## 4.3 Intermediate Treatment System

### 4.3.1 Outline

(1) *Features of intermediate treatment*

Intermediate treatment is a process to make solid waste non-toxic and harmless, non-degradable, reduced in volume and reusable through physical, chemical and/or biological treatment before discharging it into the natural environment. Based on technological considerations, intermediate treatment is normally divided into two parts: pretreatment (front-end system) and conversion treatment (rear-end system).

To date, two kinds of technology (composting and incineration) have been applied to the intermediate treatment of solid waste. In recent years, however, responding to social demand for environmental protection and resource saving, development of new types of intermediate treatment technology have taken place aimed at reutilization of solid waste as the main purpose. Presently, these new types of intermediate treatment technology are still being developed.

An outline with features of representative intermediate treatment methods are summarized in Table 4.1. Features and character of incineration and composting are further described in detail in Appendix 4.6 and 4.7.

(2) Formulation procedure of intermediate treatment system master plan alternatives

Intermediate treatment system master plan alternatives were formulated according to procedures shown in the flow chart (Fig. 4.2). Details of the study concerning item No. 1 ∿ 5 in the flow chart are described in Appendix 4.8.

### 4.3.2 Intermediate treatment system master plan alternatives

(1) Selection of the appropriate Master Plan alternatives

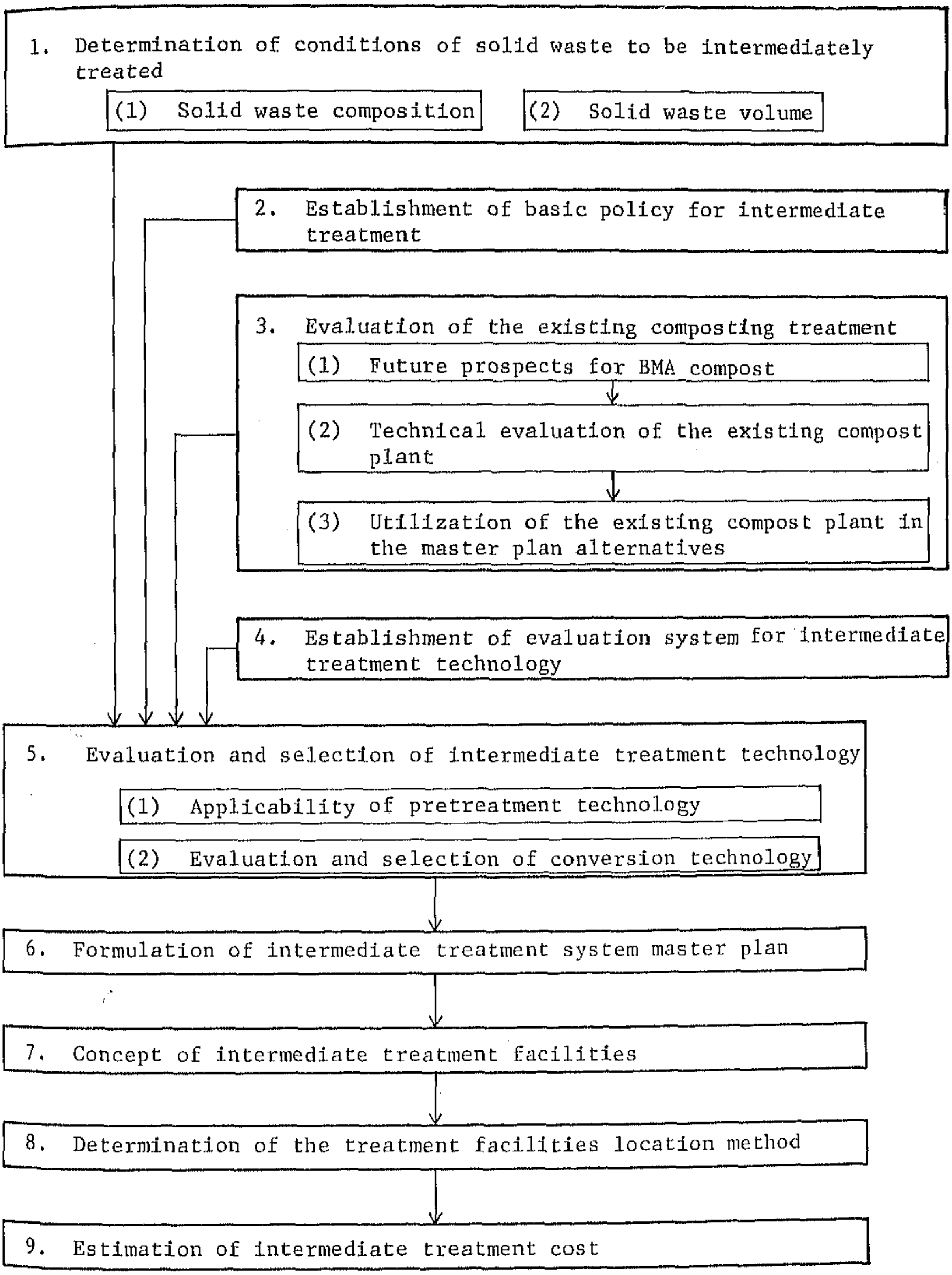
As a result of the study shown in Appendix 4.6∿4.8, incineration and composting were selected as components of the intermediate treatment technology to be adopted in the intermediate treatment system plan. Adding direct landfill method (without intermediate treatment) to the above two methods, seven combinations were formulated from the three elements;

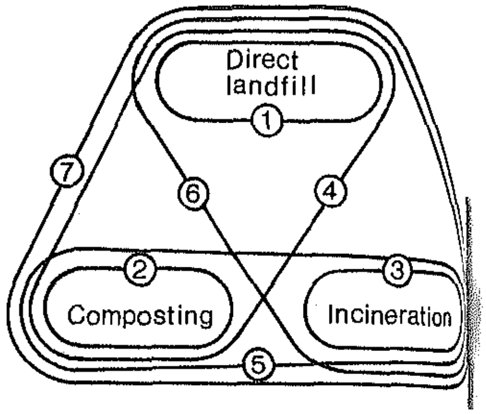
Table 4.1 Outline and features of intermediate treatment methods

(Solid waste generation) → Solid waste collection → Transportation

| Intermediate Treatment: Pretreatment (The Front End System) | Intermediate Treatment: Conversion Treatment (The Back End System) | Recovered Material | Outline | Advantages and Disadvantages | Type of Resource Recovery | |
|---|---|---|---|---|---|---|
| Pulverization (Shearing, Impaction, Friction, Compression, Compound); Separation (Dry, Semi–wet, Wet) | Incineration (Stoker incinerator, Fluidized bed incinerator, Rotary incinerator) | Steam<br>Hot water | 1. Combustibles in solid waste are incinerated through reaction with oxygen in the air and converted into exhaust gas and stable volume-reduced solid residue.<br>2. Stoker incinerator is reliable equipment having the longest history of the use.<br>3. Fluidized bed incinerator has been recently brought to practical use as an intermediate treatment technique.<br>4. Rotary incinerator is usually used in combination with stoker incinerator. Use of rotary kiln alone is very rare. | 1. The trend for increased amounts of plastics in solid waste and intensification of restriction against pollution have invited a tendency of increase of construction and operation costs of incineration facilities so as to eliminate possible sources of pollution from incineration facilities.<br>2. In the case of large mechanical incinerators with a capacity of 150 ton/day or more, attachment of waste heat boiler enables effective resource recovery, with which power generation by steam turbine or steam supply is realized. (If low calorific value of solid waste reaches to 1,000 kcal/kg, self-sustenance of electric power is realizable.)<br>3. Fluidized bed incinerator requires larger power consumption than stoker incinerator as it necessitates pulverization of solid waste (pretreatment) prior to incineration. | Direct Energy Recovery | Energy Recovery Type |
| | Pyrolysis (Internal heat type fluidized bed reactor, one-bed pyrolysis system and two-bed pyrolysis system, External heat type vertical reactor) | Fuel gas<br>Fuel oil | 1. Solid waste is heated up to high temperature in oxygen-less or low-oxygen atmosphere and decomposed into combustible gas, oil and char containing incombustibles.<br>2. This method aims at resource recovery and suppression of pollution caused by intermediate treatment but is presently under development or partly in actual use.<br>3. Technical development of pyrolysis method by internal heat type vertical reactor and rotary kiln reactor attempted in USA has ended in failure. | 1. Pyrolysis method requires pulverization of solid waste (pretreatment) prior to incineration, therefore much larger power consumption than stoker incinerator is needed.<br>2. If solid waste low calorific value (Hu) cannot reach to approximately 1,500 kcal/kg, electric power self-sustaining system by energy of solid waste alone cannot be realized. (When Hu of solid waste exceeds about 1,500 kcal/kg, surplus fuel can be obtained.)<br>3. Quantity of air-pollutive substance in combustion exhaust gas containing combustion gas of recovered fuel in this method is less than that of incineration method.<br>4. External heat type vertical reactor is inferior in reducing the treated residue.<br>5. Construction and operation costs of the facilities for this method are higher than that for incineration facilities. | Recovery of Storable and Transportable Energy | Energy Recovery Type |
| | Slagging Pyrolysis and Slag Fusion (High temperature slag fusion furnace) | Fuel gas<br>Slag | 1. By shaft furnace, combustibles in solid waste are converted into gas through pyrolysis and the incombustibles are converted into slag.<br>2. This method aims suppression of pollution caused by intermediate treatment of solid waste and saving of landfill area. The method is presently being used to determine its practicality. | 1. Preparatory pulverization of solid waste is not needed but use of auxiliary materials such as heavy oil, oxygen, coke, L.P.G, etc., in large volume is required. If solid waste low calorific value (Hu) is less than approx. 2,000 Kcal/Kg, electric power self-sustaining system by solid waste energy alone cannot be realized.<br>2. Quantity of air-pollutive substance in combustion exhaust gas containing combustion gas of recovered fuel gas (approx. 500 – 1,500 kcal/Kg) in this method is less than that of incineration method.<br>3. Construction and operation costs of the facilities for this method are higher than that for incineration facilities. | Recovery of Storable and Transportable Energy | Energy Recovery Type |
| | Methanation (Conversion to methane) (Anaerobic fermentation) | Fuel gas | 1. Methane gas is collected as fuel through anaerobic fermentation of organic materials contained in solid waste.<br>2. This system is presently under development. | 1. For adoption of this system, separated collection of garbage is an indispensable requirement.<br>2. Unsuitable waste to this method and residue remained after the treatment (fermentation) have to be disposed of in the other method. Different from thermal treatment methods mentioned above, this is not complete system by itself. | | |
| | Composting (Aerobic fermentation) | City compost | 1. City compost is produced from solid waste through aerobic fermentation of organic component in solid waste.<br>2. Like incineration, composting is practical intermediate treatment method which has a long experience history. | 1. The following conditions shall be satisfied for adoption of composting method:<br>i) Thoroughly separated collection of garbage and the other solid waste can be implemented.<br>ii) Marketability of compost has potential.<br>2. Unsuitable waste for composting must be disposed of by another method: therefore this is not a complete system by itself. | Conversion Recovery | Material Recovery Type |
| | Feeding (Conversion to feed) | Animal feed | Processing food waste and garbage contained in business waste, proteinic feed is extracted from solid waste. | 1. Waste from food industry, remains of restaurants and lunch suppliers, etc., are the materials to be treated.<br>2. Mixing of heavy metals and other toxic substances into feed shall be carefully prevented. | Conversion Recovery | Material Recovery Type |
| Compression (High pressure type) | | Landfill material | This method aims to raise transportation and landfill efficiencies by reduction of solid waste volume through compression. | 1. In the case of common waste, the compressed solid waste has to be baled with metal net and asphalt so as to prevent expansion in volume and leakage of leachate.<br>2. Volume reduction by this method is one fourth, which is similar to the reduction rate of raw waste being placed in landfill for about 5 years. | Extraction Recovery | Material Recovery Type |
| Separation | | Refuse derived fuel | Solid waste is used as solid fuel for combustion facilities other than incinerator. Some cases of application of this method are seen in steam power stations where solid waste is mixed into coal for combustion. | 1. The existing facilities have to be so designed to enable solid waste combustion.<br>2. Installation of solid waste pulverizing equipment is required. | Extraction Recovery | Material Recovery Type |
| Separation | | Ferrous metal<br>Non-ferrous metal<br>Glass<br>Paper<br>Plastics | Reutilizable materials are retrieved from solid waste through manual or mechanical selection. This aims at reducing solid waste volume to be intermediately treated and finally disposed of. | 1. Mechanical selection method has a limit in its efficiency to selectively collect material in desired types and quality.<br>2. Manual selection is the most reliable method but has the disadvantage of its working environment. | Extraction Recovery | Material Recovery Type |

Fig. 4.2 Flow for formulation of intermediate treatment sytem Master Plan alternatives






1. Total volume direct landfill
2. Total volume composting
3. Total volume incineration
4. Direct landfill + composting
5. Composting + incineration
6. Direct landfill + incineration
7. Direct landfill + composting + incineration

The composting treatment volume was estimated on the basis of the following two cases:

- Maintaining the present compost production volume.
- Increasing the volume to meet potential demand researched in the field investigation of 1980.

Incineration treatment volume was determined from capacity and number of incineration plants specified in each selected intermediate treatment system plan alternative.

(2) Concept of intermediate treatment facilities

i) Incineration plant

a. The plant capacity: from 600 to 1,500 t/d

The lower limit was determined based on the minimum sufficient scale of waste heat boiler-attached incinerator, and the upper limit was based on a consideration of avoiding traffic congestion caused by concentration of collection trucks.

b. Incinerator

- Type: Waste heat boiler-attached continuous firing mechanical furnace.
- Capacity: 200 - 500 t/24h period per furnace.
- Number of furnace: 2 or 3 units.

c. Pollution control facilities

- Prevention of air pollution: Electric precipitator (Outlet dust content 0.1 g/$Nm^3$ or less)

  Stack (Height 100 m)
- Prevention of water pollution: Contaminated water non-discharge system.

d. Resource recovery facilities

- Power generation facilities: Steam condenser turbine type power generation facilities.

Surplus power will be sold to outside consumers.

- Heat supply facilities: The following equipment will be installed when heat supply to outside consumers is planned.
  - High temperature hot water generation equipment.
  - Low temperature hot water generation equipment.
  - Cool water generation equipment (Absorption type refrigerator)

e. Building structure: Steel-reinforced concrete.

f. The plant operation rate.

The facilities which are always exposed to high temperatures, such as incinerator, are apt to wear quickly; therefore, periodical overhaul requiring shutdown of the plant operation is necessitated at least once a year. For this purpose, the operating rate of an incineration plant through a year was assumed as follows:

| | |
|---|---|
| The number of days of plant shutdown owing to breakdown: | 18 days |
| The number of days plant shutdown for inspection: | 10 days |
| The number of days of the plant shutdown for periodic overhaul: | 45 days |
| Total annual plant shutdown time: | 73 days |

The annual plant operation rate is then calculated as follows:

$$= \frac{365 - \text{days of the plant shutdown in a year}}{365}$$

$$= \frac{365 - 73}{365} = 0.80$$

ii) Composting plant

a. Composting method

Because of biodegradable and voluminous nature of compost material (solid waste), it is a principle of compost production to process the material quickly and inexpensively.

The high rate composting method follows this principle. Nevertheless, timing of compost application to farmland is limited in certain seasons and the consumption throughout the year is not expected. Therefore, when the demand is large, unmatured compost is sometimes delivered to market, and when the demand falls, surplus compost is merely piled up and left over in the secondary fermentation yard. In such cases, the significance of composting by high rate method is lost.

In the Netherlands, where demand for compost is great, compost is produced over a 10-month period. Although the longer period of fermentation necessitates a wider area, methods other than high rate composting will also be applicable if some advantages are found in construction cost and operation and maintenance cost.

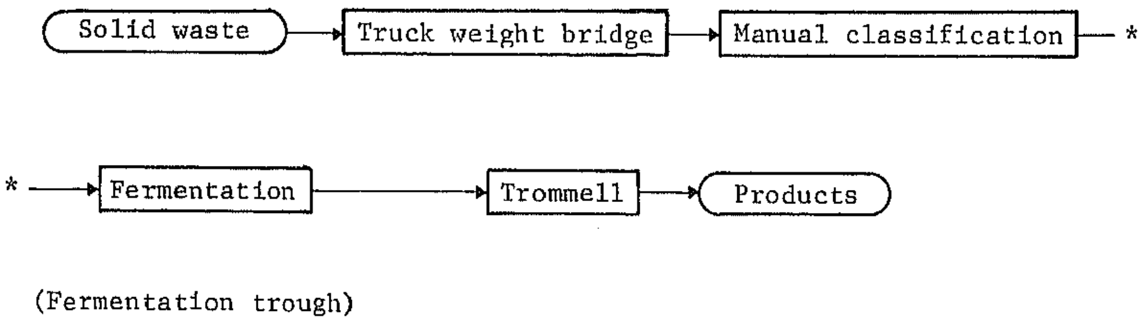
Aerated composting method is one of them.

This method was developed from aerated landfill which aims at decomposition of the organic materials in solid waste in an aerobic atmosphere by means of feeding air forcibly into the landfill site. Unsually, a fermentation trough is dug in the ground but, in Bangkok city, the trough should be made of concrete and set on the ground in order to prepare for the rise of groundwater level during the rainy seasons.

b. Concept of the plant operation

- The plant capacity was determined on the basis of capacity of the existing compost plants in Bangkok.
- Operating flow and material balance are shown in Fig. 4.3 to 4.5.
- Building : Slate-roofed

Fig. 4.3 Flow diagram of composting




c. Operating rate : 0.85

Operating rate of an existing compost plant is 0.85 in most cases. Operating rate of the compost plants to be contained in the master plan alternatives is determined to be 0.85.

(3) Future prospect of BMA compost

BMA presently relies upon composting for intermediate treatment. In this connection, some consideration was given to the future of BMA compost as described hereafter.

Fig. 4.4 Flow of the aerated compost plant facilities

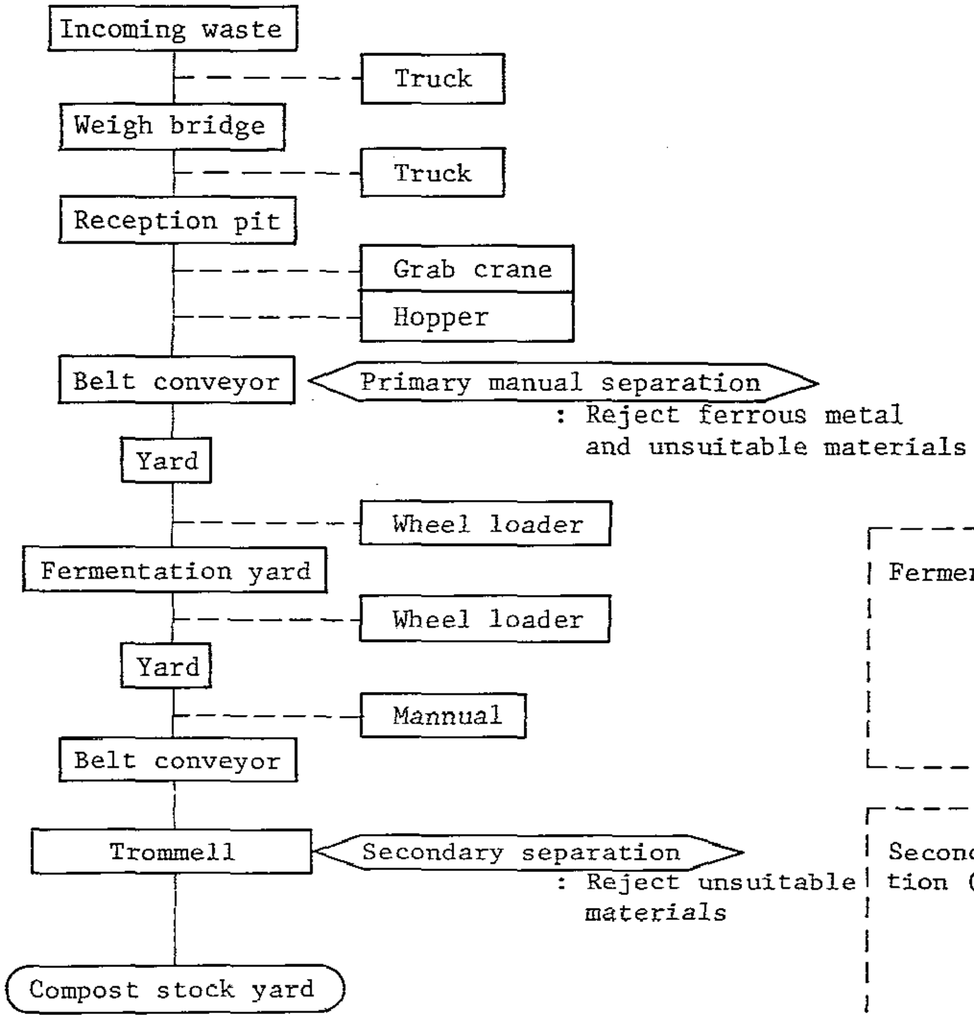
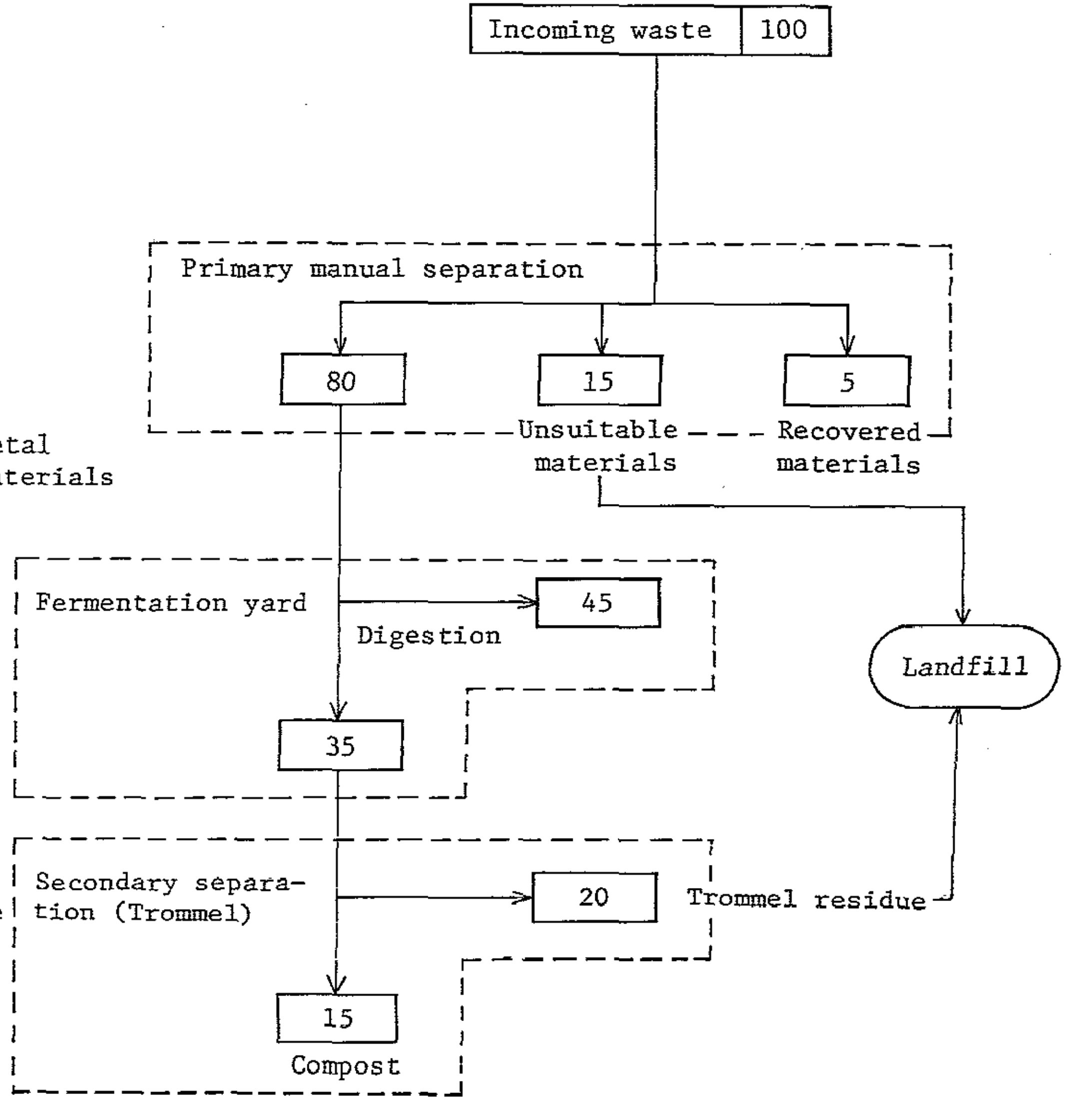



Fig. 4.5 Aerated compost plant material balance



i) A maximum permissible compost application volume in the case of considering the negative influence from heavy metal

The maximum permissible compost volume applicable to farm land was estimated based on British guidelines. This guideline specifies volume of hazardous heavy metals concentrated in soil which will be caused by application of sewage sludge to farm land, based on total volume restriction. Assuming the worst case, the maximum contents of mercury 15.40 mg/kg (sampled from On-Nooch compost before trommelling) and cadmium 21.1 mg/kg (sampled from Nong Khaem compost after trommelling) were determined from results of chemical analysis of compost (ref. Table 3.5) and taken for the estimation (ref. Appendix 4.7, Table AP4.5). Applying the above guideline to the result of the estimation, the conclusion was drawn that, if hazard by mercury should be avoided, the maximum permissible compost application volume will be approximately 4.3 t/ha per year provided application of the compost is continued every year for 30 years, and that, in the case of cadmium hazard, the permissible compost volume will be approx. 7.9 t/ha per year on the same condition as the case of mercury. Normal application volume of compost is estimated 10 t/ha per year, which exceeds the permissible volume. This means that, if normal application volume is continuously applied to farmland for 30 years, occurrence of any detrimental influence by heavy metal is possible. As mentioned above, however, this is an assumption of the worst case and, practically, the probability of occurrence of such case is almost negligible (zero).

Another estimation was made assuming average contents of mercury 6.56 mg/kg and cadmium 14.4 mg/kg. The results of this estimation revealed that the permissible compost volume will be 10.1 t/ha per year considering mercury hazard, or 11.6 t/ha per year considering cadmium hazard, for 30 years of continuous application.

Continuous use of compost as a soil improvement material for a 30 years-long period differs from common inorganic fertilizer and is less practicable; and in addition, heavy metal contained in BMA compost will be very much restricted by implementation of countermeasures proposed in the short-term improvement plan. The actual permissible compost volume therefore will be much larger; however, being conservative, it may be adequate to determine the current normal application volume 10 t/ha per year as a maximum permissible compost application volume.

ii) Compost sales price

Sales price of BMA compost in bulk is from 370 to 740 Baht per ton, and in 50 kg package from 700 to 1,100 Baht per ton. This price makes the cost for compost purchase sharing in a total agricultural management cost extremely high. If the present compost price remains constant, it will be hard to expand demand for compost in the future. Although the compost price depends upon the demand and supply, BMA should at least endeavour to offer compost at a reasonable price calculated on the basis not of production cost but rather the benefit to be gained by use of compost. The current world price is 40 Baht per ton on an average. (ref. Appendix 4.8 (3) ii) )

iii) Forecast of latent compost demand

70% of agricultural land in Thailand is occupied by paddy field; however, seeing the state of rice cultivation and considering compost quality, effect by application of compost to paddy field is questionable. Examples of compost application to paddy fields in foreign countries have incurred negative results. Use of compost may preferably be limited to fruit, flower and vegetable cultivation.

As detailed in Appendix 4.8 (3) iii), research questionnaire was made to estimate latent demand for compost taking farmland (588,000 rai) within 50 km from Bangkok city center as the study area.

Results of the research revealed that there would be latent demand for about 90,000 tons of compost annually provided that one ton of compost is applied to 10a of farmland every year. If this volume is to be produced in compost plants, the required total capacity of the plants should be approximately 1,900 t/d. Subtracting production capacity of the existing compost plants 1,120 t/d from this figure, the remainder of 800 t/d is still short. To fill this shortage, additional compost plants can be established.

Results of the research also implies that people appreciate and have interest in organic fertilizer.

To encourage the compost consumption, it is essential to organize compost supply channels and offer the compost at reasonable prices to the consumers.

iv) Measures to develop market for BMA's compost

For realization of the potential demand, it is an indispensable condition to make the compost lower in price, better and safe in quality, and easily obtainable in the market. To satisfy this condition, certain administrative measures should be undertaken related to compost quality and pricing. (ref. Appendix 4.8 (3) iv)

a. Administrative and political measures

- Concerning promotion of compost use, close mutual cooperation should be kept between the central and local authorities.
- Diversification of types of crops should be attempted and application of compost to economically worthwhile crops should be undertaken as much as possible.
- Since manual application of a large volume of compost to farmfield is hard work, utilization of machines or cattle should be promoted. For this purpose, the concerned authorities are required to provide the farmers with financial aid or other conveniences.
- To provide soil improvement in Northeast Thailand, use of compost in this region should be promoted politically.
- Diversified utilization of compost should be studied

such as mulching for protection of evaporation, covering soil of landfill and Boden Filter, other than the use as a soil improvement material.

- Public or/and private organizations should be established, which promote farmland reclamation by application of compost.

b. Compost quality

Although no particular problems are found with BMA compost for sale related to its maturity, nourishing effect and content of foreign materials, long-term use of compost may incur some problems caused by concentration of hazardous heavy metals as mentioned before. Therefore, in order to avoid hazard of heavy metal contents, attempts should be made to reduce the contents of non-compostable materials and to exclude dry batteries and glass through selection stages before or after the compost production process.

c. Price

- The type of package should be reconsidered from viewpoint of price suppression. It is recommended that emphasis replaced on the sales of compost in bulk since it saves on packing cost and stimulates mass sales.
- The compost supply depots should be set up close to the consumption areas in order to facilitate control of seasonal fluctuation of delivery, to save on transportation cost, and to maintain a smooth supply.

(4) Location of intermediate treatment facilities

Location of solid waste treatment facilities should be planned to realize effective and economical solid waste management activities in collection, transportation, intermediate treatment and final disposal, and to minimize any effect on the living environment around the facilities.

1) Preliminary examination

Prior to allocation of the facilities, the following items should be examined.

a. The future plans influencing the solid waste disposal facilities.

- Probability of change in the future City Plan.
- Change of solid waste composition and volume in the future beyond the projected term.
- Probability of change of collection method. (Introduction of classified-solid waste collection, for instance.)
- Probability of strengthening restrictions against pollution.

b. Planning of compound facilities

Construction of the following facilities in the same site should be studied, because it is advantageous from both the economical and pollution control points of view.

- Office, garage and repair shop for collection trucks.
- Night soil treatment facilities, sewerage facilities.
- Public facilities which utilize recovered energy.
  - Incineration plants generate large volumes of waste heat. Therefore, establishment of heat-consuming public facilities adjoining the incineration plant will be beneficial.

ii) Conditions for facility site selection

In selection of sites for solid waste treatment facilities, the following conditions should be taken into overall consideration.

a. Natural conditions

- Area

  The area should be wide enough to provide sufficient distance between the facilities and the neighbouring residents in order to mitigate nuisance of noise, vibration and odour, as well as to provide an adequate area for the scale of facilities.

- Land shape

  For an incineration plant, a flat site square in shape is desirable.

- Soil
- Topography

  Topography of the plant site should not be much affected by regular disasters, particularly by floods. Places where polarized air currents are apt to occur, such as nearby lakes and tall buildings, should be avoided.

- Climate

b. Land-use condition

- Specified area in accordance with the City Plan

  Proper areas for incineration plants are Mixed-use low density or Industrial areas.

  For compost plants and landfill sites, Agricultural areas are suitable.

- Scenic spots and places of historic interest

  The site should be located at remote places away from scenic spots and historic places.

- The future development of the city

  Influence of urbanization and possibility of change of the future land-use pattern should be taken into consideration.

- Harmony with the surrounding environment.

c. Traffic condition

Collection and transportation cost consumes a large part of the total solid waste management budget. For effective implementation of collection and transportation, the following items should be carefully examined.

- Correlation between the planned facility location and the planned collection and transportation area.
- Incoming solid waste volume to the facility.
- Manner of collection work.
- Transportation routes (Roads and waterways).
- Transportation measures (Trucks and barges).
- Road condition.
  - The present road condition and the future road construction plans should be studied.
- Traffic condition (Traffic congestion).

d. Utility service condition (serviceability of utilities)

- Electric power
- Gas pipelines
- Water supply
- Sewerage, or any facilities to accept effluent
- Telephone

e. Socio-economic environment conditions

- Public consciousness of the neighbouring inhabitants.
- Land price
- Number of people who have to be relocated
- Possibility of the land acquisition

iii) Areas necessary for establishment of intermediate treatment facilities.

a. Incineration plant

The required area for establishment of an incineration plant depends upon the type, capacity and number of incinerators and attached facilities to the plant. Judging from the experience in Europe and in Japan, the planned incineration plant in Section 4.3.2.(2).i) (plant capacity of 1,100 - 1,500 t/day, 3 units of waste heat boiler-attached continuous firing mechanical furnace, each with the capacity of 400 - 500 t/24h) requires about 50 $m^2$ for every t/24h of the plant capacity.

b. Compost plant

The site area required for a compost plant is very much influenced by the type of fermentation trough and period of fermentation.

Compared with high rate composting plants, aerated composting plants require wider areas mainly for their secondary fermentation area. If the period of the primary fermentation is assumed to be 60 days with aerated composting method, 110 $m^2$ per composting treatment ton (plant capacity) will be sufficient for establishment of the compost plant. If the compost residue is planned to be under for landfill at the plant site, an additional 240 $m^2$ for every ton (plant capacity) per day will be needed.

### 4.3.3 Intermediate treatment cost

In order to obtain basic data for calculation of intermediate treatment cost, an estimation was made of the construction cost of intermediate treatment facilities and their operation cost, based on the facilities planned in Sections 4.3.2.(2). These prices were converted into Thai-local prices in Section 4.5.

(1) Construction cost of intermediate treatment facilities

The construction costs in Japan as of 1980 are as follows:

i) Incineration plant

Ref. figure 4.6

ii) Compost plant

Ref. figure 4.7

(2) Operation and maintenance cost of intermediate treatment facilities

The cost to run (operate, repair and provide general management) intermediate treatment facilities in Japan as of 1980 was as follows:

i) Incineration plant cost

| | | |
|---|---|---|
| Personnel expenses | 3,300 yen/t | (solid waste) |
| All other expenses | 1,700 yen/t | ( -do- ) |
| Total operating cost | 5,000 yen/t | (solid waste) |

ii) Compost plant cost

| | | |
|---|---|---|
| Personnel expenses | 3,100 yen/t | (solid waste) |
| All other expenses | 1,000 yen/t | ( -do- ) |
| Total operating cost | 4,100 yen/t | (solid waste) |

Fig. 4.6 Construction cost of an incineration plant

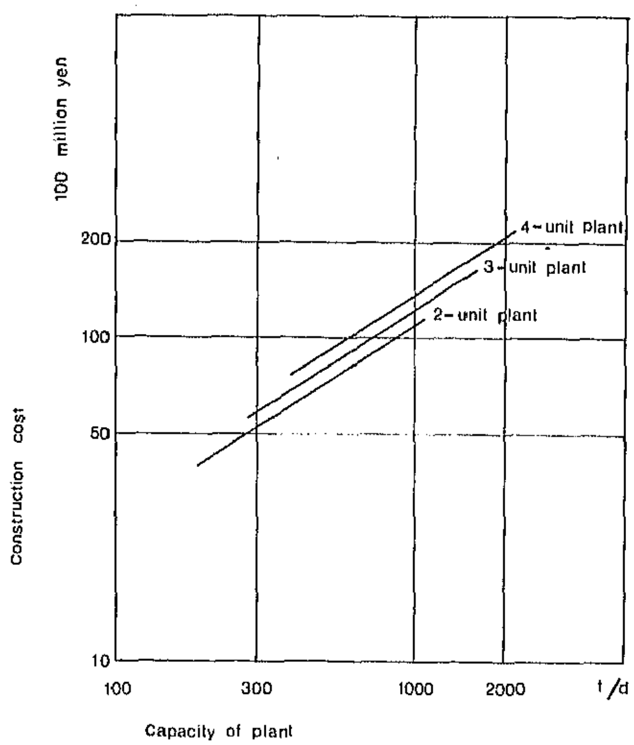
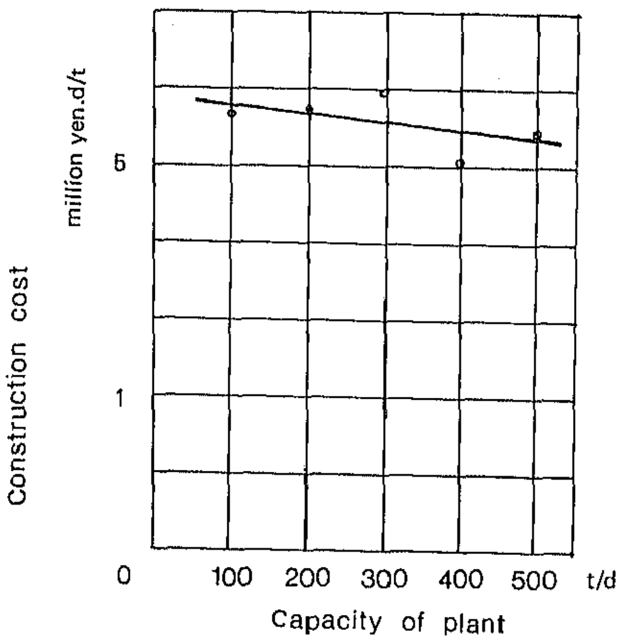



Fig. 4.7 Construction cost of a compost plant



## 4.4 Final Disposal System

### 4.4.1 Foreword

Establishment of final disposal system alternatives were executed in accordance with the work flow diagram which is shown in Fig. 4.8. Among these working items in Fig. 4.8, the detailed description of technical study for final disposal system alternatives and the basic consideration results for formulation of the final disposal system are shown in the Appendices 4.9 and 4.10.

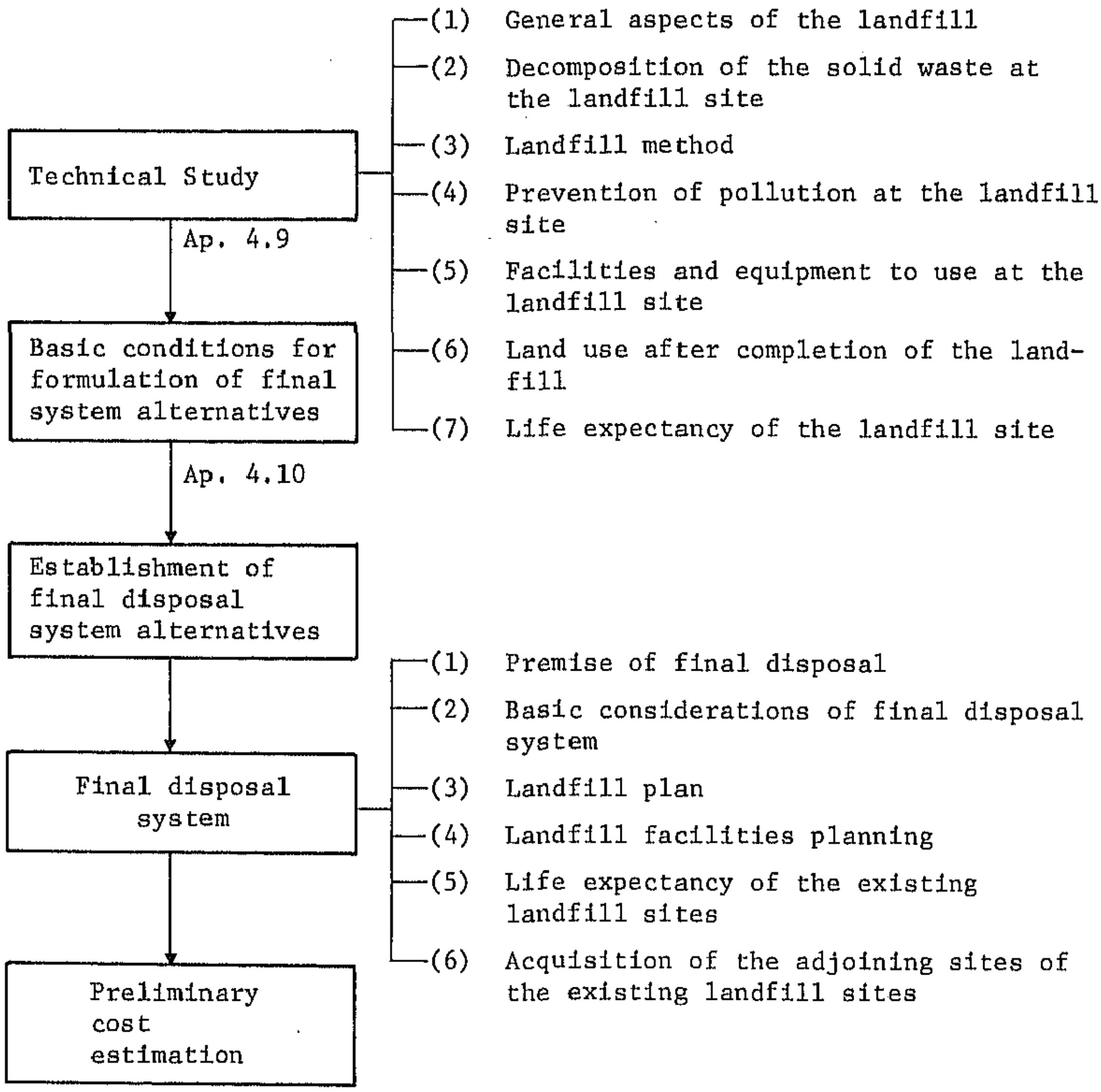
In this paragraph, to establish the appropriate Master Plan alternatives, final disposal system alternatives and preliminary cost estimation results of the final disposal system alternatives were presented.

### 4.4.2 Final disposal system alternatives

(1) Premise

It is difficult to prevent the occurrence of pollution from a final disposal site even though appropriate countermeasures have been executed. Therefore in order to minimize negative influence to the environment, the following conditions were considered to establish the final disposal system alternatives: to reduce the total solid waste landfill volume, to decontaminate the solid waste and to convert the solid waste so it can be used as landfill.

Fig. 4.8 Work flow for establishment of final disposal system alternatives




(2) Basic conditions for formulation of the final disposal system

i) Project life span

Target year for this study is the year 2000, but for the purpose of keeping the reliability of the proposed solid waste management system, the project life span for the final disposal system was determined as of the year 2010.

ii) Grade of final disposal site

- In order to minimize negative influence to the environment, suitable facilities for the following purposes should be attached to the final disposal site for solid waste storage, leachate collection and drainage, leachate treatment, improving imperviousness, rainwater drainage, prevention of solid waste diffusion, etc.

- Considering the climate of Bangkok city, the improved sanitary landfill method should be adopted.

iii) Pretreatment

Although solid waste pretreatment (pulverization) prior to landfill provides certain advantages (ref. Appendix 4.9. (3) iv)), it is economically inferior and operationally difficult. Hence it is not recommended for adoption.

iv) Landfill height and shape

There are three factors to determine landfill height: height of already-completed landfill in the existing site, landfill capacity to be secured, and the future utilization of the reclaimed land.

Considering these factors, average landfill height is determined to be 15 meters (3 meters x 5 layers) from the existing ground surface, except for the sites where construction of facilities are planned. For these sites, average landfill height will be 3 meters.

Some additional solid waste volume can be carried in after completion of landfill due to increased capacity resulting from solid waste subsidence but this will not be considered. Average slope gradient of the embankment of the landfill should be standardized as 1:3.

v) Maintenance and improvement of the existing landfill sites

- In preparing a landfill plan of the existing landfill sites, shape of already-completed landfill shall be regarded as unchangeable and the idea to remove already-landfilled solid waste shall be excluded from the plan.
- For environmental protection and early utilization of the reclaimed land, any applicable facilities shall also be attached to the completed landfill as necessary, such as rainwater collection, leachate treatment and gas discharge facilities.

vi) Sectionalizing landfill

At landfill sites which have larger landfill capacity and longer life expectancy like On-Nooch, one layer landfill shall be completed about one year.

Sectionalizing landfill makes it possible to construct facilities step by step according to the necessity, to reduce leachate treatment volume at one time, and to facilitate landfill operation control.

vii) Leachate treatment facilities

In Bangkok city, effluent from solid waste treatment facilities is not subject to the restrictions on effluent specified by the Factory Act; however, for the sake of precaution against negative influence on the environment, the restrictions of the Factory Act shall be taken as the standards which leachate treatment facilities should satisfy.

(3) Landfill plan

1) Pre-embankment sectionalizing landfill method and structure of embankment.

In the case of a site where landfill is newly started, a pre-embankment landfill method should be adopted.

In this method, the scheduled landfill area is enclosed by the previously-constructed embankment and solid waste is placed inside the embankment.

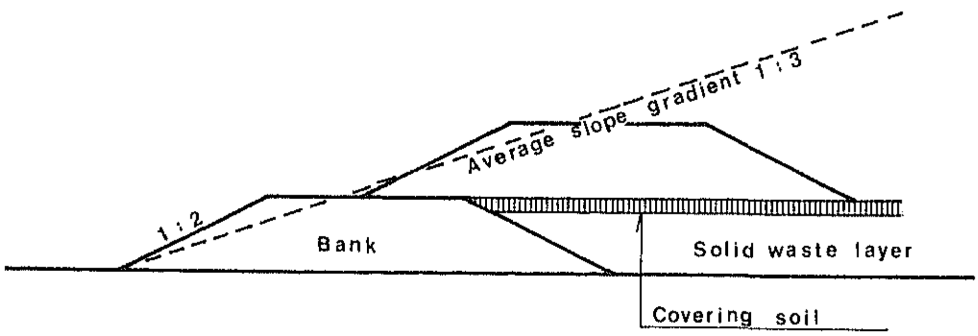
Some of the main advantages of this method are:

- facilititation of operation control
- protection of scenic environment
- prevention of diffusion of rank odour and waste
- prevention of leakage of leachate out of the site

a. Structure of embankment

- The shape of the embankment section, with slope gradient 1:3 on an average and the height 3 meters, is standardized for the following reasons. The embankment will be constructed step by step as the landfilling progresses. The shape of an embankment section is shown in figure 4.9.

Fig. 4.9 Model shape of embankment section (Average shape gradient 1:3)




Results of unconfined compression tests carried out at On-Nooch final disposal site indicate that the unconfined compressive strength of the soil layer 3 to 5 meters below the ground surface is from 0.93 to 1.95 $t/m^2$ or cohesion of 0.5 $t/m^2$ which is a relatively small value. If a sharp stress increase is added to such ground, it could cause instability or slide failure of the ground. Therefore, the embankment should be constructed in lifts, so that an increase in the soil shear strength bearing capacity can be anticipated.

- Width of the embankment should be determined considering prevention of leachate permeation and use of the flat top of the embankment as an access road.

b. Clayey soil dug up from the landfill site is to be used for construction of the embankment. Use of surplus compost as the construction material of inner part of the embankment will be considered.

ii) Thickness of solid waste layer and overlay

- The standard thickness for each solid waste layer, including the thickness of cover soil should be 3 m.
- The standard thickness of cover soil over the layer should be 30 cm.
- Overlay should be made at the end of landfill work day as a rule. However, if it is difficult to this work at the end of the day because of the work progress or availability of covering it should be made within a week.
- Compost residue, surplus compost and incinerator ash are usable as substitutes for covering soil.
- To increase the effects of the overlay, soil dug up from the landfill site should be mixed up with the substitutes described above and used for covering soil.
- Thickness of final overlay shall be kept more than one meter, preparing for uneven subsidence and rainwater permeation. Soil condition of the final overlay preferable by clayey soil.

(4) Facilities planning

Basic conditions for formulation of the final disposal site and the facilities planning based on the landfill planning are described as follows:

i) Solid waste storage structure

Embankment should be constructed equal to the progress of the landfill work.

ii) Leachate collection and drainage facilities

- It is inevitable to store the intensive rainwater during rainy season inside the landfill site for some period of time. To control this rainwater, leachate collection and drain facilities should be installed inside the foot of the embankment slope gradient. For the better functioning of the disposal site, installation of leachate collection and drainage facilities at the bottom of the landfill site also is desirable but, from an economical point of view, the installation at the bottom should be excluded from the plan.

a. Structure of leachate drainage

Leachate drainage consists of pipes with small holes on their circumference and crushed stones as covering material. Such a model structure is shown in figure 4.10.

In determining the hole size and the pipe diameter, the probability of choking the holes and subsidence of the pipes should be taken into account.

b. Leachate conveyance equipment

It is not preferable to permit leachate to stay inside the landfill site. For the prompt discharge, leachate collection pits should be installed inside the landfill site and collected leachate should be pumped out to the reservoir pond. Each pit should have a separate pump. (ref. figure 4.11)

Fig. 4.10 Model structure of leachate drainage (for new landfill site)

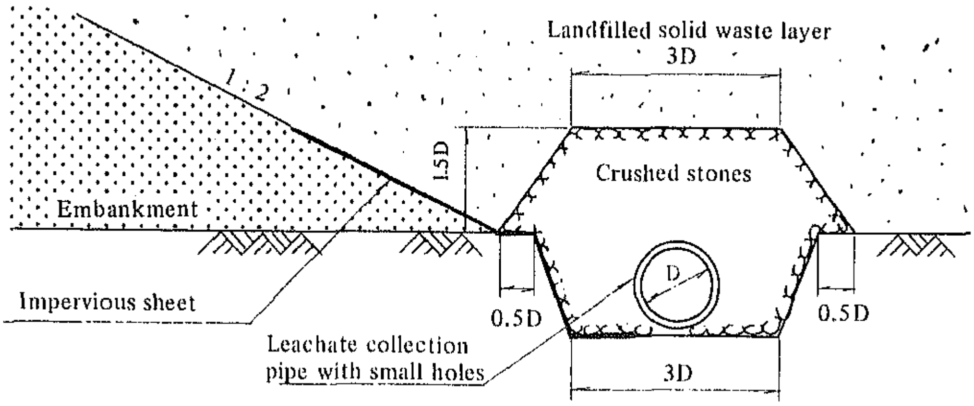
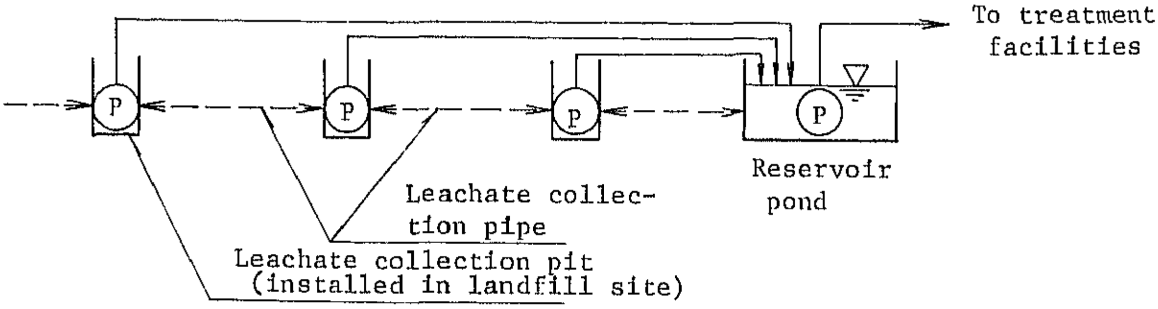



Fig. 4.11 Leachate pumping system



iii) Leachate reservoir pond

A leachate reservoir pond should be constructed to maintain the operation of the leachate treatment facilities.

The function of the reservoir pond is not only to ease the treatment facilities from quantity overload but also to improve the quality of and stabilize the leachate. The type of reservoir pond should be constructed as an impervious type.

Capacity of the reservoir pond should be determined by deducting the treatment facilities' capacity and leachate evaporation volume from the average rainfall occurring during the rainy season.

If the landfill volume is large, the reservoir pond should be constructed with a large capacity. To avoid overestimate planning of the reservoir pond capacity and considering economy, it should be considered to the leachate should be kept for some period in the landfill sites.

iv) Impervious facilities

Results of soil analysis at On-Nooch final disposal site indicate soil permeability coefficient from 10-7 to 10-8 cm/s, which is regarded as impermeable. There will therefore be no need for creating an impervious structure at the bottom of the landfill site.

To prevent permeance through side walls, the following countermeasures should be adopted.

- Leachate collection pipes should be installed at a lower level than the landfill solid waste layer.
- The embankment should be made of impervious clay.

Some survey reports indicate that Bangkok clay layer contains a thin sand layer which may permit flow horizontally; accordingly, if high permeability is confirmed, certain countermeasures such as construction of a sheet pile cutoff wall must be considered.

v) Rainwater collection and drain facilities

a. Completed landfill site

Water drainage ditches should be curved on the surface of the completed landfill to reduce flow of rainwater into landfill and, consequently, to prevent uneven subsidence of the landfill surface. The ditches, with a small cross section, should be placed to achieve a certain density.

b. Countermeasure against floods

To check inflow of flood rainwater into the final disposal site, small embankments should be constructed on boundary line of the final disposal site. The embankment will also function as a buffer green belt.

vi) Gas discharge facilities

For safety of landfill work and earlier stabilization of landfill, the gases generated from landfill layer such as methane and hydrogen sulfide should be exhausted in the proper manner during the landfilling operation.

vii) Prevention of solid waste diffusion

Prevention of solid waste diffusion will be achieved by implementation of pre-embankment landfill and on-the-day overlay.

viii) Control and management facilities

The following facilities should be set up. In addition, equipment for weighing and recording of incoming solid waste volume should be installed by all means as it is essential for proper operation of the final disposal site.

- Facilities relating to collection trucks and incoming solid waste: access roads, truck control facilities, reception facilities, and car-wash equipment.
- Facilities for management, maintenance and other miscellaneous purposes: office, rest room, repair shops, warehouse, garages, fire-extinguishing equipment, and disinfection equipment.
- Leachate treatment facilities. (ref. paragraph ix) below)

ix) Leachate treatment facilities

a. Determination of leachate treatment capacity

Quality and quantity of leachate fluctuated by hour, day, season and by year. Compared with factory effluent, fluctuation of leachate is large in both quality and quantity.

Leachate treatment capacity is usually determined to enable the treatment facilities to cope with average leachate volume during the rainy season. In the case of Bangkok city, however, if the capacity should satisfy the requirement during rainy seasons, huge treatment facilities are necessitated despite the fact that no leachate for treatment is generated during dry seasons. Therefore, leachate treatment capacity in Bangkok city is planned in the following manner:

Based on the model water balance of the final disposal site (figure 4.12), the following equations were established:

$$R = Es + Qo + Q$$

Where, R : Rainfall (mm)

Es : Evaporation (mm)

Q : Permeating water (mm) $Q = Q_1 + Q_2$

$q$ : Inflow water (mm) $q = q_1 + q_2$

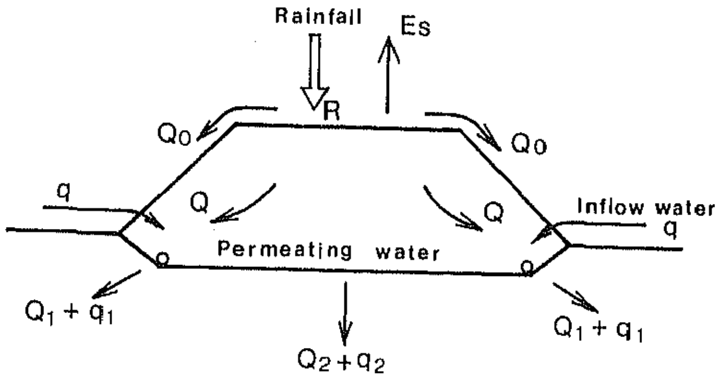
If $q = 0$, $Qo = 0$ and $Q_2 = 0$, that is to say, there is neither surface flow nor inflow nor permeance, leachate volume to be treated $Q_1$ is expressed by the equation below:

$$Q_1 = R - Es$$

The leachate treatment capacity ($Q_1$) of the completed landfill where surface water flow ($Qo$) is discharged to the outside of the landfill site was established as follows.

$$Q_1 = R - (Es + Qo)$$

Fig. 4.12 Water balance model




Where,
- R : Rainfall (mm)
- Es : Evaporation (mm)
- Qo : Surface water flow (mm)
- Q : Permeating water (mm)
- $Q_1$ : Leachate (Rainfall treatment volume ) (mm)
- $Q_2$ : Permeating water to the underground (Rainfall) (mm)
- q : Inflow water to the landfill site (Flood and underground water) (mm)
- $q_1$ : Leachate (Inflow water treating volume) (mm)
- $q_2$ : Permeating water to the underground (Inflow water permeating volume) (mm)

Average rainfall and evaporation volumes in Bangkok city are given in Table 4.2. (Ref. Appendix 4.10 for further details)

Table 4.2 Average rainfall and evaporation volumes in Bangkok
(Average of the years from 1951 to 1975)

(Unit : mm)

| Period | Rainfall | Evaporation |
|---|---|---|
| Per annum | 1,543.9 | 995.9 |
| Rainy season | 1,349.9 | 438.3 |
| Dry season | 194.0 | 557.6 |

During the dry season, evaporation volume far exceeds rainfall; accordingly, leachate volume for treatment is negligible.

Leachate treatment capacity Qy ($m^3$/year) is obtained from the equation below:

$$Qy = \frac{1}{1000} (C_1 A_1 + C_2 A_2) \cdot I$$

Where,

Qy : Leachate treatment capacity ($m^3$/year)

$C_1$ : Coefficient of seepage in a working section

$C_2$ : Coefficient of seepage in a completed section

$A_1$ : Water collection area where landfill operating ($m^2$)

$A_2$ : Water collection area where landfill completion ($m^2$)

I : Rainfall during the rainy season (R)

- Permeating volume (Es) (mm)

Coefficient of leachate is depending on the shape of landfill and rainfall condition, however, the following figures are established as $C_1 = 1.0$, $C_2 = 0.4$.

b. Presupposition of leachate quality

For planning of leachate treatment facilities, the quality of leachate to be treated was assumed as follows bases on the investigation results of the leachate sampled at the base of the landfill slope and inside the mound at the On-Nooch landfill site.

BOD : 200 ppm

SS : 200 ppm

c. Planned quality of treated leachate

Effluent quality stipulated in the Factory Act is taken as a target of leachate treatment as stated below:

BOD : 20 ppm

SS : 30 ppm

pH : 5 - 9

d. Leachate treatment method

When BOD and SS treatment are required, the treatment should be based on "Biological treatment + Chemical coagulating sedimentation treatment". Addition of chemical coagulating sedimentation will assist reduction of BOD and, at the same time, enable leachate to reduce COD to 40 to 50% of its original value.

Coagulating sedimentation is effective also for removal of heavy metals.

The biological treatment facilities should have flexibility against fluctuation of the treatment volume and also provide ease of operation and maintenance. Especially when the activated sludge process is adopted, proper arrangement is required to prepare for dry-up of leachate and careful operation by experienced specialists. The activated sludge process is particularly sensitive to fluctuation of leachate quantity and quality.

Reviewing merits and demerits of various leachate treatment methods, the two methods described in figure 4.13 were chosen.

Both leachate treatment methods are also advantageous in terms of construction cost and ease of operation and maintenance.

Arranging two or three leachate treatment system of the same method in a row should be considered to prepare for fluctuation of leachate volume.

(5) Life expectancy and duration of use of the existing landfill sites

Life expectancy of the existing 6 final disposal sites was estimated for the following three cases. The results of the estimates are shown in Appendix 4.11.

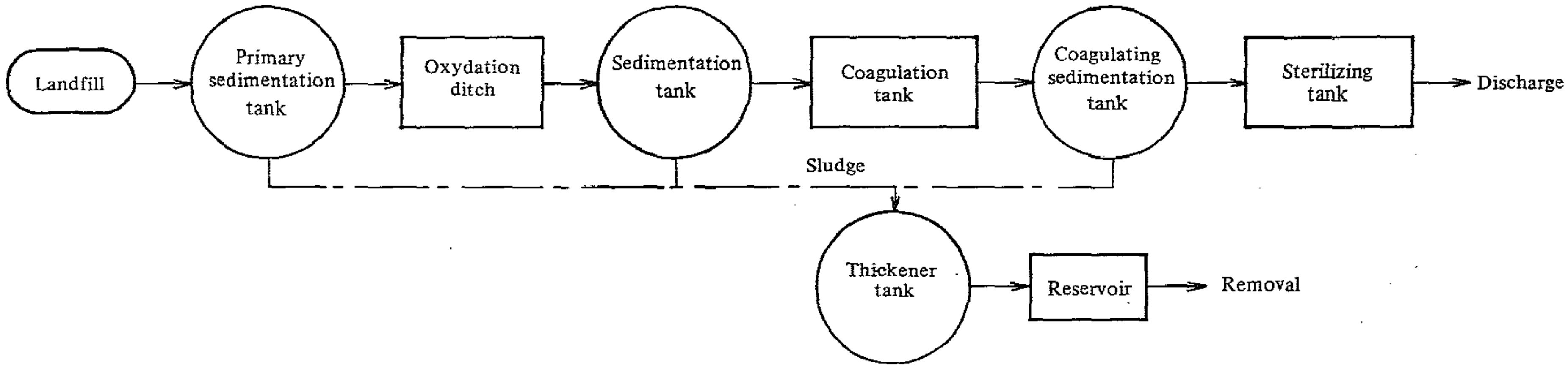
Case 1: For convenience of use of the reclaimed land in the future, flat landfill (3 m high) is applied over most of landfill site.

Case 2: Considering expansion of capacity (extension of life expectancy), mound landfill (15 m high) is applied to most the area except the portion where the existing compost plant site and administration facilities are planned for the future.

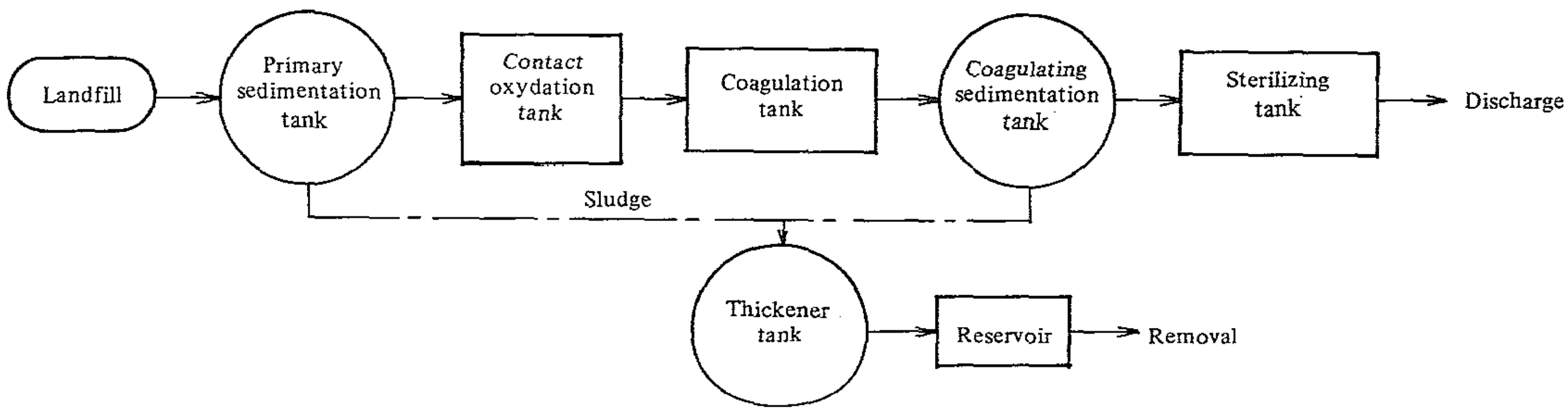
Case 3: In addition to case 2, the existing compost plant is assumed to close down and the site is reclaimed with mound landfill (15 m high).

Fig. 4.13 Leachate treatment process flow

① Oxydation ditch method

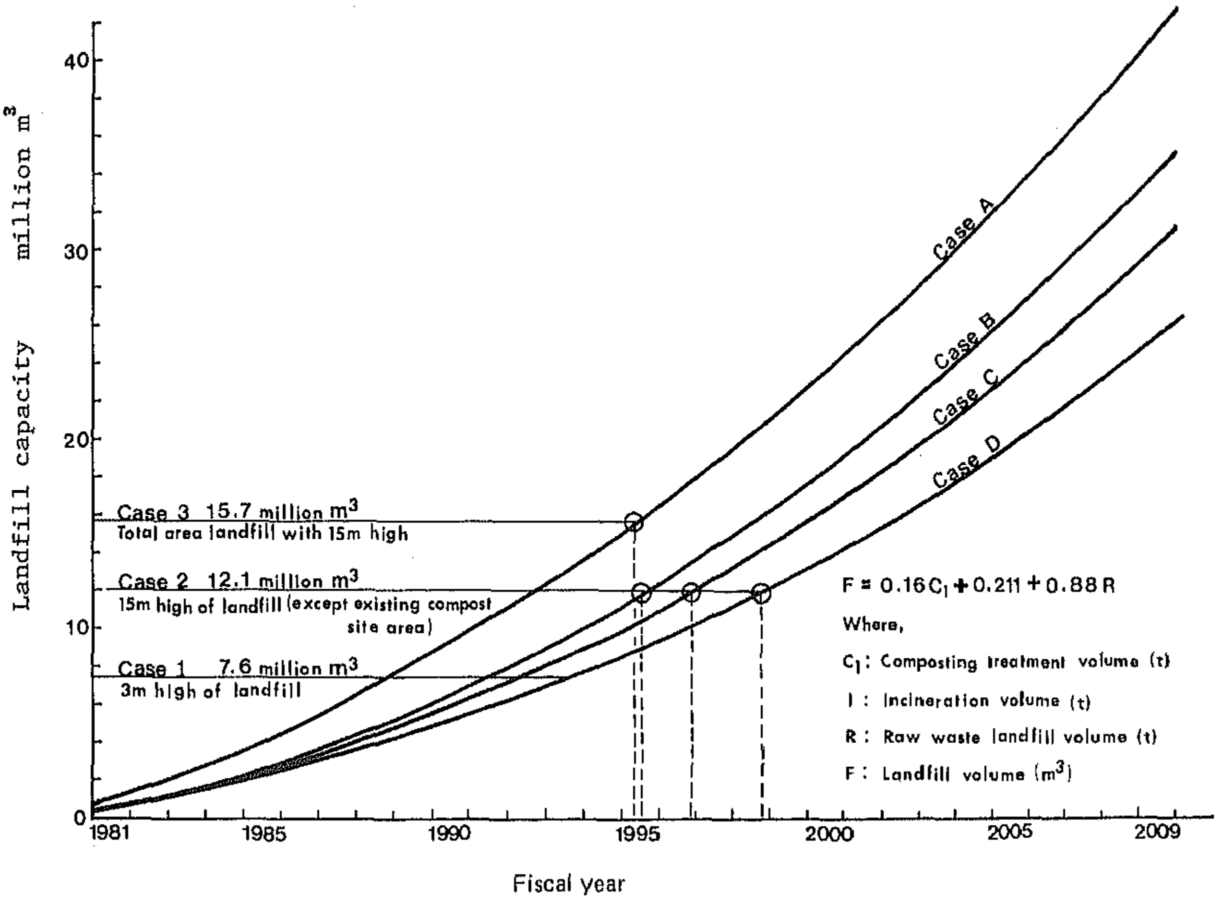



② Contract oxydation method



Based on the life expectancy estimated for the above cases, the duration of use of the existing landfill sites was calculated. For this calculation, four alternative cases were considered. Based on these four alternative cases, evaluation of the life expectancy of the existing landfill sites by solid waste disposal system combinations is shown in Fig. 4.14.

Fig. 4.14 Evaluation of life expectancy of the existing landfill sites




Case A (Total volume landfill):

The existing compost plants are assumed to be closed down; therefore, the total volume of the planned collection volume is landfilled.

Case B (Continuation of the existing solid waste management system):

The present treatment capacity 1,120 t/d of the existing compost plant is maintained in the future.

Case C (Enlargement of compost production facilities):

In addition to the present total treatment capacity 1,120 t/d of the existing compost plants, new composting facilities with a total treatment capacity 800 t/d are established by the year 2000.

Case D (Combination of composting, incineration and landfill):

In addition to Case B, incineration plants with a total capacity of 1,200 t/d are established by the year 2000.

In the case of total volume landfill (Case A), the landfill capacity achieves a maximum volume but the solid waste volume which is necessary to dispose is also a maximum, therefore, the life expectancy of the landfill site is the shortest. In the Case of B, C and D, the maximum landfill volume will be determined by Case 2. The landfill sites will reach their life expectancy before the year 2000.

(6) Acquisition of the adjoining sites for the existing landfill sites

The capacity of the existing landfill sites does not satisfy the demand in the future. The acquisition of additional land for future demand is necessary before the year 2000 even though any alternative case may be applied. In this section, the following conditions should be taken into considerations:

i) Status of the existing landfill sites in the Master Plan

Continuous use of the existing landfill sites in the future will be beneficial not only based on availability of the sites and the related facilities, but also ease of the site expansion. The large-scale landfill is advantageous in operation, maintenance and in economy. Therefore, utilization of the existing landfill sites is taken as policy for formulation of final disposal system in the Master Plan. In the case of shortage of landfill sites in the future, the adjoining open space to the existing landfill site is expected to be acquired as much as possible, except Tung Kru landfill site which is specified in the land-use plan of the year 2000 to be low density residential and commercial mixed-use area.

ii) Location and capacity of new landfill sites establishment

In the case of the existing landfill sites capacity does not satisfy the future demand, it is recommended to acquire the additional land in the adjoining sites of the existing landfill sites. Even after this countermeasure has been applied, if the capacity is not satisfactory, the new landfill sites should be considered. For establishment of new landfill sites, the following factors should be considered.

a. Conditions for additional site location

- Transport efficiency

  Transportation is a large part of solid waste management cost; therefore, location of landfill site should be selected for efficiency of transportation.

- Consistency with the future land-use plan

  Due to the nature of landfill, location of additional landfill sites should not be selected in those areas which are specified in the future land-use plan as active areas such as residential or commercial areas or densely populated areas.

- Economic conditions

  Location of the final disposal site should be determined based upon general examination of transportation cost, maintenance and operation cost, etc.

- Conditions relating to environmental preservation

  Location of the final disposal sites should be selected in areas where operation of the disposal site is less influenced by daily life of the neighbouring inhabitants, less contamination to water for fishery and agricultural use, and less deterioration to landscape and environment.

- Other conditions

  Topography, geology, disaster prevention, etc.

b. Selection of final disposal site

Most of conditions mentioned above can be commonly applied to selection of a compost plant site.

Accordingly, if acquisition of adjoining sites to the existing landfill sites becomes impossible for any reason, the proposed sites for new compost plants or their adjoining sites could be substituted for new landfill sites.

c. Scale of final disposal site

A moderate scale of a final disposal site is determined based on various factors such as solid waste collection area, solid waste volume to the landfilled, duration of use of the site, landfill method to be adopted, and so forth. The design of a final disposal site is desired to permit a life span of at the least ten years since it requires a considerable amount of investment for landfill and control facilities that makes the site operation uneconomical if it is used for a relatively short term.

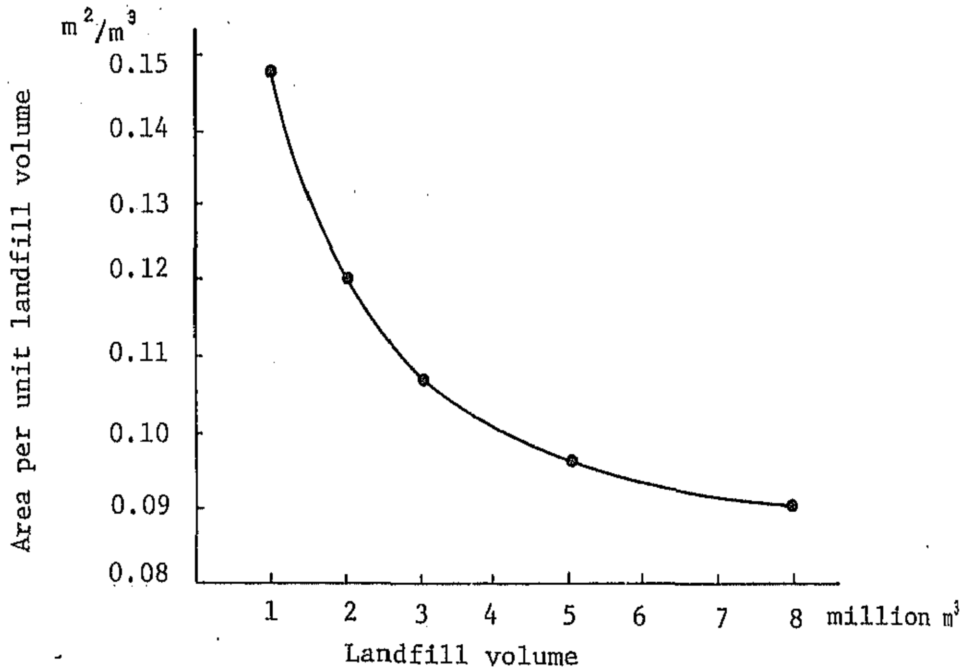
The relation between landfill volume and unit area is shown in figure 4.15.

### 4.4.3 Cost required for establishment of final disposal system

(1) Facilities construction cost

Based on the criteria established in Section 4.4.2 the facilities construction cost of the final disposal system was estimated. By this criteria, final disposal will be executed with control and management facilities such as environmental preservation facilities, gas discharge facilities and final over lay on the solid waste layer. As a result, facilities construction cost were estimated to be 900 yen per ton of raw waste landfill disposal and after the conversion into Thai local currency, it was estimated to be 50 Baht per ton of raw waste landfill disposal and 42 Baht per ton of incineration residue disposal, respectively.

Fig. 4.15 Landfill volume and unit area
(h = 15.0 m square site)




(2) Maintenance and operation costs

i) Number of workers required for landfill work

The relation between landfill volume and number of landfill workers, unit disposal volume are shown in Fig. 4.16, 4.17. Based on these Figures, number of workers required for one ton of landfill work was assumed to be 0.03 persons. (Apply this figure for the landfill site where the disposal volume is more than 50 tons/day)

ii) Landfill equipment

Assuming landfill work including overlay for each 3 meter thick solid waste layer is carried on by an ordinary bulldozer, working efficiency of the bulldozer per hour was estimated to be as follows:

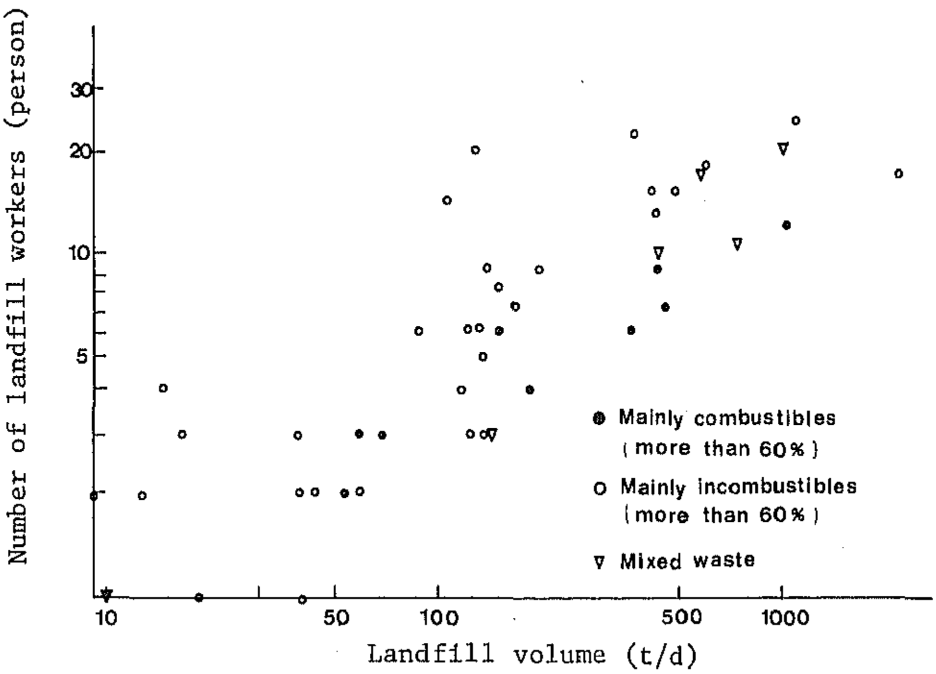
76 $m^3/h$ by a 11 t class bulldozer (damp ground type)

104 $m^3/h$ by a 21 t class bulldozer (damp ground type)

45 $m^3/h$ by a 0.6 $m^3$ class backhoe (for scraping of covering soil)

In addition to the above equipment, the landfill site should be equipped with indispensable machines such as dump trucks, patrol cars, fire extinguishers, sterilizers, water sprinklers, etc.

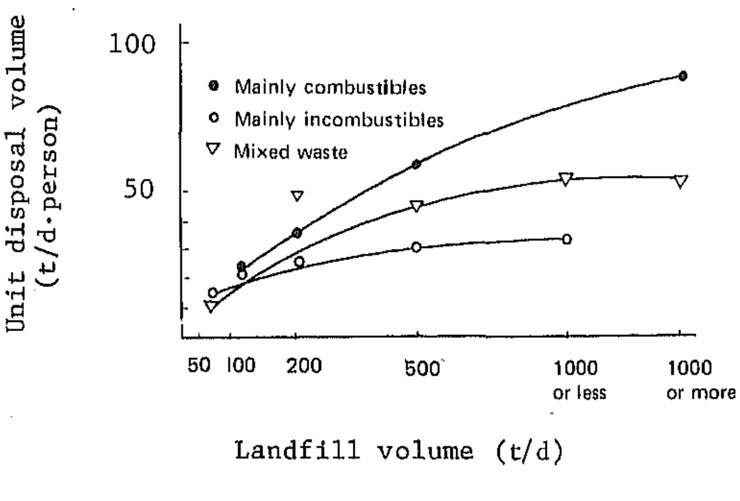
Fig. 4.16 Landfill volume and number of workers




Note 1. Incl. receptionists and controllers
2. Excl. operators of leachate treatment facilities

Source : 1980 report by Japan Waste Management Association

Fig. 4.17 Work volume per worker




Source: 1980 report by Japan Waste Management Association

iii) Operation and maintenance costs

Based on the experience of Tokyo Metropolitan Government, operation and maintenance costs for final disposal sites were estimated as shown in Table 4.3.

The costs were further converted into Thai local currency and the result was 70 Baht per ton of raw waste and 57 Baht per ton of incineration residue, respectively.

Table 4.3 Operation and maintenance costs (per ton of solid waste)

| Item | Amount (yen) | Content |
|---|---|---|
| 1. Landfill work cost | 1,700 | Wages for landfill and overlay work, equipment, pollution prevention, and others |
| 2. Facilities operation and maintenance cost | 364 | Landfill facilities (leachate collection and drain, etc.), office, reception, electricity, water, etc. |
| 3. Leachate treatment facilities operation cost | 36 | |
| Total | 2,100 | |

## 4.5 Appropriate Master Plan Alternatives

### 4.5.1 Formation of solid waste management system alternatives

(1) Components of solid waste management system

In order to establish the Master Plan for solid waste management system from solid waste generation to the final disposal, four main components of the system are considered: collection, transportation, intermediate treatment and final disposal. These components are the solid waste management systems (hereafter referred to as the systems). For formation of solid waste management system alternatives, the Study team has adopted the following system alternatives:

i) Collection (discharge)

- Mixed discharge and mixed collection are assumed.
- At-station collection is assumed and door-to-door collection will be applied according to character of the areas.

ii) Transport

- Direct transport by collection trucks to the processing plants and disposal sites (Land transport)
- Transfer from collection trucks to conveying trucks or barges (Land and water transport)

iii) Intermediate treatment

- Utilization of existing composting plants
- Establishment of aerated composting plants
- Establishment of incineration plants

iv) Final disposal

- Application of sanitary landfill method

(2) Basic alternatives of systems

All possible systems were listed and are described in Section 4.3.2. Seven basic alternatives of systems were devised from combinations of three elements: two kinds of intermediate treatment systems (i.e., compost plant and incineration plant), and one type of final disposal system.

The seven basic alternative types were further subdivided into 20 cases as shown in Table 4.4 according to the differences of transport mode (directly or with some transfer) and compost plant capacity (based on either the present capacity or forecast of the latent demand for compost).

Table 4.4 Master Plan alternatives (20 cases)

| | Alternative type | Case No. | Collection | Transport | | Intermediate treatment | | | Landfill*3 | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Direct | Transfer | Composting*1 Existing capacity | Composting*1 Expanded capacity | *2 Incineration | Solid waste | Processed waste | |
| A | Landfill only | 1 | O | O | | | | | O | | |
| | | 2 | O | O | O | | | | O | | |
| B | Composting only *4 | 3 | O | O | | O | | | | O | |
| | | 4 | O | O | O | | O | | | O | |
| C | Incineration only *4 | 5 | O | O | | | | O | | O | |
| | | 6 | O | O | O | | | O | | O | |
| D | Landfill & composting | 7 | O | O | | O | | | O | | The same case as the existing system. |
| | | 8 | O | O | O | O | | | O | | |
| | | 9 | O | O | | | O | | O | | |
| | | 10 | O | O | O | | O | | O | | |
| E | Composting & incineration | 11 | O | O | | O | | O | | O | |
| | | 12 | O | O | O | O | | O | | O | |
| | | 13 | O | O | | | O | O | O | | |
| | | 14 | O | O | O | | O | O | O | | |
| F | Incineration & landfill | 15 | O | O | | | | O | O | | Solid waste from central area shall mainly be incinerated. |
| | | 16 | O | O | O | | | O | O | | |
| G | Landfill, composting & incineration | 17 | O | O | | O | | O | O | | Solid waste from central area shall mainly be incinerated |
| | | 18 | O | O | O | O | | O | O | | |
| | | 19 | O | O | | | O | O | O | | |
| | | 20 | O | O | O | | O | O | O | | |

*1 Existing capacity = 1,120 t. Expanded capacity = 1,920 t.

*2 Incineration will be made by the waste heat boiler-attached incinerator for the purpose of thermal energy recovery.

*3 Alternative landfill sources are raw waste landfill and rejected waste or residue landfilling, which are discharged from intermediate treatment process.

*4 The residues after the processing are disposed of at landfill sites.

## 4.5.2 Planning the location of intermediate treatment and final disposal facilities

The planning of location of facilities should realize the shortest handling time and the most economical solid waste management system covering collection, transportation, intermediate treatment and final disposal. It should also contribute to the protection and preservation of the natural and living environment.

(1) Examination basis

In selecting the location of solid waste treatment and disposal facilities, it is essential to consider distribution of solid waste generation, in the other words, the generation volume in each area. In accordance with the distribution of generation volumes and the items described in Section 4.3.2, the applicable location of the facilities were determined.

(2) Location

i) Location of intermediate treatment facilities

Considering the items mentioned in paragraph (1), the applicable sites for construction of intermediate treatment facilities were surveyed, examined and selected in the following manner.

a. Adequate areas for intermediate treatment facilities

Those areas which are planned in the land-use plan for the year 2000 to be high density residential, commercial mixed use areas (an area within about 5-kilometer radius from the city center) were excluded from the study areas for construction of intermediate treatment facilities in order to minimize possible environmental conflicts.

b. Incineration plants

In general, for transport efficiency and incineration efficiency, incineration plants should be constructed as near to solid waste generation points as possible.

Incineration plants are less influential to the surrounding environment; accordingly, they can be set up near the city center providing a site is obtainable. From this point of view, surrounding areas in the above mentioned approximate 5-kilometer radius area were considered suitable areas for incineration plants. Consequently, sites around which urbanization has not progressed are much sought. The sites should also be accessible from main roads (including the future road network) and rivers, and be available for property acquisition.

For the convenience of collection and transport simulation, one site was selected in each suitable zone. As a result, 12 sites were selected around the outskirts of city center as possible sites for construction of incineration plants. (Refer to Fig. 4.18)

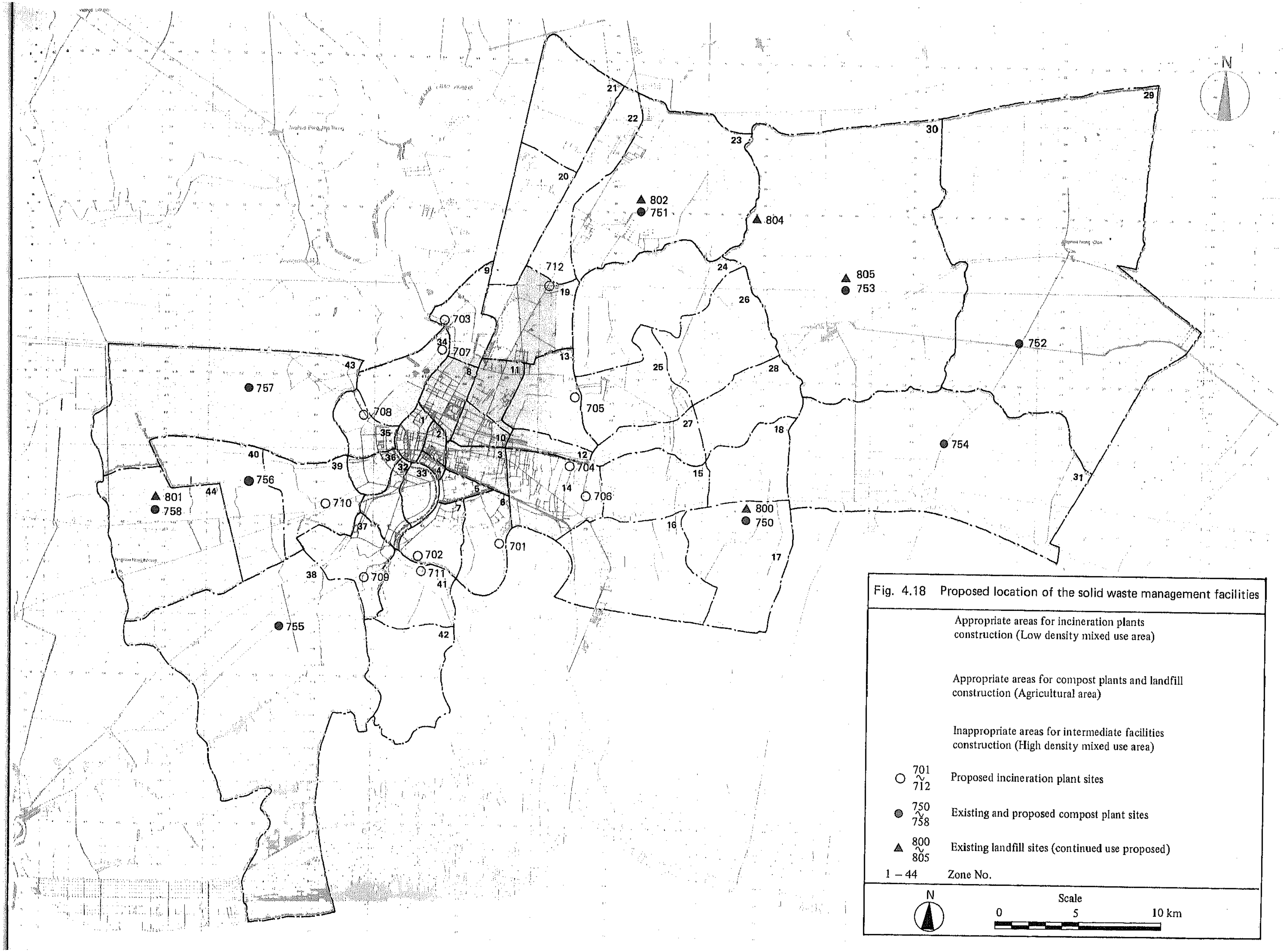



Fig. 4.18 Proposed location of the solid waste management facilities

Appropriate areas for incineration plants construction (Low density mixed use area)

Appropriate areas for compost plants and landfill construction (Agricultural area)

Inappropriate areas for intermediate facilities construction (High density mixed use area)

○ 701 ~ 712 Proposed incineration plant sites

● 750 ~ 758 Existing and proposed compost plant sites

▲ 800 ~ 805 Existing landfill sites (continued use proposed)

1 – 44 Zone No.

N

Scale

0 5 10 km

Solid waste generation volume in the areas encircling these 12 sites happens to be nearly equal to the generation volume from the other areas of the city. This means that the selected sites are satisfactory from viewpoint of transport efficiency.

c. Compost plants

Location of compost plants should be determined based on consideration of influences to the surrounding environment (such as odor), avoiding construction of plants in the central residential and commercial areas, and convenience of supplying compost products to consumers. Based on these aspects, the green areas specified by Land-use plan for the year 2000 were taken as possible areas to construct compost plants. One site was selected in each suitable zone after taking related factors into account such as relations with the existing and the future main radial trunk roads, with the location of the existing compost plants and with the utilization of the planned Outer Ring Road. As a result, 9 sites were selected as suitable compost plant sites outside the city center area (about 20 to 30 km for 5 sites on the Bangkok side and about 15 km for 4 sites on the Thonburi side).

On the basis of these site selection conditions, a vacant place survey was conducted and the result was shown in Appendix 4.12.

ii) Location of final disposal sites

In accordance with the policy of final disposal sites mentioned in Section 4.4.2, the existing landfill sites excluding Tung Kru are planned to be utilized in the future as follows:

a. On-Nooch

b. Nong Khaem

c. Ram Intra

d. Bung Tanode

e. Bung Phrayasalum

There is presently no function of landfilling at Nong Khaem, but to cope with increasing solid waste volumes in the future, the neighbouring lands of the existing Nong Khaem compost plant should be acquired as a landfill site.

iii) Planning transfer facilities location

a. Use of waterway (Land-to-river transfer)

The purpose of land-to-river transfer is to transport solid waste collected in the central business district to the incineration plants along the Chao Phraya river since transport on the waterway has higher transport efficiency.

Field investigations to locate suitable vacant lots for the construction of transfer facilities were made in each zone among settled 44 zones along the Chao Phraya river (zone number 1, 2, 4 and 5) and one site each was found in zone numbers 1 and 5. Due to rapid urbanization and development along the Chao Phraya river, other places on the Bangkok side of the river were unable to be selected as transfer station sites.

b. Road transport (Land-to-land transfer)

A comparison of transport costs was made between a case of solid waste transfer from collection trucks to conveying trucks and a case of the direct transport. The conclusion was that the transfer method would not be effective if the road distance from the collection point to the destination was less than approximately 12 kilometers.

Accordingly, the transfer method was planned to be applied in principle for cases of transporting solid waste to remote compost plants and final disposal sites located in the suburban areas. Several sites were considered as suitable land-to-land transfer sites; therefore, the centers of each zone were assumed as transfer sites for facilitating simulation.

### 4.5.3 Collection and transport simulation

The purposes of collection and transport simulation are:

1) to produce an optimum system from a certain mathematical model, which minimizes costs required for collection and transport, intermediate treatment and final disposal
2) to determine the location, scale and number of the intermediate treatment facilities and final disposal sites,
3) to formulate an appropriate transportation plan, in accordance with the above produced optimum model system.

In a sense, this simulation can be called solid waste management system simulation. Solid waste management cost used in this section is a preliminary cost estimated for establishment of solid waste Master Plan and this cost will be further examined in Chapter 5.

(1) Methodology

i) Model formula

In formulation of the model, the following assumptions were made.

a. Solid waste in each zone was assumed to be generated from the zone center.

b. Intermediate treatment facilities, final disposal sites and transfer stations were assumed to be located as specified in Section 4.5.2.

c. The existing final disposal sites except Tung Kru were assumed to be existing in the future at their present locations. (Refer Section 4.4)

d. Transport cost and maintenance, operation and depreciation costs of the facilities were assumed to be linearly proportional to solid waste volume.

Based on these assumptions, the following model was formulated.

To minimize the total cost for solid waste collection, transport, intermediate treatment and final disposal, the following equation was formulated:

$$C = \sum_{i}\sum_{j} d_{ij} \cdot x_{ij} + \sum_{i}\sum_{j} (C_{\bar{o}j} + C_{tj})\, x_{ij} + \sum_{j} y_j f_j$$

subject to $\sum_{j} x_{ij} = q_i$

$$\sum_{i} x_{ij} \leq b \cdot y_j$$

$$Y_j = [1: \text{if } \sum_{i} x_{ij} > 0,\ 0: \text{if } \sum_{i} x_{ij} = 0]$$

Where, $C$: Total cost (Baht/d)

$x_{ij}$: Solid waste volume transported from i-zone to j-facility (t/d)

$d_{ij}$: Unit transport cost from i-zone to j-facility (Baht/t)

$C_{\bar{o}j}$: Linearly proportional costs to solid waste volume, such as maintenance cost, operation cost, depreciation cost, etc.

$C_{tj}$: Secondary transport cost from j-facility to final disposal sites (Baht/t)

$f_j$: Fixed charge of j-facility (Baht)

$q_i$: Solid waste generation volume in i-zone (t/d)

$b$: Volume limitation (t/d) (treatment capacity)

The first term of the right part of the above equation indicates collection and transport cost, and the second and third terms indicate facilities-related costs. (The second term covers proportional costs to solid waste volume and the third covers fixed charges which have no relation with solid waste volume.)

ii) Computation method

An outline of operation based on the model is shown in flowchart in Fig. 4.19.

Simulated operation was achieved according to the following steps:

Step 1: Data input

a. O-D matrix of the transport cost (between the original zones and treatment and disposal facilities)

b. Facilities-related costs

c. Initial location of the facilities

Step 2: Set up of primary territory

Connection of the original zones with each of treatment and disposal facilities (In zone number order, each zone is connected to treatment and disposal facilities to minimize the transport cost.)

Step 3: Framing of blocks

Taking volume limitation into account, the primarily-set territories are corrected to minimize the total transport cost. (Linear programming)

Step 4: Correction of the initial locating of the facilities

In each territory or block, the location is sought which minimizes transport cost, treatment and disposal costs, and fixed charges.

Step 5: Reiteration of the procedure

The process from the above Step 2 to Step 4 is repeated until no correction of facilities location is required.

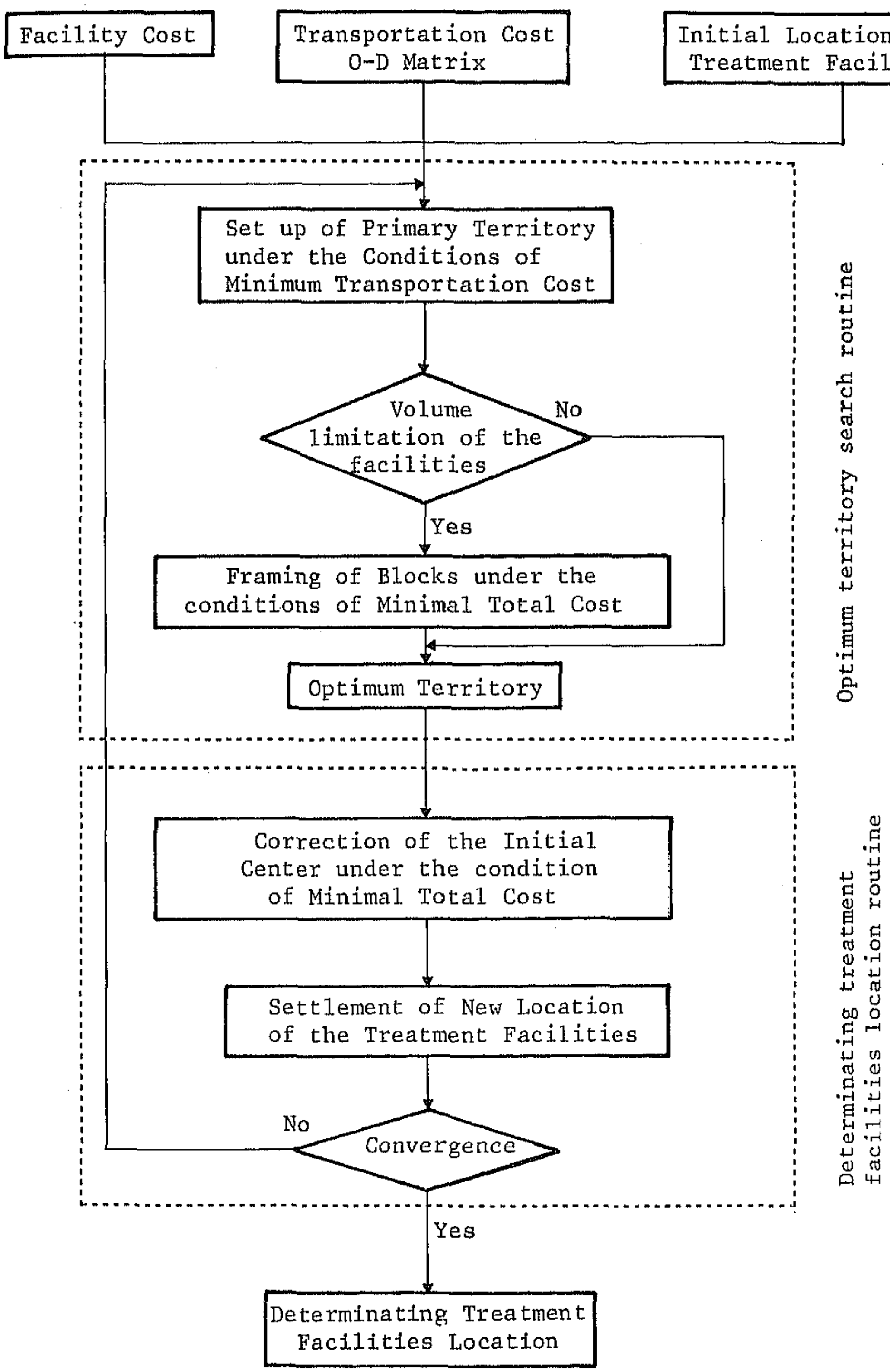
(2) Conditions for the computation

Necessary conditions for collection and transport simulation were assumed as stated below. The present status and the future plans concerning lands, roads, river and canals were taken into consideration. Furthermore, the present status of sanitary administration by BOS and results of sanitary utility enterprises in Japan and in other countries were also taken into consideration.

i) Scale of the facilities

Scale of the solid waste disposal facilities are summarized as follows, based on the results examined which are described in Section 4.3.2.

Fig. 4.19 Simulation work flow to determine location



a. Incineration plant

| | Capacity (t/d) | | Rate of operation (%) |
|---|---|---|---|
| | Facility scale basis | Disposal capacity basis | |
| Lower limit | 600 | 480 | 80 |
| Upper limit | 1,500 | 1,200 | |

b. Compost plant

| | Capacity (t/d) | | Rate of operation (%) |
|---|---|---|---|
| | Facility scale basis | Disposal capacity basis | |
| Lower limit | 300 | 255 | 85 |
| Upper limit | 600 | 510 | |

c. Transfer facilities

Capacity of a transfer station

| | |
|---|---|
| land-to-river | 500 t/d |
| land-to-land | 180 t/d |

ii) Areas required for construction of the facilities

The required areas for construction of solid waste management facilities were estimated based on the results described in Section 4.3.2(4).

a. Incineration plant: 50 $m^2$/t·d (facility scale basis)

b. Compost plant
(Aerated composting): 350 $m^2$/t·d (facility scale basis)

c. Transfer station

Land-to-land
(container pusher): 5 $m^2$/t·d (facility scale basis)

Land-to-river : 10 $m^2$/t·d (facility scale basis)

d. Final disposal site

Based on the results examined which are described in Section 4.4.3, the cubic volume and the areas required for construction of the facilities are summarized as follows:

| Landfill materials | Cubic volume required (Cubic volume conversion rate) $m^3/t$ | Areas required $m^3/t$ |
|---|---|---|
| Solid waste (Open dump method) | 0.80 | - |
| Solid waste (Sanitary landfill) | 0.88 | 0.085 |
| Incineration residue (Ash) | 1.0 | 0.097 |
| Compost residue | 1.0 | 0.097 |
| Surplus compost | 1.0 | - |

iii) Material balance

| Type of treatment facilities | Generation volume of residue (kg per ton of solid waste) |
|---|---|
| Incineration | |
| Incineration residue | 200 |
| Existing compost | |
| Compost product | 150 |
| Trommel residue | 120 |
| Incineration residue of unsuitable materials for composting | 60 |
| Aerated compost | |
| Compost product | 150 |
| Unsuitable materials for composting | 150 |
| Trommel residue | 200 |

iv) Road network and river

The future road network and the number of lanes in Bangkok for the year 2000 was determined from data obtained from Department of Town and Country Planning (DTCP) of the Ministry of Interior and Department of Highways of the Ministry of Communications, and the travel speed of the future road network was assumed in accordance with the traffic congestion which exists in the central business district.

As for the river, the Chao Phraya river was taken as the focus and one section of approximately 27-km of the river as shown on Fig. 4.20 was selected to be the waterway transport route due to constraints of limited construction sites for transfer stations and incineration plants along the river.

v) Type and capacity of collection truck, conveying truck and conveying barge

Based on the study results described in Section 4.2.2 in the case of without-transfer, use of 7.5 $m^3$-compactors was planned (the same as the present situation) and, for the case of land-to-land transfer, 7.5 $m^3$-compactors would be used for collection and

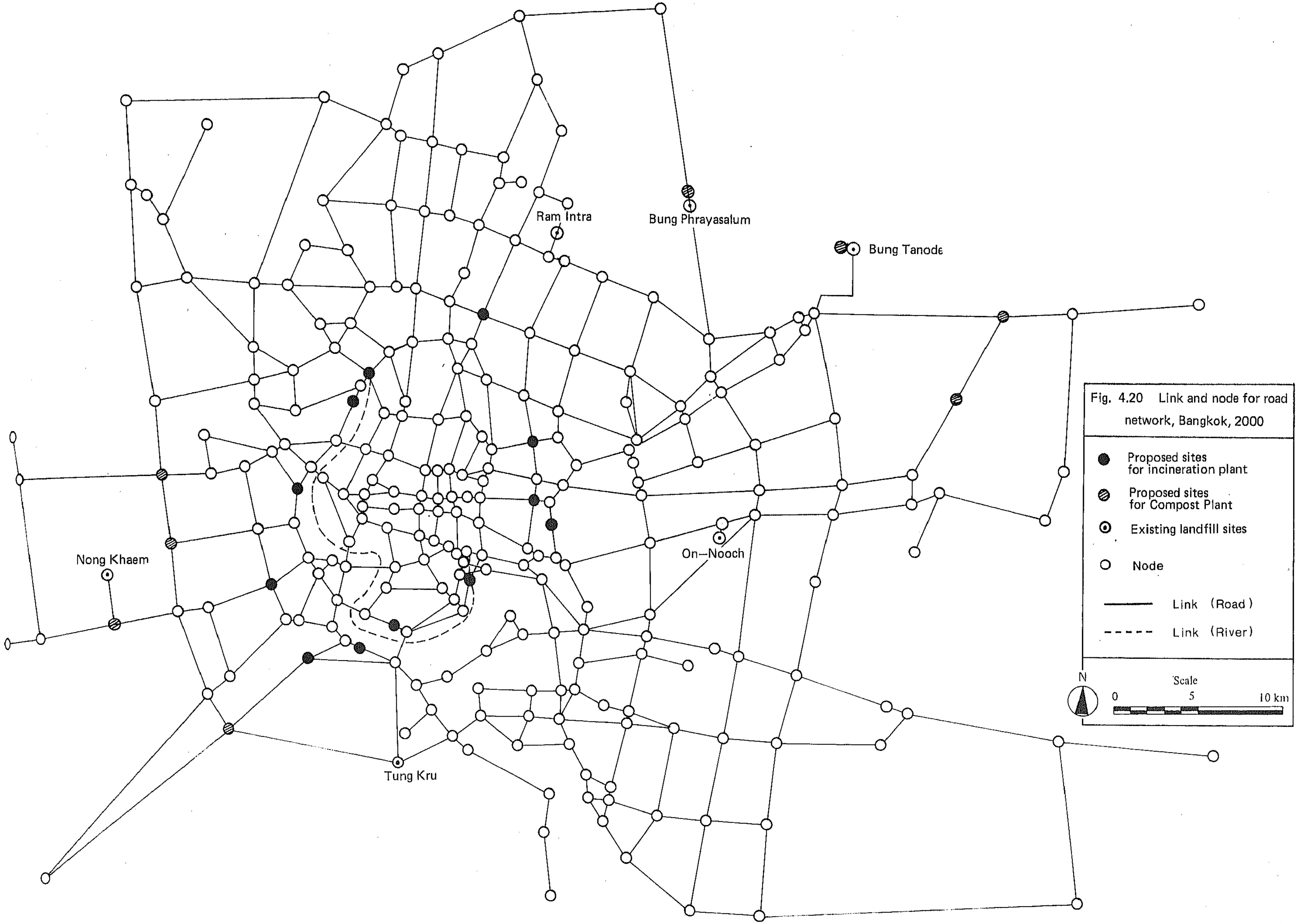



Fig. 4.20 Link and node for road network, Bangkok, 2000

transport up to the transfer stations, where the collected waste would be transferred to 10-ton container trucks (Land-to-land) for the further transport to the processing (intermediate treatment) plants or to the final disposal sites. In the land-to-river transfer case, capacity of barges was assumed to be 200 tons per unit.

vi) Land acquisition cost

In order to estimate acquisition cost of the land required for solid waste disposal facilities, land prices in each zone were investigated. From the results of the investigation, mean values of the published land prices in the year 1974 (the latest data) in each zone was calculated and modified to 1980-year prices by applying the annual GPP growth rate (1980/1974 = 1.8) in order to match the land price with cost of the facilities.

The estimated land acquisition cost in the year 1980 by zones is shown in Table 4.5.

Table 4.5 Land acquisition cost (1980)

(Unit: Baht/m²)

| Zone No. | Acquisition Cost | Zone No. | Acquisition Cost | Zone No. | Acquisition Cost |
|---|---|---|---|---|---|
| 1 | 2,130 | 16 | 740 | 31 | 20 |
| 2 | 3,580 | 17 | 200 | 32 | 370 |
| 3 | 2,640 | 18 | 350 | 33 | 410 |
| 4 | 4,670 | 19 | 860 | 34 | 230 |
| 5 | 3,040 | 20 | 80 | 35 | 260 |
| 6 | 870 | 21 | 20 | 36 | 300 |
| 7 | 1,000 | 22 | 170 | 37 | 70 |
| 8 | 1,450 | 23 | 90 | 38 | 10 |
| 9 | 1,400 | 24 | 110 | 39 | 90 |
| 10 | 1,870 | 25 | 340 | 40 | 60 |
| 11 | 1,130 | 26 | 120 | 41 | 430 |
| 12 | 1,040 | 27 | 350 | 42 | 130 |
| 13 | 500 | 28 | 140 | 43 | 10 |
| 14 | 1,220 | 29 | 10 | 44 | 50 |
| 15 | 410 | 30 | 20 | | |

Estimated by the Study team on the basis of the published land cost by Expressway and Rapid Transit Authority of Thailand.

Based on the above land acquisition cost, total land cost of the disposal facilities was calculated assuming the total amount necessary to acquire all the required land was financed with annual interest of 12%.

vii) Facilities costs

Approximate costs relating to the facilities (investment cost, operation and maintenance costs of incineration plants, compost plants and final disposal sites) were calculated based on the study results described in Sections 4.3.3 and 4.4.3.

The calculated costs were converted into 1980 Thailand prices by considering a ratio between local currency portion and foreign currency portion as shown in Table 4.6. CIF prices were applied for the foreign currency portion. The table below shows breakdown of local and foreign currencies composition for each time of the facilities.

Table 4.6 Composition of local and foreign currencies for the facilities

| Facilities | | | Foreign currency (%) | Local currency (%) |
|---|---|---|---|---|
| Incine-ration | Plant | | 80 | 20 |
| | Buildings | | - | 100 |
| Compo-sting | Plant | | 80 | 20 |
| | Buildings | | - | 100 |
| Land-fill | Facilities | | - | 100 |
| | Sewerage | | 30 | 70 |
| Transfer | Open dump method (land-to-land) | | - | 100 |
| | Container method (Land-to land) | Building | - | 100 |
| | | Trucks | 100 | - |

a. Incineration plant and composting plant

(a) Depreciation

Based on the figures mentioned in Section 4.3.3, the relation between disposal volume (facility scale basis) and the construction cost of incineration plant and compost plant in Thailand prices was analyzed using the following formulas:

- Incineration Plant

$$C = 971{,}000x + 85{,}500{,}000$$

- Compost Plant

$$C = 403{,}000x + 8{,}790{,}000$$

Where, C: Investment cost (Baht)

X: Solid waste treatment volume (facility scale basis: t/d)

Applying an operation rate to the plants and an assumed life expectancy of 20 years, and assuming no salvage value of the plants after 20 years, the depreciation cost of the plants are formulated as follows:

- Incineration Plant

$$D = 166x + 14{,}640$$

- Compost Plant

$$D = 65x + 1{,}416$$

Where, D: Depreciation expense (Baht/d)

x: Solid waste treatment volume (Disposal capacity basis)

(b) Operation and maintenance cost

Based on the operation and maintenance cost of the plants described in Section 4.3.3, the operation and maintenance cost of the plants in Thailand prices were estimated at 130 Baht per ton for the incineration plant and 149 Baht per ton for the compost plant.

b. Transfer facilities

Based on the operation and maintenance cost of the transfer facilities described in Section 4.2.2, the cost of the transfer facilities was estimated in Thailand prices as follows:

| Transfer type | Depreciation cost (Baht/t) | Operation and maintenance cost (Baht/t) |
|---|---|---|
| Land-to-river | 5 | 45 |
| Land-to-land | 10 | 10 |

c. Landfill

Investment cost, operation and maintenance cost mentioned in Section 4.4.3 were converted to Thailand prices and are summarized as follows:

| | Depreciation expense (Baht/t) | Operation and maintenance cost (Baht/t) |
|---|---|---|
| Raw waste | 50 | 70 |
| Incineration residue | 58 | 80 |
| Compost residue | 58 | 80 |

The bases for the computation mentioned above are summarized in Table 4.7.

(3) Result of the computation

1) The computerized cases

Concrete data about location and capacity of the facilities were added to the 20 alternative cases mentioned in Section 4.5.1. Consequently 30 cases of Master Plan alternatives were formulated as shown in Table 4.8. These 30 cases were undertaken for computation to clarify the cost (as of the year 2000) needed for

## Table 4.7 Summary of the basis for computation

<table>
<tr><th rowspan="2">Sub System</th><th rowspan="2" colspan="2">Method</th><th rowspan="2">Criteria of Sub-system Facilities Location</th><th rowspan="2">Number of Facilities</th><th rowspan="2" colspan="2">Capacity</th><th rowspan="2" colspan="3">Required Area</th><th colspan="3">Treatment Cost (Thailand 1980 Prices)</th></tr>
<tr><th>Depreciation Cost</th><th>Operation and Maintenance Cost</th><th>Total Cost</th></tr>
<tr><td rowspan="5">Collection and Transport</td><td colspan="2">Direct transport</td><td>–</td><td>–</td><td>Collection Truck</td><td>Compactor (7.5 m³)</td><td colspan="3">–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td rowspan="4">Transfer</td><td rowspan="2">Land-to-land</td><td rowspan="2">CBD and its surrounding area</td><td rowspan="2">44*</td><td>Facility</td><td>180 t/d</td><td rowspan="8">Facility scale basis</td><td rowspan="2" colspan="2">5 m²/t/d</td><td rowspan="2">5 Baht/t</td><td rowspan="2">45 Baht/t</td><td rowspan="2">50 Baht/t</td></tr>
<tr><td>Transport truck</td><td>10 t</td></tr>
<tr><td rowspan="2">Land-to-river</td><td rowspan="2">Along Chao Phraya river</td><td rowspan="2">2</td><td>Facility</td><td>500 t/d</td><td rowspan="2" colspan="2">10 m²/t/d</td><td rowspan="2">10 Baht/t</td><td rowspan="2">10 Baht/t</td><td rowspan="2">20 Baht/t</td></tr>
<tr><td>Barge</td><td>200 t/ship</td></tr>
<tr><td rowspan="4">Intermediate Treatment</td><td rowspan="2" colspan="2">Incineration (Waste heat boiler attached)</td><td rowspan="2">Low density (Mixed-use area the periphery of CBD)</td><td rowspan="2">12</td><td>Max.</td><td>1,500 t/d</td><td rowspan="2" colspan="2">50 m²/t/d</td><td rowspan="2">** 166x + 14,640 Baht/t</td><td rowspan="2">130 Baht/t</td><td rowspan="2">–</td></tr>
<tr><td>Min.</td><td>600 t/d</td></tr>
<tr><td rowspan="2" colspan="2">Compost</td><td rowspan="2">Agricultual area</td><td rowspan="2">9</td><td>Max.</td><td>600 t/d</td><td rowspan="2" colspan="2">350 m²/t/d</td><td rowspan="2">** 65x + 1,416 Baht/t</td><td rowspan="2">149 Baht/t</td><td rowspan="2">–</td></tr>
<tr><td>Min.</td><td>300 t/d</td></tr>
<tr><td rowspan="5">Final Disposal</td><td rowspan="5" colspan="2">Sanitary Landfill</td><td rowspan="5">Existing landfill sites<br>(Except the Tung Kru landfill site)</td><td rowspan="5">5</td><td>On-Nooch</td><td>5,643,000 m³</td><td rowspan="5">Disposal volume basis</td><td rowspan="2">Raw waste</td><td rowspan="2">0.085 m²/t</td><td rowspan="2">50 Baht/t</td><td rowspan="2">70 Baht/t</td><td rowspan="2">120 Baht/t</td></tr>
<tr><td>Nong Khaem</td><td>5,278,000 m³</td></tr>
<tr><td>Ram Intra</td><td>697,000 m³</td><td rowspan="3">Ash, Residue</td><td rowspan="3">0.097 m²/t</td><td rowspan="3">58 Baht/t</td><td rowspan="3">80 Baht/t</td><td rowspan="3">138 Baht/t</td></tr>
<tr><td>Bung Tanode</td><td>33,000 m³</td></tr>
<tr><td>Bung Phrayasalum</td><td>24,000 m³</td></tr>
</table>

* For the computation, possible location of land-to-land transfer station are assumed to be in each zone.

** "x" indicates the disposal volume.

implementation of each plan, the most suitable destinations of solid waste, and the incoming solid waste volume to each of the facilities.

ii) Results of computation

The results of the computation of each Master Plan alternative are shown in Table 4.9.

Each cost is indexed with the base cost in the year 1979 (315 Baht/t).

The related information is given in Appendix 4.13, such as;

- Node number of treatment plants and disposal sites used in the selected Master Plan alternatives and treatment volume estimated at each facility
- Expenditures in collection and transport cost and facilities cost

The above results do not include cost for management at BOS headoffice or cost for collecting road, river and Khlong solid waste.

The results of the computation are summarized as follows:

a. Percentage of solid waste volume to be intermediately treated ranges from 40 to 90% of the total disposal volume depending on the number and location of intermediate treatment facilities.

b. If the number and capacity of compost plant is changed from three sites with a total capacity of 1,120 t/d to five sites with the sum of 1,920 t/d without changing the number of incineration plants, the cost of composting facilities increases about 50% and the cost of landfill decreases 20 - 30%. Nonetheless, the total cost is only influenced a little by the change (approximately 2% increase in the total cost).

c. Increase in number of incineration plants from 1 site to 2 sites (without change in number of compost plants or the total capacity) causes about 100% increase in the cost of incineration. Although the cost of landfill decreases 50 - 60%, the total cost increases 8 - 11%.

d. The cost of facilities is inversely proportional to collection and transport cost.

   In most cases, the increased facilities cost exceeds the decrease in collection and transport cost, with the gap between the increase and the decrease becoming larger as the number of incineration plants increases.

Table 4.8 The Master Plan alternatives (30 cases)

| Alternative Treatment and Disposal System | Case number | Number of treatment and disposal facilities: Incineration plant | Compost plant | Final disposal site | Transfer station | Outline of features of the Master Plan alternative | Purposes |
|---|---|---|---|---|---|---|---|
| Landfill only | 1–(1) | | | 5 | | Five disposal sites excluding Tung Kru. No limitation of incoming solid waste volume to each disposal site. | To find out suitable destinations of solid waste and to obtain appropriate incoming waste volume to the destination, under limitation of minimum transport cost. |
| | 1–(2) | | | 5 | | Five disposal sites excluding Tung Kru. Acceptable waste volume is determined according to the disposable volume in each final disposal site. | The appropriate destination and incoming volume to the destination are determined on the basis of disposable volume. |
| | 2–(1) | | | 5 | 19 | The same as case 1–(1), but transport transfer is made. | Evaluation of the effect of transport transfer is attempted. |
| | 2–(2) | | | 5 | 19 | The same as case 1–(2), but transport transfer is made. | - do - |
| Composting only | 3–(1) | | 9 | | | The existing 3 plants (1,120 t/d) plus additional 6 plants (each 765 t/d). | The existing plants will cope with solid waste with same capacity as present: the rest of the solid waste will be treated evenly by the six new plants. |
| | 3–(2) | | 5 | | | As to the plants with capacity of 300 t/d or larger, no limitation of incoming volume is made. | To find out suitable destinations and appropriate incoming volume. |
| | 4–(1) | | 9 | | 17 | The same as case 3–(1), but transport transfer is made. | Evaluation of the effect of transport transfer is attempted. |
| | 4–(2) | | 5 | | 14 | The same as case 3–(2), but transport transfer is made. | - do - |
| Incineration only | 5 | 5 | | | | Treatment capacity (possibly aquiring the site area) of each plant is taken into consideration. | Combination to determine cost minimum is sought. In terms of capacity constraints minimum number of sites will be 5. |
| | 6 | 5 | | | 3 | The same as case 5, but transport transfer is made. | Evaluation of the effect of transport transfer is attempted. |
| Composting + landfill | 7 | | 3 | 5 | | The existing three compost plants cope with 1,120 t/d: the other volume is landfilled. | Continuation of the existing system. |
| | 8 | | 3 | 5 | 19 | The same as case 7, but transport transfer is made. | Evaluation of the effect of transport transfer is attempted. |
| | 9 | | 5 | 5 | | Demand for compost is assumed 1,920 t/d. The existing plants are utilized. Surplus waste for composting is landfilled. | Formulation of number, location and capacity of additional plants to satisfy the increased compost demand. |
| | 10 | | 5 | 5 | 17 | The same as case 9, but transport transfer is made. | Evaluation of the effect of transport transfer is attempted. |
| Incineration + composting | 11 | 4 | 3 | | | Total volume of solid waste other than treated in the existing compost plants is incinerated. Therefore, 4 incineration plants are required. | Study of incineration treatment utilizing the existing compost plants. |
| | 12 | 4 | 3 | | 6 | The same as case 11, but transport transfer is made. | Evaluation of the effect of transport transfer is attempted. |
| | 13 | 4 | 5 | | | Compost demand 1,920 ton/day. The existing compost plants are used. Surplus solid waste is incinerated. | To examine establishment of incineration plants and additional compost plants to satisfy increasing compost demand. |
| | 14 | 4 | 5 | | 5(1)* | The same as case 13, but transport transfer is made. (One land-to-river transfer station is required.) | Evaluation of the effect of transport transfer is attempted. |
| Incineration + landfill | 15 | 1 | | 5 | | Only one incineration plant with capacity of 1,500 t/d is established at the most suitable place, and excessive waste for incineration is landfilled. | Study of total minimum cost with incineration + landfill. If number of incineration plants becomes two or more, the total cost also increases. |
| | 16 | 1 | | 5 | 16 | The same as case 15, but transport transfer is made. | Evaluation of the effect of transport transfer is attempted. |
| Incineration + composting + landfill | 17–(1) | 1 | 3 | 5 | | Only one incineration plant is established at the most suitable place. The existing compost plants are used. Excessive solid waste for treatment is landfilled. | Combination of the three minimum cost sub-systems (without transfer). |
| | 17–(2) | 2 | 3 | 5 | | The same as case 17–(1), but one more incineration plant is added. | Examination of a balance between collection/transport cost and expanded facilities cost from addition of incineration plant. Study of the total cost. |
| | 18–(1) | 1 | 3 | 5 | 14 | The same as case 17–(1), but transport transfer is made. | Evaluation of the effect of transport transfer is attempted. |
| | 18–(2) | 2 | 3 | 5 | 8 | The same as case 17–(2), but transport transfer is made. | - do - |
| | 19–(1) | 1 | 5 | 5 | | One incineration plant at the most suitable place. Compost demand 1,920 t/d. Use of the existing compost plants. | Combination of the minimum cost with increased compost demand. |
| | 19–(2) | 2 | 5 | 5 | | The same as case 19–(1), but one more incineration plant is added. | Examination of a balance between collection/transport cost and expanded facilities cost from addition of incineration plant. Study of the total cost. |
| | 19–(3) | 2 | 4 | 3 | | Increase of capacity of Nong Khaem compost plant. Close down On-Nooch final disposal site. | New compost plant near to Nong Khaem is affiliated with Nong Khaem compost plant. The future land-use on On-Nooch area is considered. |
| | 19–(4) | 3 | 4 | 3 | | Incineration plants at three sites. Compost demand 1,920 t/d. Use of the existing compost plants. | Reduction of landfill disposal volume by increasing disposal capacity of intermediate treatment facilities. |
| | 20–(1) | 1 | 5 | 5 | 12 | The same as case 19–(1), but transport transfer is made. | Evaluation of the effect of transport transfer is attempted. |
| | 20–(2) | 2 | 5 | 5 | 4 | The same as case 19–(2), but transport transfer is made. | - do - |

* Figure in ( ) shows number of land-to-river stations.

Table 4.9 Results of collection and transport simulation (Year 2000)

(1980 prices)

| Alternative treatment and disposal system | Case No. | Number of treatment and disposal site: Incine-ration plant | Com-post plant | Final disposal site | Trans-fer station* | Collection and transport cost (Baht/d) | Facilities cost (Baht/d) | Total cost (Baht/d) | Unit treatment and disposal cost: Cost (Baht/t) | Rank | Index 315=100 (Base year 1979) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Landfill only | 1-(1) | | | 5 | | 942,039 | 819,392 | 1,761,431 | 318 | 3 | 101 |
| | 1-(2) | | | 5 | | 958,781 | 866,462 | 1,825,243 | 329 | 5 | 104 |
| | 2-1 | | | 5 | 19 | 681,523 | 996,064 | 1,677,590 | 303 | 1 | 96 |
| | 2-(2) | | | 5 | 19 | 685,747 | 1,043,134 | 1,728,881 | 312 | 2 | 99 |
| Composting only | 3-(1) | | 9 | | | 1,039,624 | 1,227,282 | 2,266,906 | 409 | 21 | 130 |
| | 3-(2) | | 5 | | | 873,037 | 1,256,208 | 2,129,245 | 384 | 17 | 122 |
| | 4-(1) | | 9 | | 17 | 720,101 | 1,370,437 | 2,090,538 | 377 | 16 | 120 |
| | 4-(2) | | 5 | | 14 | 705,504 | 1,380,482 | 2,085,986 | 377 | 15 | 120 |
| Incineration only | 5 | 5 | | | | 701,830 | 2,014,464 | 2,716,294 | 490 | 29 | 156 |
| | 6 | 5 | | | 3 | 681,285 | 2,039,859 | 2,721,144 | 491 | 30 | 156 |
| Compost-ing + landfill | 7 | | 3 | 5 | | 960,073 | 920,704 | 1,880,777 | 339 | 8 | 108 |
| | 8 | | 3 | 5 | 19 | 765,238 | 1,077,350 | 1,842,588 | 333 | 6 | 106 |
| | 9 | | 5 | 5 | | 913,751 | 953,890 | 1,867,641 | 337 | 7 | 107 |
| | 10 | | 5 | 5 | 17 | 716,302 | 1,095,228 | 1,811,530 | 327 | 4 | 104 |
| Incine-ration + compost-ing | 11 | 4 | 3 | | | 751,758 | 1,879,402 | 2,631,160 | 475 | 28 | 151 |
| | 12 | 4 | 3 | | 6 | 721,820 | 1,899,450 | 2,621,270 | 473 | 27 | 150 |
| | 13 | 4 | 5 | | | 724,284 | 1,794,428 | 2,518,712 | 455 | 26 | 144 |
| | 14 | 4 | 5 | | 5(1)* | 697,875 | 1,810,665 | 2,508,540 | 453 | 25 | 144 |
| Incine-ration + landfill | 15 | 1 | | 5 | | 857,963 | 1,110,848 | 1,968,811 | 355 | 10 | 113 |
| | 16 | 1 | | 5 | 16 | 673,585 | 1,234,876 | 1,908,461 | 344 | 9 | 109 |
| Incine-ration + Compost-ing + landfill | 17-(1) | 1 | 3 | 5 | | 870,459 | 1,178,662 | 2,049,121 | 370 | 13 | 117 |
| | 17-(2) | 2 | 3 | 5 | | 804,122 | 1,399,712 | 2,203,834 | 398 | 19 | 126 |
| | 18-(1) | 1 | 3 | 5 | 14 | 721,012 | 1,281,869 | 2,002,881 | 362 | 11 | 115 |
| | 18-(2) | 2 | 3 | 5 | 8 | 730,387 | 1,466,983 | 2,197,370 | 397 | 18 | 126 |
| | 19-(1) | 1 | 5 | 5 | | 827,562 | 1,230,310 | 2,057,872 | 371 | 14 | 118 |
| | 19-(2) | 2 | 5 | 5 | | 753,728 | 1,520,816 | 2,274,544 | 411 | 23 | 130 |
| | 19-(3) | 2 | 4 | 3 | | 774,671 | 1,492,072 | 2,266,743 | 409 | 20 | 130 |
| | 19-(4) | 3 | 4 | 5 | | 732,033 | 1,720,922 | 2,452,955 | 443 | 24 | 141 |
| | 20-(1) | 1 | 5 | 5 | 12 | 702,545 | 1,317,263 | 2,019,808 | 365 | 12 | 116 |
| | 20-(2) | 2 | 5 | 5 | 4 | 731,239 | 1,542,759 | 2,273,998 | 410 | 22 | 130 |

* Figure in ( ) shows number of land-to-river transfer stations.

e. Adoption of transport transfer

Applying transport transfer reduced the total cost in each case calculated. The results are shown in Table 4.10 below.

Table 4.10 Change of cost from adoption of transport transfer

(Unit: %)

| Alternative systems | Ratio of cost change: with / without | | | | |
|---|---|---|---|---|---|
| | Compared Case Nos. (A / B) | Collection & transport | Facilities | Total | Note No. below |
| Landfill only | 2-(1)/1 | 72 | 122 | 95 | 1) |
| | 2-(2)/1 | 72 | 120 | 95 | 2) |
| Composting only | 4-(1)/3 | 69 | 112 | 92 | 3) |
| | 4-(2)/3 | 81 | 110 | 98 | 1) |
| Incineration only | 6/5 | 97 | 101 | 100 | |
| Composting + landfill | 8/7 | 80 | 117 | 98 | 4) |
| | 10/9 | 78 | 115 | 97 | 5) |
| Incineration + composting | 12/11 | 96 | 101 | 100 | 4) |
| | * 14/13 | 96 | 101 | 100 | 5) |
| Incineration + landfill | 16/15 | 79 | 111 | 97 | 6) |
| Incineration + composting + landfill | 18-(1)/17 | 83 | 109 | 98 | 7) |
| | 18-(2)/17 | 91 | 105 | 100 | 8) |
| | 20-(1)/19 | 85 | 107 | 98 | 9) |
| | 20-(2)/19 | 97 | 101 | 100 | 10) |

* Includes effect of land to river transfer (357 t/d)

Note :
1) No limit on incoming solid waste volume is made.
2) The incoming volume is limited.
3) The existing plant + new plant of 750 t/d.
4) Composting 1,120 t/d.
5) Composting 1,920 t/d.
6) One incineration plant.
7) Composting 1,120 t/d + one incineration plant.
8) Composting 1,120 t/d + two incineration plants.
9) Composting 1,920 t/d + one incineration plant.
10) Composting 1,920 t/d + two incineration plants.

The conclusions from the table are summarized as follows:

a. With introduction of transfer method:

- Collection and transport cost is reduced in all cases. (3 - 31% reduction)

- Facilities cost increases in all the cases. (1 - 22% increase)
- The total cost decreases in most cases except cases such as No. 5 and 6 in which there is no change since the total cost is inflated by effect of the land rent.

b. The effect of introducing transport transfer is larger when the method is applied to suburban type solid waste management systems such as total volume landfill and total volume composting.

c. The effect of introducing transport transfer is smaller when it is applied to the cases which involve incineration plants located near the city center.

- In the case of total volume incineration, the total cost of the case with transport transfer is larger than without transport transfer. In this case, transfer facilities are constructed on the outskirts of the city where solid waste collected from suburban areas is transferred for further transport to incineration plants in the city areas.
- No particular effect is noted from application of transport transfer to the incineration & composting system.
- In the case of establishing only one incineration plant (cases No. 15, 16, 17, 18-(2), 19 and 20-(1)), solid waste volume to be incinerated is 1,200 t/d which is only 22% of the forecast collection volume in the year 2000 (5,540 t/d) so that the rest of the solid waste volume is transported to compost plants and final disposal sites. In this case, introduction of transport transfer reduces total cost 2 - 3%.
- For cases with two or more incineration plants, the effect of introducing transport transfer is negligeable.

Thus, the application of land-to-land transport transfer should be studied for suburban type treatment and disposal (total volume landfill and total volume composting) where its application to the cases involving incineration is less effective.

As to land-to-river transport transfer, there is no substantial effect except for case No. 14. Besides acquisition of land for the transfer station in the urbanized area along Chao Phraya River is believed to be extremely difficult. Hence, it is concluded that solid waste transport utilizing the Chao Phraya River as the waterway is impractical.

iii) Revenue from resource recovery

The prospected revenue from resource recovery was calculated for each of the 30 Master Plan alternative cases. The revenue obtained is from sale of by-products produced by each system.

Based on the current state of resource recovery, the resources to be recovered were defined and the recovery costs determined. After inserting the revenue from resource recovery into the calculation, the total cost of each Master Plan alternative was re-estimated.

a. Landfill

The value added to reclaimed land by landfilling of solid waste was evaluated.

The reclamation cost was estimated as 150 Baht/$m^2$, which is the sum of the cost of soil (Bangkok price) required for one square meter of land reclamation (120 Baht) and the labour cost for the same (30 Baht).

The necessary area covered by one ton of solid waste landfill is 0.085 $m^2$; accordingly, the land reclamation cost per ton of solid waste is calculated as 150 (Baht/$m^2$) x 0.085 ($m^2$/t) = 12.75 Baht/t)

b. Compost plant

Revenue from resource recovery per ton of solid waste processing is stated below.

| Material | Weight of recovered material from one ton of solid waste (kg) (A) | Price (Baht/t) (B) | Revenue from resource recovery (Baht/t) (A) x (B) |
|---|---|---|---|
| Ferrous metal | 80 | 440* | 35.2 |
| Compost | 150 | 469* | 70.4 |
| Trommel residue | | | |
| e. CP | 120 | 14.55** | 1.7 |
| n. CP | 200 | 14.55** | 2.9 |
| Ash (e. CP) | 60 | 14.55** | 0.9 |
| Unsuitable materials for composting (n. CP) | 150 | 12.75 | 1.9 |
| Total | | | |
| e. CP | | | 108.2 |
| n. CP | | | 110.4 |

Note: * The current sales price. (Compost price is the mean value of types No. 1 and No. 2)

** Necessary area for landfill of 1 ton of ash is 150 Baht/$m^2$ x 0.047 $m^2$/t = 14.55 Baht/t.

e. CP and n. CP mean existing compost plant and new compost plant respectively.

c. Incineration plant

Electric power from generation facilities attached to the incineration plant and the value added to land reclaimed by landfilling with incineration residue were evaluated.

Power generation:

| | | |
|---|---|---|
| Unit power price | : | 1.14 Baht/kW·h |
| The forecast calorific value of solid waste in Bangkok in the year 2000 | : | 1,500 kcal |
| Theoretical power generation per ton of solid waste | : | 270 kW·h/t |
| Operation rate of the generation | : | 0.85 |
| Operating power generation per ton of solid waste | : | 230 kW·h/t |
| 1) Power for internal consumption in the plant | : | 60 kW·h/t |
| 2) Power for sale | : | 170 kW·h/t |
| Discount rate (on power for-sale) | | 50% |

Accordingly, revenue from 1 ton of solid waste treatment is calculated as follows:

(60 x 1.14)+(170 x 1.14 x 0.5) = 165.3 Baht/t

Ash: 200 kg of residue is generated by incineration of 1 ton of solid waste; therefore, 200 kg x 14.55 Baht/t = 2.91 Baht/t

Hence, the total revenue obtained is 168.2 Baht/t.

Applying the above figures to each type of treatment and disposal system, the total cost of each Master Plan alternative including revenue from resource recovery was calculated. The results are shown in Table 4.11.

Fig. 4.21 shows change of unit treatment and disposal cost for each Master Plan alternative both with and without revenue.

If revenue from resource recovery is taken into account, unit treatment and disposal costs average around 300 Baht/t with the difference between the largest unit cost and the smallest, 61 Baht/t On the other hand, if the revenue is not considered, unit treatment and disposal costs range from 300 to 500 Baht/t with the difference between the largest and the smallest, 188 Baht/t.

iv) Summary of the results of computation

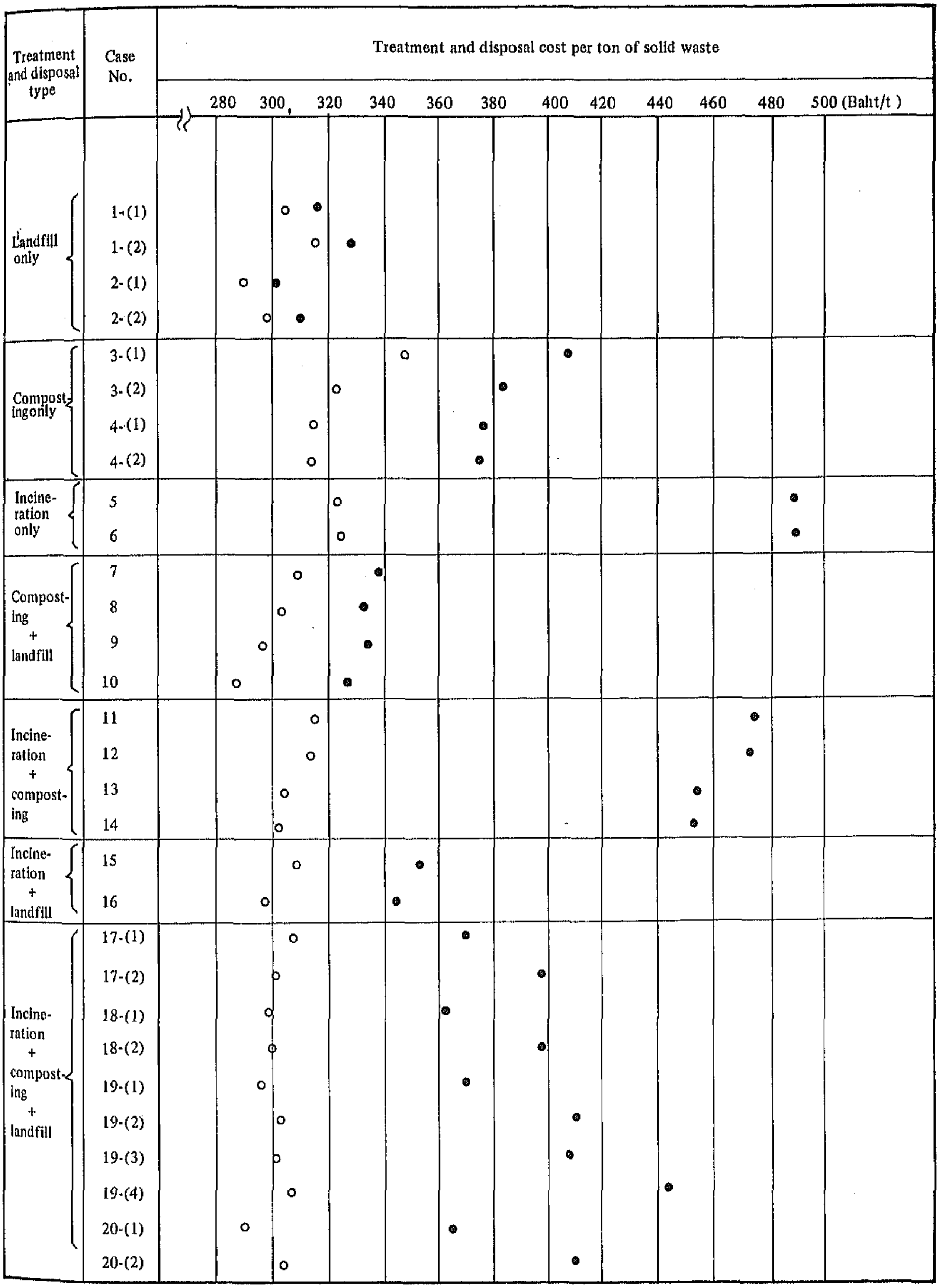
The results of computation are summarized as follows:

a. To cope with increasing solid waste volume, the total cost needed for solid waste management in the year 2000 will be three times as much as the present cost.

Table 4.11 Total cost, taking revenue from resource recovery into account (Year 2000)

| Treatment and Disposal Type | Case No. | ① The expected revenue from resource recovery (Baht/d) | | | | | ② Total Cost | ② − ① Total net cost | Unit treatment and disposal cost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Landfill Site (12.8 Baht/t) | The Existing Compost Plant (108.0 Baht/t) | Additional Compost Plant (110.9 Baht/t) | Incineration Plant (168.2 Baht/t) | Total | (Baht/t) | (Baht/t) | Unit cost (Baht/t) | Rank | Index 315=100 (Base year 1979) |
| Landfill only | 1-(1) | 70,912 | | | | 70,912 | 1,761,431 | 1,690,519 | 305 | 17 | 97 |
| | 1-(2) | 70,912 | | | | 70,912 | 1,825,243 | 1,754,331 | 317 | 25 | 101 |
| | 2-(1) | 70,912 | | | | 70,912 | 1,677,590 | 1,606,678 | 290 | 3 | 92 |
| | 2-(2) | 70,912 | | | | 70,912 | 1,728,881 | 1,657,969 | 299 | 8 | 95 |
| Composting only | 3-(1) | | 102,600 | 242,369 | | 344,969 | 2,266,906 | 1,921,937 | 347 | 30 | 110 |
| | 3-(2) | | 102,600 | 242,369 | | 344,969 | 2,129,245 | 1,784,276 | 322 | 27 | 102 |
| | 4-1 | | 102,600 | 242,369 | | 344,969 | 2,090,538 | 1,745,569 | 315 | 23 | 100 |
| | 4-(2) | | 102,600 | 242,369 | | 344,969 | 2,085,986 | 1,741,017 | 314 | 22 | 100 |
| Incineration only | 5 | | | | 931,828 | 931,828 | 2,716,294 | 1,784,466 | 322 | 28 | 102 |
| | 6 | | | | 931,828 | 931,828 | 2,721,144 | 1,789,316 | 323 | 29 | 103 |
| Composting + landfill | 7 | 58,752 | 102,600 | | | 161,352 | 1,880,777 | 1,719,425 | 310 | 21 | 98 |
| | 8 | 58,752 | 102,600 | | | 161,352 | 1,842,588 | 1,681,236 | 303 | 15 | 96 |
| | 9 | 50,048 | 84,024 | 94,487 | | 228,559 | 1,867,641 | 1,639,082 | 296 | 4 | 94 |
| | 10 | 50,048 | 84,024 | 94,487 | | 228,559 | 1,811,530 | 1,582,971 | 286 | 1 | 91 |
| Incineration + composting | 11 | | 102,600 | | 772,038 | 874,638 | 2,631,160 | 1,756,522 | 317 | 26 | 101 |
| | 12 | | 102,600 | | 772,038 | 874,638 | 2,621,270 | 1,746,632 | 315 | 24 | 100 |
| | 13 | | 84,024 | 94,487 | 657,662 | 836,173 | 2,518,712 | 1,682,539 | 304 | 16 | 97 |
| | 14 | | 84,024 | 94,487 | 657,662 | 836,173 | 2,508,540 | 1,672,367 | 302 | 12 | 96 |
| Incineration + landfill | 15 | 55,552 | | | 201,840 | 257,392 | 1,968,811 | 1,711,419 | 309 | 20 | 98 |
| | 16 | 55,552 | | | 201,840 | 257,392 | 1,908,461 | 1,651,069 | 298 | 6 | 95 |
| Incineration + Composting + Landfill | 17-(1) | 43,392 | 102,600 | | 201,840 | 347,832 | 2,049,121 | 1,701,289 | 307 | 18 | 97 |
| | 17-(2) | 28,032 | 102,600 | | 403,680 | 534,312 | 2,203,834 | 1,669,522 | 301 | 11 | 96 |
| | 18-(1) | 43,392 | 102,600 | | 201,840 | 347,832 | 2,002,881 | 1,655,049 | 299 | 7 | 95 |
| | 18-(2) | 28,032 | 102,600 | | 403,680 | 534,312 | 2,197,370 | 1,663,058 | 300 | 9 | 95 |
| | 19-(1) | 34,688 | 84,024 | 94,487 | 201,840 | 415,039 | 2,057,872 | 1,642,833 | 297 | 5 | 94 |
| | 19-(2) | 19,328 | 84,024 | 94,487 | 403,680 | 601,519 | 2,274,544 | 1,673,025 | 302 | 14 | 96 |
| | 19-(3) | 19,328 | 74,844 | 103,913 | 403,680 | 601,765 | 2,266,743 | 1,664,978 | 301 | 10 | 96 |
| | 19-(4) | 7,219 | 74,844 | 103,913 | 562,797 | 748,773 | 2,452,955 | 1,704,182 | 308 | 19 | 98 |
| | 20-(1) | 34,688 | 84,024 | 94,487 | 201,840 | 415,039 | 2,019,808 | 1,604,769 | 290 | 2 | 92 |
| | 20-(2) | 19,328 | 84,024 | 94,487 | 403,680 | 601,519 | 2,273,998 | 1,672,479 | 302 | 13 | 96 |

Fig. 4.21 Change of unit treatment and disposal cost




Remark ● Total cost without revenue.
○ Total net cost (with revenue)

b. The unit treatment and disposal cost in most cases excluding some cases of total volume landfilling is higher than that of 1979 (315 Baht/t). The highest are the total volume incineration cases which reach 491 Baht/t, 1.6 times as much as 1979-year cost (excluding revenue from resource recovery).

   The mean value of the unit costs of all cases is 387 Baht/t.

c. When the prospective revenue from resource recovery is taken into account, total cost of each Master Plan alternative averages 300 Baht/t (the mean value is 307 Baht/t). The difference between the largest total cost and the smallest total cost is much less than the difference in the case without accounting for resource recovery revenue.

d. Even if compost treatment capacity is increased from 1,120 to 1,920 t/d, treatment cost as a whole will not change much. (Only about 1% will be reduced on average in all cases of 'composting + landfill', 'incineration + composting' and 'incineration + composting + landfill'.)

e. Increasing the number of incineration plants increases the total cost. In the case of 'incineration + composting + landfill', increase of one incineration plant increases total cost about 10% for every plant.

f. Application of land-to-land transport transfer to suburban type alternatives (total volume landfill and total volume composting) reduces total cost 2% - 8% but it does not contribute much to the cost of alternatives which involve incineration plants located near the city center.

g. Land-to-river transport transfer is effective only in one case (No. 14) which is composed of incineration and composting; no effect can be expected with its application to any other case. Solid waste transport along the waterway was concluded to be impractical because of the difficulty to acquire the land.

### 4.5.4 Selection of the appropriate Master Plan alternatives

(1) Evaluation items

In order to select the appropriate Master Plan alternatives, selection of evaluation items is required with which the process and results of the reduction can be justified. The criteria should be agreeable by both parties who have formulated the Master Plan alternatives and who will be implementing the Plan.

Each evaluation items is composed of evaluation factor(s) which are further composed of more detailed evaluation elements.

As evaluation factors, the four goals of the Study (namely, economy, environmental protection, resource recovery, and consistency with BAM's administrative conditions) are believed to be reasonable with the addition of 'technology' which includes an evaluation of each Master Plan alternative from an overall technical point of view.

Other than the evaluation items, one constraint for selection of the alternatives is that "several Master Plan alternatives must not be selected from any one of the seven treatment and disposal types."

By this constraint, selection of similar cases of the Master Plan alternatives can be avoided and, as a result, a variety of appropriate Master Plan alternatives may be selected.

i) Evaluation method and items

To develop each evaluation factor, evaluation elements were formulated which are in line with the character and purpose of the Study.

After detailed examination, the specific evaluation factors and elements (evaluation items) were determined as shown in Table 4.12.

The deterministic evaluation method was adopted. The general features of the evaluation methods are introduced in Appendix 4.14.

ii) Rating method

For rating, three-rank symbols 'a', 'b' and 'c' were mainly used. Compared with the popularly used 5-rank method or 10-rank method, the 3-rank method has advantages in high sensitivity, simplicity and reproducibility.

In addition to these advantages, there are some more reasons which necessitated application of 3-rank rating method.

Since most of the evaluation items (except cost-related items) are qualitative items, quantification would be difficult or meaningless.

a. Rating with evaluation elements

Applying evaluation items each Master Plan alternative was evaluated and given one of the three ranks; 'a' for good, 'b' for fair, and 'c' for poor. For some evaluation items, judgement worlds 'good', 'fair' and 'poor' might not fit in which case, 'a' was given to advantageous alternatives in terms of the evaluation element, 'b' to the average alternatives and 'c' to disadvantageous ones.

b. Rating with qualitative and quantitative evaluation elements

Relative evaluation was applied to rating with qualitative evaluation elements since the rating is based on a kind of merit system, and several Master Plan alternatives could all receive an 'a' for the same evaluation element.

Only two quantitative evaluation elements were adopted in the Study and both relate to cost: W1 (total treatment and

Table 4.12 Evaluation items

| Evaluation factor | | Evaluation element | | Explanation |
|---|---|---|---|---|
| V | Technology | V1 | Reliability of the system. | Flexibility, applicability and adaptability of the system. |
| | | V2 | Ease of operation | Technical standard and size of organization required for the operation. |
| | | V3 | Practicability of the Plan | Possibility of the facilities site acquisition and appropriateness of facilities location |
| W | Economy | W1 | Unit treatment and disposal net cost | Amount after subtracting revenue from resource recovery from treatment and disposal cost. (permission of solid waste). |
| X | Environmental protection | X1 | Adaptability to natural environmental cycles. | Reduction of burden to environment. Grade of solid waste stability and volume-reducibility. |
| | | X2 | Ease to pass anti-pollution standards. | |
| | | X3 | Reliability of operation of pollution prevention equipment | Facility of operation and maintenance of equipment according to quality and quantity of pollutant to be treated. |
| Y | Resource recovery | Y1 | Significance of resource recovery. | Saving of virgin resources. Social requirement. |
| | | Y2 | Marketability of recovered resources. | Ease of sales and market development. |
| | | Y3 | Stability of supply to the market | Balance between demand and supply. |
| Z | Administrative situation | Z1 | Coordination with the existing system. | Sufficiency of the improvement. |
| | | Z2 | Reasonableness for budgeting. | Utilization of the existing compost plants. Minimizing rise of overheads. |
| | | Z3 | Adaptability to the administrative organization. | Modification of the organization. Necessity to secure competent personnel. |
| | | Z4 | Adequacy of solid waste management system. | Appropriateness of the system to Bangkok in the year 2000. |
| | | Z5 | Balance with the other urban institutions | Availability of urban transportation system, sewer system, water supply, power supply, telecommunication system, etc. |

Note: In selection of the appropritate Master Plan alternatives from the prospective alternatives, not more than one alternative should be selected from the same treatment and disposal type.

disposal cost per ton of solid waste) and Z2 (reasonableness for budgeting). After rating the Master Plan alternatives in terms of the cost criteria, a summary table was produced according to their economic advantage in terms of the evaluation element, and rank was given to the alternatives by levels.

(2) Evaluation method

According to the following method and conditions, evaluation and selection on 30 cases of the Master Plan alternatives was made to select the most appropriate Master Plan alternatives.

1) Process of the evaluation

Through the work process shown in figure 4.22 which contains three evaluation and selection sequences, three appropriate Master Plan alternatives were finally selected. By means of repetitive evaluation and selection, the required accuracy of evaluation for each stage was maintained.

Process of the evaluation and selection is as follows:

- N1 cases of the typical Master Plan alternatives which represent each of seven treatment and disposal types were selected from among the 30 cases of the Master Plan alternatives.
- Evaluation was made on the N1 cases of the selected alternatives for four evaluation factors: (W) economy, (X) environmental protection, (Y) resource recovery, and (Z) administrative situation; and N2 cases of the prospective Master Plan alternatives were selected.
- Final and overall evaluation was made on the N2 cases of the prospective alternatives from the technical point of view, and N3 final appropriate Master Plan alternatives were selected. In this selection, the constraint that "not more than one appropriate Master Plan alternative shall be selected from the same treatment and disposal type" was applied and, consequently, three cases of the appropriate Master Plan alternatives were selected from among the best alternatives in each treatment and disposal type.

ii) Ranking of the Master Plan alternatives

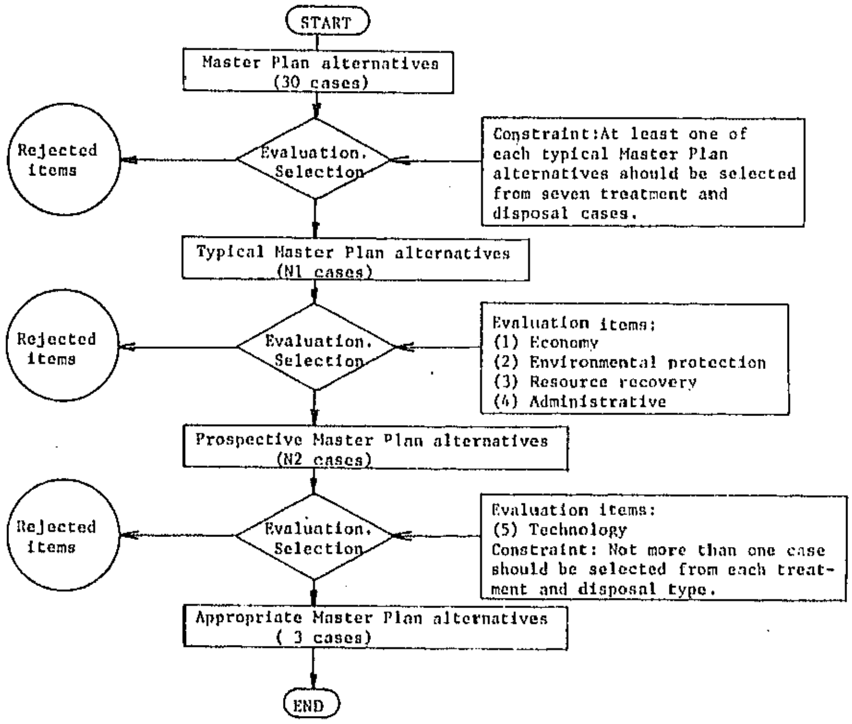
Higher rank was given to the alternative which had more 'a's than others, provided it had no 'c's.

In the final evaluation, results of rating with evaluation factors were reviewed and respected.

iii) Rating

Five evaluation factors and 15 evaluation elements shown in table 4.12 were adopted and the rating method given in Appendix 4.15 was used. 2-rank rating method with ranks 'a' and 'b' was applied to particular evaluation elements. [Note: However, most of the elements were rated with 3-rank rating method (a, b and c)].

Fig. 4.22 The process of evaluation



(3) Evaluation

i) Selection of typical (N1) cases of the Master Plan alternatives

According to the following conditions, N1 cases of the Master Plan alternatives which are typical of each treatment and disposal type were selected from among the 30 Master Plan alternatives:

a. One or more Master Plan alternative typical of each treatment and disposal type will be selected from seven types.

b. The alternatives which have well-balanced location of treatment and disposal facilities will be selected.

c. The alternatives which coordinate with the existing solid waste management system will be selected.

d. The most economical alternatives will be selected.

As result, 15 cases of the Master Plan alternatives were selected as shown in Table 4.13.

ii) Selection of N2 cases of the prospective Master Plan alternatives

The selected 15 cases and seven types were undertaken for the second evaluation and selection, where the evaluation was made applying four evaluation factors: (W) economy, (X) environmental protection, (Y) resource recovery, and (Z) administrative situation and 12 evaluation elements. Rating of the 15 cases was made using the same method as explained in Appendix 4.15.

Results of the second evaluation and the selected prospective N2 Master Plan alternatives are shown in Table 4.14.

The nine selected prospective N2 Master Plan alternatives are as follows: Case No. 9 and 10 from composting + landfill type, Case No. 13 and 14 from composting + incineration type, and Case No. 17-(2), 18-(2), 19-(2), 19-(4), and 20-(2) from composting + incineration + landfill type.

Some alternatives were rated with 'c' in evaluation elements Z1 (consistency with the existing solid waste management system) and Y2 (marketability of recovered resource) and, consequently, they were rejected during the second selection.

iii) Selection of the final appropriate Master Plan alternatives

To select three final appropriate Master Plan alternatives, the third evaluation and selection was made on the nine cases of the prospective Master Plan alternatives from the view point of technology (V) applying three evaluation elements: V1 (reliability of the system), V2 (ease of the operation), and V3 (practicability of the plan). Taking the before-mentioned constraints into account, three final appropriate Master Plan alternatives were selected from three different treatment and disposal types. Results of the third evaluation and the selected final appropriate Master Plan alternatives are shown in Table 4.15. The selected

## Table 4.13 $N_1$ Master Plan alternatives (15 cases)

| Alternative treatment and disposal system | Case No. | Treatment & disposal volume. Number of facility sites. | | | | | | | | Cost per ton of solid waste (Baht/t) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Incineration | | Composting | | Final disposal | | Transfer facilities | | Treatment cost | Collection & transport cost | Revenue from resource recovery | Ordinary expenses *1 | Total treatment and disposal net cost *2 |
| | | t/d | No. of sites | t/d | No. of sites | t/d | No. of sites | t/d | No. of sites | | | | | |
| Landfill only | 1-(2) | | | | | 5,540 | 5 | | | 329 | 173 | 13 | 243 | 316 |
| | 2-(2) | | | | | 5,540 | 5 | 3,098 | 19 | 312 | 123 | 13 | 218 | 299 |
| Composting only | 3-(2) | | | 5,540 | 5 | | | | | 384 | 157 | 62 | 299 | 322 |
| | 4-(2) | | | 5,540 | 5 | | | 2,168 | 14 | 377 | 127 | 62 | 287 | 315 |
| Incineration only | 5 | 5,540 | 5 | | | | | | | 490 | 126 | 168 | 256 | 322 |
| Composting + landfill | 9 | | | 1,630 | 5 | 3,910 | 5 | | | 337 | 164 | 41 | 255 | 296 |
| | 10 | | | 1,630 | 5 | 3,910 | 5 | 2,412 | 17 | 327 | 129 | 41 | 239 | 286 |
| Incineration + composting | 13 | 3,910 | 4 | 1,630 | 5 | | | | | 455 | 130 | 151 | 263 | 304 |
| | 14 | 3,910 | 4 | 1,630 | 5 | | | 516 (357) | 5(1) | 453 | 125 | 151 | 260 | 302 |
| Incineration + landfill | 16 | 1,200 | 1 | | | 4,340 | 5 | 2,280 | 16 | 344 | 121 | 47 | 221 | 297 |
| Incineration + composting + landfill | 17-(2) | 2,400 | 2 | 950 | 3 | 2,190 | 5 | | | 398 | 145 | 96 | 253 | 302 |
| | 18-(2) | 2,400 | 2 | 950 | 3 | 2,190 | 5 | 771 | 8 | 397 | 131 | 96 | 247 | 301 |
| | 19-(2) | 2,400 | 2 | 1,630 | 5 | 1,510 | 5 | | | 411 | 136 | 109 | 253 | 302 |
| | 19-(4) | 3,346 | 3 | 1,630 | 4 | 564 | 3 | | | 443 | 132 | 135 | 259 | 308 |
| | 20-(2) | 2,400 | 2 | 1,630 | 5 | 1,510 | 5 | 297 | 4 | 410 | 131 | 109 | 250 | 301 |
| | | | | | | | | Average | | 391 | 137 | 86 | 254 | 305 |

Note. *1. *Ordinary expense is the sum of collection, transport, operation and maintenance cost of the facilities.*
*2. The net cost was obtained by subtracting revenue from resource recovery from treatment cost. (ref. Appendix 4.15)
. Figures in ( ) show number of land-to-river tranfer facilities and solid waste volume handled at the facilities.
. The final landfill volume is landfilled raw waste volume which does not include rejected compost, compost residue, and incineration residue.
. Each cost per ton of solid waste is the net cost and does not include overheads (ordinary expenses) of the head office.
Treatment costs do not include costs of collecting solid waste from roads, rivers and Khlongs.

Table 4.14 Selection of prospective $N_2$ Master Plan alternatives

| Alternative treatment and disposal systems | | Economy (W) | Environmental protection (X) | | | Resource recovery (Y) | | | Administrative situation (Z) | | | | | Total ranking | | | Selection results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Case No. | W1 | X1 | X2 | X3 | Y1 | Y2 | Y3 | Z1 | Z2 | Z3 | Z4 | Z5 | a | b | c | |
| Landfill only | 1-(2) | b | b | b | b | b | a | b | c | a | a | b | b | 3 | 8 | 1 | |
| | 2-(2) | a | b | b | b | b | a | b | c | a | a | b | b | 4 | 7 | 1 | |
| Composting only | 3-(2) | b | a | a | b | a | c | a | b | b | a | a | a | 7 | 4 | 1 | |
| | 4-(2) | b | a | a | b | a | c | a | b | b | a | a | b | 6 | 5 | 1 | |
| Incineration only | 5 | b | a | a | a | a | a | b | c | b | b | a | a | 7 | 4 | 1 | |
| Composting + landfill | 9 | a | b | b | b | b | a | b | a | b | a | b | b | 4 | 8 | | ○ |
| | 10 | a | b | b | b | b | a | b | a | a | a | b | b | 5 | 7 | | ○ |
| Incineration + composting | 13 | a | a | a | a | a | a | b | a | b | b | a | a | 9 | 2 | | ○ |
| | 14 | a | a | a | a | a | a | b | a | b | b | a | a | 9 | 2 | | ○ |
| Incineration + landfill | 16 | a | b | b | b | b | a | b | c | a | a | b | b | 4 | 7 | 1 | |
| Incineration + composting + landfill | 17-(2) | a | a | a | b | b | a | b | a | a | a | a | a | 9 | 3 | | ○ |
| | 18-(2) | a | a | a | b | b | a | b | a | a | a | a | a | 9 | 3 | | ○ |
| | 19-(2) | a | a | a | b | a | a | b | a | a | a | a | a | 10 | 2 | | ○ |
| | 19-(4) | a | a | a | a | a | a | a | a | b | b | a | a | 10 | 2 | | ○ |
| | 20-(2) | a | a | a | b | a | a | b | a | a | a | a | a | 10 | 2 | | ⊙ |

Table 4.15 Selection of the appropriate Master Plan alternatives

| Treatment and disposal type | Case No. | Technological viewpoint (V) | | | Selection Results | Unit treatment and disposal net cost per ton of solid waste (Baht/t) | Incineration (t/d) | Composting (t/d) | Landfill (t/d) | Transfer (t/d) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | V1 | V2 | V3 | | | | | | |
| Composting + landfill | 9 | b | a | a | O | 296 | | 1,630(5) | 3,910(5) | |
| | 10 | b | a | b | | 286 | | 1,630(5) | 3,910(5) | 2,412(17) |
| Incineration + composting | 13 | a | b | a | O | 304 | 3,910(4) | 1,630(5) | | |
| | 14 | a | b | b | | 302 | 3,920(4) | 2,630(5) | | 516(5)<br>(351)(1) |
| Incineration + composting + landfill | 17-(2) | a | a | a | | 302 | 2,400(2) | 950(3) | 2,190(5) | |
| | 18-(2) | a | a | b | | 300 | 2,400(2) | 950(3) | 2,190(5) | 771(8) |
| | 19-(2) | a | a | a | O | 302 | 2,400(2) | 1,630(5) | 1,510(5) | |
| | 19-(4) | a | b | a | | 308 | 3,346(3) | 1,630(4) | 564(3) | |
| | 20-(2) | a | a | b | | 302 | 2,400(2) | 1,630(5) | 1,510(5) | 297(4) |

Note 1) Unit treatment and disposal net cost (Baht per ton of solid waste) is the cost from which the expected revenue from resource recovery was reduced. It does not contain headoffice overheads and costs for collection of solid waste from roads, rivers and khlongs.

2) Figures in parentheses show number of plants and stations.

3) Example: In case No. 14, (357)(1) indicates solid waste volume 357 t/d to be handled at 1 transfer station.

final appropriate Master Plan alternatives are as follows:

Case No. 9 from composting + landfill type,

Case No. 13 from composting + incineration type,

Case No. 19-(2) from composting + incineration + landfill type.

None of these cases involve transport transfer. The estimate by the Study team indicated that, in the case of Bangkok city, introduction of transport transfer is economical only when the transport distance is about 12 km or longer.

The cases involving transport transfer, none of which could have survived three routines of evaluation and selection, were re-examined to make clear the reasons why they were eliminated.

Case No. 10 has 17 transfer stations in the city center areas, which are expected to save 10 Baht per ton of the total treatment and disposal cost; however, the planned transfer stations are all located in the already densely-populated areas so that acquisition of the site should be extremely difficult; from this aspect, Case No. 10 is regarded as impractical.

Three other with-transfer cases (No. 14, 18-(2), and 20-(2)) also have the same difficulties as above and, what is worse, hardly any economic benefit by introduction of the transfer system is expected.

It should be noted that Case No. 19-(2) was selected from composting + incineration + landfill type as one of the appropriate Master Plan alternatives in priority to Case No. 17-(2) of the same type despite the latter was given equivalent rating to the former in the final evaluation. This is due to the fact that, compared with Case No. 17-(2), Case No. 19-(2) was given higher rate in the second evaluation (Case No. 19-(2) is advantageous in terms of overhead cost and collection and transport cost) and it was larger intermediate treatment capacity; therefore, it can be said to be a more stable treatment and disposal system.

(4) Presentation of the appropriate Master Plan alternatives

Selected three appropriate Master Plan alternatives are described as follows:

a. Selected three treatment and disposal types of the Master Plan were following combinations.

   Composting + landfill, composting + incineration, and composting + incineration + landfill.

b. Reflecting the results of compost marketing research, establishment of two more compost plants, with respective capacities of 260 and 540 t/d (plant scale basis) in addition to the existing compost plants, are planned in every case.

   With these five compost plants, 1,630 t/d of solid waste on an average will be processed and 245 t/d of compost produced.

Aerated composting method will be introduced in the additional compost plant as it is more reliable and economical in operation than the currently adopted high rate composting method.

If material retrieval is required, it can be achieved by putting additional classification equipment into processing line in the new compost plant.

c. Incineration plant

In case No. 13, four incineration plants [(1,500 t/d) x 1 plant, (1,200 t/d) x 1 plant, and (1,100 t/d) x 2 plants] with a total of 4,900 t/d capacity will be established to cope with a total of 3,910 t/d of solid waste.

In case No. 19-(2), two plants [(1,500 t/d) x 2 plants] with a total of 3,000 t/d capacity will be established for incineration treatment of an average of 2,400 t/d of solid waste.

Attached waste heat boiler incinerators will be installed in all incineration plants to recover steam for power generation. Electric power volume to be recovered from one ton of solid waste is estimated from 150 to 270 kW·h.

d. Final disposal site

In case No. 9, 3,910 t/d of solid waste is planned to be directly distributed to five final disposal sites for immediate landfill.

In case No. 13, no raw waste will be directly landfilled since total volume of collected solid waste is planned to be intermediately treated.

In case No. 19-(2), 1,510 t/d of raw waste is to be directly landfilled at five disposal sites.

In every case, landfill is to be made using the sanitary landfill method.

e. Transfer facilities

No case involves transport transfer since, as already mentioned, it produces little economic merit and land acquisition for transfer stations is impractical. Notwithstanding, the value of the transfer method should not be judged only from the aspect of transport cost saving, but also should be viewed in terms of utility as temporary solid waste storage which assures transport in case of emergency such as breakdown of treatment or disposal facilities.

Two appropriate final Master Plan alternatives among three happened to be planned to construct incineration plants at the outskirts of the city which also is suitable for setting up transfer stations. Therefore, if transfer facilities are attached to these incineration plants, they will be able to assure normal transport even if unexpected problems arise with the treatment and disposal facilities.

Unit treatment and disposal cost and total investment cost required to execute the selected three appropriate Master Plan alternatives were summarized as shown in Table 4.16 and location and capacity of the facilities planned in the appropriate Master Plan alternatives were shown in Table 4.17. Location of the proposed facilities and solid waste transport destination were shown in Appendix 4.16.

(5) Comments and recommendations

Through the evaluation described in this paragraph, three appropriate Master Plan alternatives were selected from 30 prospective Master Plan alternatives.

In the year 2000, about 5,500 tons of solid waste is forecast to be collected daily from the entire metropolitan Bangkok area. To cope with this enormous volume of solid waste without problems, smooth operation of a sophisticated and huge solid waste management system is indispensable.

Comments and recommendations are summarized as follows:

a. In every case, unit treatment and disposal net cost (including operation and maintenance cost, headoffice overhead and roads and canales clearing cost) is below within 385 Baht/t. Based on the forecase share in GPP of Bangkok city in the year 2000 to be paid for maintenance of sanitary administration activities, the figure of 385 Baht/t is thought to be reasonable from the socio-economic point of view.

b. Case No. 9 is intended to maintain the existing solid waste management system while the case No. 13 is aimed at total volume intermediate treatment. Case No. 19-(2) can be said to be a combination of these two alternatives. The variety of alternatives will enable flexible selection of the Master Plan.

c. Prior to construction of new compost plants, qualitative improvement of the compost produced in the existing plants and development of compost market should be endeavoured.

d. Transfer facilities should be attached to incineration plants in order to secure flexible solid waste transport.

Table 4.16 Costs of the appropriate Master Plan alternatives

| | | Number of plants | | | Unit cost (Baht/t)*2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Alternative treatment and disposal system | Case No. | Incineration | Composting | Landfill | *3 Total cost | Treatment & disposal cost | Collection & transport cost | Revenue from resource recovery | *4 Ordinary expenses | Facilities investment cost*1 (million Baht) |
| Composting + landfill | 9 | – | 5 | 5 | 296 | 337 | 164 | 41 | 255 | 2,252 |
| Incineration + composting | 13 | 4 | 5 | – | 304 | 455 | 130 | 15 | 263 | 6,322 |
| Incineration + composting+ landfill | 19–(2) | 2 | 5 | 5 | 302 | 411 | 136 | 10 | 253 | 4,702 |

*1 Excluding land acquisition, and maintenance and operation cost

*2 Unit treatment and disposal cost does not contain headoffice overheads and costs for collecting solid waste from roads and khlongs.

*3 Revenue by resource recovery subtract from total required investment cost.

*4 Ordinary expenses are expressed as a sum of collection, transport, operation and maintenance cost included in investment for the facilities.

Table 4.17 Location and capacity of the facilities planned in the appropriate Master Plan alternatives

| Alternative treatment and disposal System | Case No. | Facilities | Treatment or disposal volume (t/d) | Capacity (t/d) | Location | Remark |
|---|---|---|---|---|---|---|
| Compost-ing + Landfill | 9 | Compost plant (1) | 540 | 640 | On-Nooch | The existing plant |
| | | " (2) | 270 | 320 | Ram Intra | -do- |
| | | " (3) | 217 | 260 | Bang Khun Tian | |
| | | " (4) | 463 | 540 | Taling Chan | |
| | | " (5) | 140 | 160 | Nong Khaem | The existing plant |
| | | Landfill (1) | 1,558 | | On-Nooch | -do- |
| | | " (2) | 2,072 | | Nong Khaem | -do- |
| | | " (3) | 255 | | Ram Intra | -do- |
| | | " (4) | 15 | | Bung Phrayasalum | -do- |
| | | " (5) | 10 | | Bung Tanode | -do- |
| Incinera-tion + Compost-ing | 13 | Compost plant (1) | 540 | 640 | On-Nooch | The existing plant |
| | | " (2) | 270 | 320 | Ram Intra | -do- |
| | | " (3) | 217 | 260 | Bang Khun Tian | |
| | | " (4) | 463 | 540 | Taling Chan | |
| | | " (5) | 140 | 160 | Nong Khaem | The existing plant |
| | | Incineration plant (1) | 1,200 | 1,500 | Yannawa | Residue is land-filled at On-Nooch |
| | | " (2) | 932 | 1,200 | Bang Kapi | -do- |
| | | " (3) | 881 | 1,100 | Bangkok Noi | Residue is land-filled at Nong Khaem |
| | | " (4) | 897 | 1,100 | Phasi Charoen | -do- |
| Incinera-tion + Compost-ing + Landfill | 19-(2) | Compost plant (1) | 540 | 640 | On-Nooch | The existing plant |
| | | " (2) | 270 | 320 | Ram Intra | -do- |
| | | " (3) | 217 | 260 | Bang Khun Tian | |
| | | " (4) | 463 | 540 | Taling Chan | |
| | | " (5) | 140 | 160 | Nong Khaem | The existing plant |
| | | Incineration (1) plant | 1,200 | 1,500 | Yannawa | Residue is landfilled at On-Nooch |
| | | " (2) | 1,200 | 1,500 | Dusit | Residue is landfilled at Nong Khaem |
| | | Landfill site (1) | 500 | | On-Nooch | The existing plant |
| | | " (2) | 941 | | Nong Khaem | -do- |
| | | " (3) | 44 | | Ram Intra | |
| | | " (4) | 15 | | Bung Phrayasalum | The existing plant |
| | | " (5) | 10 | | Bung Tanode | -do- |

Note. The operation rates are; 0.85 for each compost plant, and 0.80 for each incineration plant.