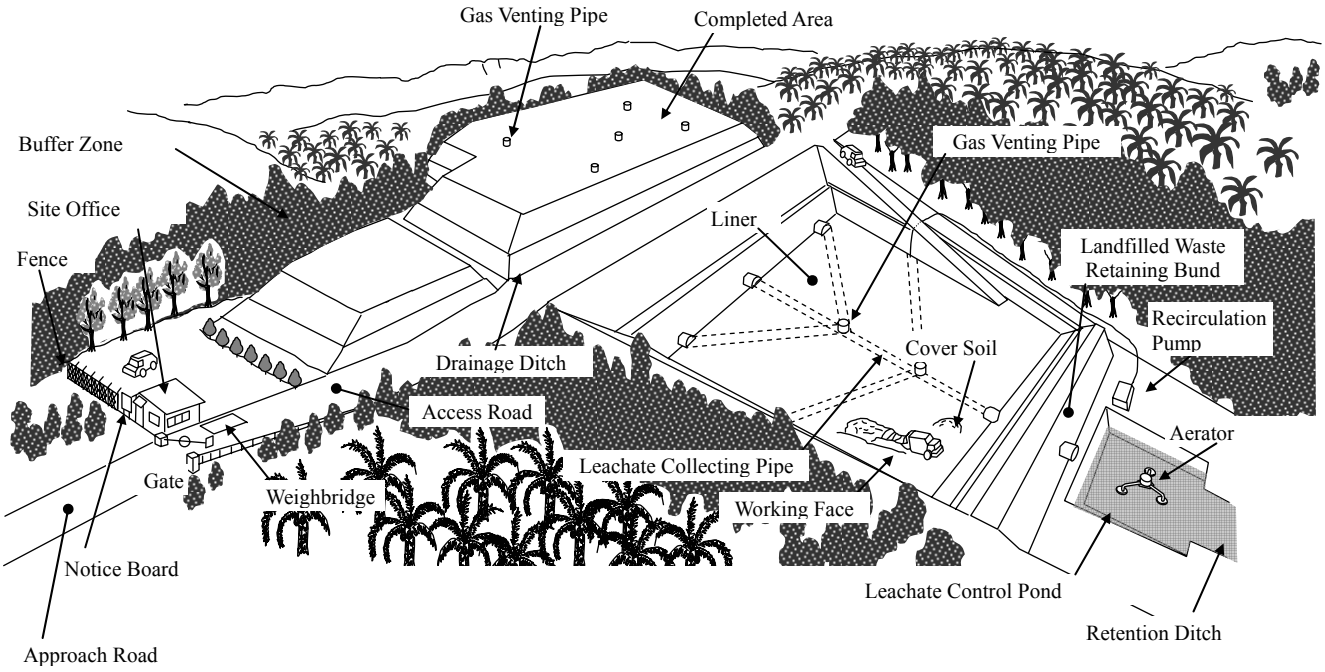

Figure A23-1 Typical Sanitary Landfill System

2. Classification of Sanitary Landfill Levels

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

Level 1: Controlled tipping

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

Level 3: Sanitary landfill with leachate recirculation system

Level 4: Sanitary landfill with leachate treatment facilities

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

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

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

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

The summary of the classification of the levels and the proposed facilities are tabulated in **Table A23-1**.

Table A23-1 Level of Sanitary Landfill System

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

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

2.1 Level 1

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

(1) Target

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

(2) Achievements

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

(3) Necessary Improvements to the Next Level

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

(4) Environmental Issue

- Since only periodic cover materials are provided, the environmental impacts are still present, such as:
- Surface and groundwater pollution by leachate
- Scattering of waste and dusty
- Breeding of insects and rodents
- Unpleasant view of landfill
- Noise pollution
- Unpleasant odour

2.2 Level 2

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

(1) Target

- Sanitary landfill with a bund and daily cover soil

(2) Achievements

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

(3) Necessary Improvements to the Next Level

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

(4) Environmental Issue

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

2.3 Level 3

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

(1) Target

- Sanitary landfill with leachate recirculation system

(2) Achievements

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

(3) Necessary Improvements to the Next Level

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

(4) Environmental Issue

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

2.4 Level 4

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

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

(1) Target

- Sanitary landfill with leachate treatment facilities

(2) Achievements

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

(3) Environmental Issue

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

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

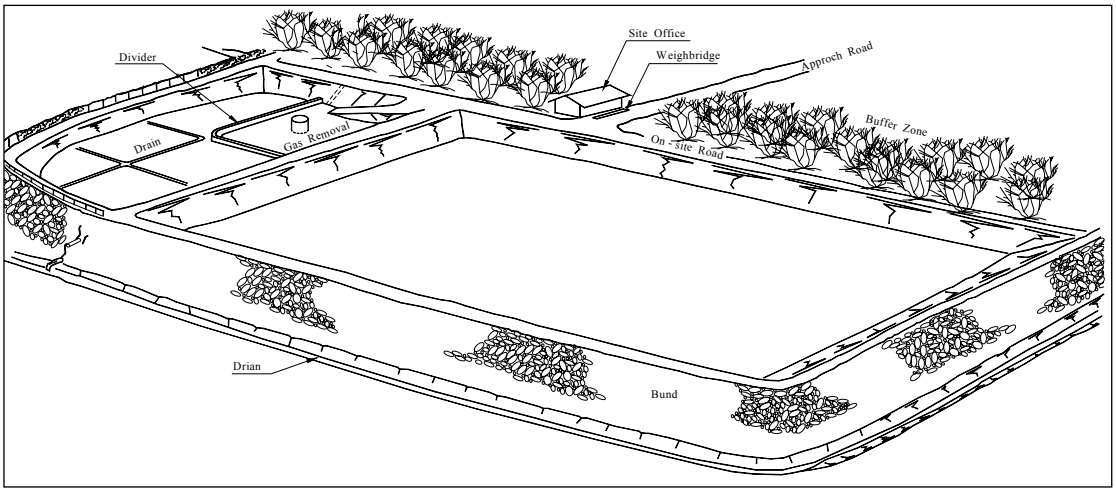

Figure A23-2 (a) Typical Layout for the Level 2 Sanitary Landfill

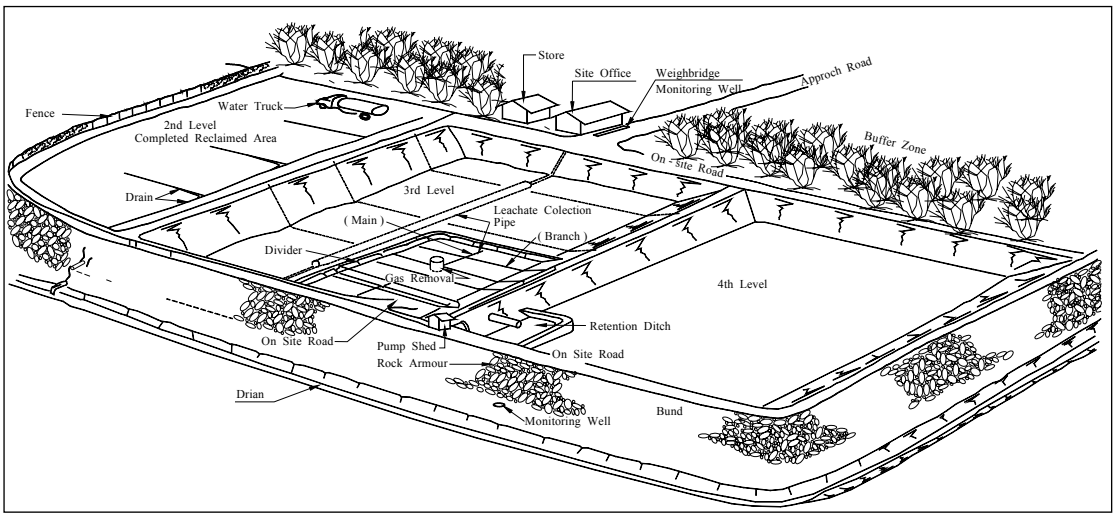

Figure A23-2 (b) Typical Layout for the Level 3 Sanitary Landfill

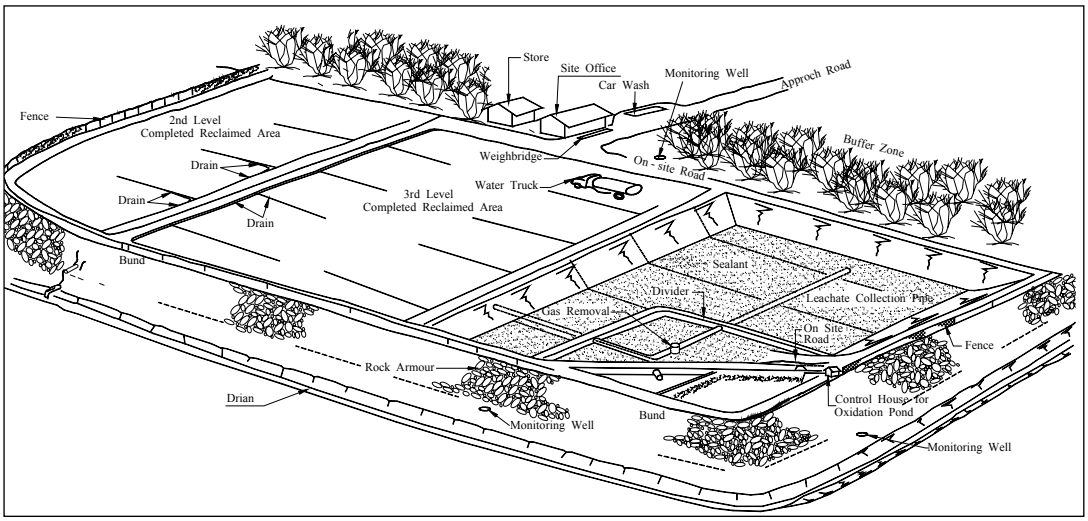

Figure A23-2 (c) Typical Layout for the Level 4 Sanitary Landfill

Appendix 24

Referred Standards/Guidelines

(1) "Plan and Design Guideline of Final Disposal Site", Japan Waste Management Association, 2001

(2) "Guidance for Safety Management at Mining site" :Occupational Safety and Health Act (Japan) 1970

(3) US EPA. (1994) Design, Operation, and Closure of Municipal Solid Waste Landfills. EPA report no. 625/R-94/008. Washington, DC.

(4) COUNCIL DIRECTIVE 1999/31/EC of 26 April 1999 on the Landfill of Waste

(5) UK DOE (1991) Waste Management Paper No 26, 27