7.2 Basic Scheme of Sludge Treatment/Disposal

7.2.1 Methodology of Sludge Treatment/Disposal Planning

(1) General

In the technical terminology of the "Sludge Treatment/Disposal", the "Sludge Disposal" means the ultimate activities to release or return components of sludge into the nature in the manners like landfill, agricultural application, utilization as raw materials, etc. Meanwhile, the "Sludge Treatment" stands for the activities which process or treat sludge so as to meet the conditions or requirements for its disposal, prior to the disposal activities. The review of the experience and current practices in developed countries may bring about a certain indicative direction for the sludge treatment/disposal planning in BMA.

1) Japan

In Japan, the generated sludge increased at a rapid rate in parallel with the development of sewage facilities had become very problematic, especially in urban areas. The current methods of ultimate sludge disposal including beneficial uses correspondent with final treatment are summarized in Table 7.2.1.1.

While landfill disposal has still accounted for about a half share, the beneficial uses of sludge in Japan has been aggressively tackled and increasingly enlarged recently. The utmost scarcity in land space suitable for landfill sites contributes to the current status and the beneficial use-oriented disposal expectedly will be furthermore expanded in future. The current relationship between ultimate disposal and sludge treatment in Japan can be also seen in this table.

Table 7.2.1.1 Current Sludge Treatment and Ultimate Disposal in Japan

Final Treatment \ Ultimate Disposal	Disposal		Beneficial Uses		Others	Total
	Landfill Disposal at Inland	Landfill Disposal at Seaside	Agricultural Uses	Construction Materials		
Dewater	863	312	44	12	91	1,322 (57 %)
Incineration	108	125	11	35	17	296 (13 %)
Drying	28	0	12	0	0	499 (22 %)
Composting			471	0		
Thickening and Digestion	10	0	1	0	179	190 (8 %)
Total	1009 (44 %)	437 (19 %)	527 (23 %)	47 (2 %)	287 (12 %)	2,307 (100 %)

Note: Figures are shown in the unit of 1,000 m^3/year and based on the statistics as of 1995.

Source: Partly modified, "Utilization Guideline for Tree Planting in Urban Area by Using Sewage Sludge", the Ministry of Construction in Japan, 1995.

2) European Countries

In European countries, where are endowed with a long history in sewage, the preferred method of sludge disposal is utilization in agriculture, followed by landfill disposal. Nevertheless, the option for incineration of sludge is gaining more importance recently, because of the problems of increasing volumes and reduction in available space for sludge disposal.

(2) Determination Steps and Evaluation Parameters

The decision on how to treat and how to dispose sludge in BMA, which is the ultimate objectives in this Study, depends on various factors To make the decision, the following steps have been applied to this Study, as depicted in Figure 7.2.1.1:

- The 1st step: the analysis and understanding of sludge characteristics like organic constituents, nutrients, toxic substances, etc.,
- The 2nd step: the examination and the selection on final disposal alternatives ranging from beneficial uses to disposal,
- The 3rd step: the establishment of sludge treatment process suitable for respective final disposals, employing thickening, digestion, dewatering, etc., and
- The last step: the comparative study on the aggregation of sludge treatment facilities between individual and aggregated system, including sludge transportation.

The outcomes in each step has been evaluated from the viewpoints of :

- Technical reliability of applied method,
- Effectiveness to sludge volume minimization,
- Possibility of environment and human health risk to be caused by activities,
- Economical efficiency and effectiveness of applied technology,
- Availability of land area and human resources to realize schemes, and
- Beneficial utilization of natural resources.

7.2.2 Ultimate Sludge Disposal Options

(1) Options of Ultimate Sludge Disposal

The options for ultimate disposal of sludge may be categorized into just disposal and beneficial uses depending on whether the direct intention for the reuse of sludge is accommodated in their activities or not, as shown in Figure 7.2.2.1.

1) Disposal Options

Landfill disposal:

Landfill disposal, which takes place either inland or seaside, is a main stream method throughout the world at the present. This will still continue to be a large and reliable exit of sludge even in future, mainly because of its economical effectiveness.

Ocean dumping:

For sludge disposal, ocean dumping still takes place in limited countries. However, since the "London Treaty" was adopted with the motion that waste discharge into the ocean should be banned afterward 1995, newly planned schemes employing ocean dumping has been rarely heard in the wake of the increasing consciousness for the natural environment preservation.

Accordingly, landfill disposal out of the disposal options has been identified as the sole realistic option in BMA.

2) Beneficial Uses Options

In beneficial use options, certain substances in sludge like inorganic matters, organic matters as well as nutrient elements are utilized for specific purposes.

Organic fertilizer:

Since early times, sewage sludge has been used for organic fertilizer and, in some cases, soil conditioner, due to the suitable contents of organic and nutrients like nitrogen (N), phosphorus (P) and potassium (K). The technology in this field, which ranges from simple to sophisticated type in terms of sludge composting, has been almost established across the world. Given possible huge market size for compost fertilizer, as much as some 600 t DS/d in nearby provinces as detailed in the section 4.5, this is identified as a highly prospective option in BMA.

Construction materials:

This option utilizes mainly the inorganic portion in sludge as raw materials. Among possible and practical materials for construction are subbase material, concrete products, asphalt filler, cement materials, bricks, etc. In Japan, the reuse for construction materials is becoming the popular trend in many local communities, since this is regarded as the most ideal way from the viewpoint of resources recycling. This option, however, cannot necessarily result in the reasonable economic balance due to the necessity of high-cost sludge treatment like drying, incineration, and, in some cases, even pyrolysis.

Recovery of digestion gas:

The utilization of digestion gas generated in anaerobic biodegradation process is practical and, in some cases, even essential as fuel of a boiler and/or a gas turbine electric generator. One kg of typical sludge can produce methane predominant gas of some 600 Nm^3 equivalent to calorific value of about 3,000,000 kcal. This option has already become common practice in developed countries. When the sludge treatment facilities in BMA are equipped with digestion, the introduction of digestion gas recovery is recommendable at the early stage.

Fuel in co-incineration[1]:

Sewage sludge can be incinerated together with municipal solid waste (MSW), where MSW supplies the heat required for sludge drying, so that the combustion is self-sustainable without supplying auxiliary fuel. Sludge with solid contents higher than 20 % is reported to meet the above requirement, when mixed in MSW in the range of 71 : 29. While natural gas/oil is used as fuel in most of the power plants in Thailand, two power

[1] : Quoted from the Final Report of AIT Master Plan.

stations dependent on lignite as their fuel are under operation. Previous survey shows that theoretically all sewage sludge generated in BMA can be disposed of by burning in a power station after mixed with lignite.

Meanwhile, the rotary kilns for cement material making is reported as one of the technically possible alternatives. In this scheme, the utilization of sewage sludge as a fuel and inorganic source is aimed to reduce the cement production cost. While conceived as the utmost ideal manner from the viewpoint of energy and natural resources recycling, such options in co-incineration will remain at the lower priority for the time being. This is because these options have many issues to be solved technically, economically, as well as institutionally.

(2) Prioritized Ultimate Disposal Options

As seen from the above, in the broader classification of disposal, the time-wise priority for sludge disposal may be concluded as follows, based on the short-term and the long- term strategies as mentioned in the subsection 7.1.1:

1) In the short-term:

- To establish the safe and sound landfill disposal, using the landfill sites which are existing at present and developed afterward,
- On the other hand, to promote agricultural uses of as much sludge as possible in line with market demand of sludge compost, and
- To establish the recovery of digestion gas.

2) In the long-term:

- To progress the landfill more carefully in natural environment and human health,
- To continue and expand the effort for agricultural uses, and
- To promote maximum volume reduction and a various kind of beneficial uses, accompanied by technology research and development activities.

As mentioned above, both landfill disposal and agricultural use will continue to be the main pillar in ultimate sludge disposal in BMA.

7.2.3 Landfill Disposal Scheme

(1) Prospect of Landfill Sites

Landfill disposal, which can accommodate a large and secure volume of sludge, will continue to be a main stream of ultimate sludge disposal. Within or adjacent to BMA, there are several existing sites for landfill disposal in Kampangsaen, Lad Krabang, and Samuk Prakarn. Of them, Kampansaen in Nakhon Pathom Province, being used mainly for municipal solid waste (MSW) is the most promising site having a landfill capacity of some 38 million m^3. The sludge generated in BMA will be disposed here in the mode of "Co-Landfilling" with MSW.

To predict the remaining life of Kampansaen site, the following conditions are assumed:

1) MSW (municipal solid waste)

- Population in BMA: 8.0 million in 2000 to 11.9 million in 2020
- Waste generation rate: 500 g/cap/d in 2000 to 900 g/cap/d in 2020
- Collection ratio: 50 % in 2000 to 80 % in 2020

2) Sewage Sludge Generated in BMA

All the sludges generated in BMA are assumed to be disposed by landfilling, after dehydrated without digestion or composting.

- Dry solid base: 302 t/d,
- Dewatered sludge: 1,510 t/d (80 % moisture assumed)

As seen from Figure 7.2.3.1, the Kampansaen landfill site is evaluated to have enough capacity to cope with both MSW and sewage sludge in BMA for around 19 years. Given other existing and planned landfill sites besides this, BMA will not have a shortage of landfill capacity within the target year of 2020.

(2) Standards and Regulations of Landfill Disposal

1) General

The sludge generated by wastewater and night soil treatment has properties, which might cause nuisance issues to the environment and the human health. Therefore, different standards and regulations depending on their conditions and practice have been set out in many countries to prevent possible water pollution, air pollution, odor emission, etc. caused by landfilling activities.

a) Japan

The sludge generated from public sewage treatment is handled with special care, almost equally to that given to industrial waste, as it possibly contains some hazardous substances. Accordingly, the sludge for landfilling is regulated to meet the following input requirements:

- To be dehydrated less than 85% moisture, or to be incinerated less than 15% ignition loss,
- To not contain hazardous substances like heavy metals and toxic solvents beyond the limits given in Table 7.2.3.1 measured by the extraction examination using normal water[1]:

If sludge contains hazardous substances, it must be treated, so they are less than the standard values, by using proper method like cement solidification, incineration, pyrolysis, etc. Otherwise, sludge, must be disposed of in a strictly controlled type of landfill, which is perfectly isolated from the outside.

The normal sludge can be disposed in accordance with specified manners in the controlled-type of landfill site, which are equipped with adequate storage structures, leachate seepage, leachate collection and treatment systems, water quality monitoring system, disaster-proof facilities, etc. The technical standard for inland landfilling has been specified as 3.0 m depth of sludge layer for digested dehydrated sludge and 0.5 m depth layer for undigested dehydrated sludge.

Table 7.2.3.1 Criteria for Toxic Substances for Landfill Disposal in Japan

Measured Items	Units	Standards
Alkyl mercury compounds	mg/l	Not detected
Mercury (Hg) or its compound	mg/l	0.005
Cadmium (Cd) or its compound	mg/l	0.3
Lead (Pb) or its compounds	mg/l	3
Organic phosphorus compounds (Org-P)	mg/l	1
Hexavalent chromium (Cr^{+6})	mg/l	1.5
Arsenic or its compounds (As)	mg/l	1.5
Cyanide (CN)	mg/l	1
PCB	mg/l	0.003
Trichloroethylene	mg/l	0.3
Tetrachloroethiylene	mg/l	0.1

Source: Governmental Ordinance in Japan for Discernment Criteria for Solid Waste Containing Metal and Others.

Note: The standard values stand for the measurement results by the extraction examination with 10-times dilution.

b) Other Developed Countries

In Germany, landfill disposal of sewage sludge has been practiced extensively since old times. The sludge disposal to landfill sites, in the past,

[1]: Using not acid liquid but normal water, this examination is conducted to assess the leaching in the natural conditions after landfill disposal.

required a minimum dry solid (DS) content of 35 %. Thus, sludge had to be mechanically dewatered and post-treated by lime conditioning to raise the DS content of the sludge, also aiming to improve the soil mechanical properties of sludge. Meanwhile, new regulations for landfill disposal of solid wastes has given so called input criteria for a number of physical and chemical parameters. This appears to lead to a complete new orientation in treatment and disposal of sludge, making incineration a necessary treatment before landfill disposal.

In the United States, the EPA's sewage sludge use and disposal regulation covers landfill activities. Only the key points are highlighted here:

- The sludge should not be hazardous and there should be no occurrence of aquifer contamination by nitrate,
- The concentration of arsenic (As), chromium (Cr) and nickel (Ni) should be within the specified limits. If it does not comply a liner and leachate collection system may be required,
- Sludge should meet the designated pathogen requirement or should be treated by a certain-type process reducing the pathogens permitted by the authority, and
- The sludge should meet the certain level of the "Vector Attraction Reduction Criteria". This requires sludge to be treated by any one of the process of alkaline stabilization, thermal drying, composting or aerobic/anaerobic digestion in specified conditions.

2) Current Situation and Issues in BMA

In Thailand, the treatment and landfill disposal method for industrial wastes have been set up in the Notification issued by MOI[1]. It aims to control hazardous substances to be discharge from factories, like mercury (Hg), cadmium (Cd), chromium (Cr), lead (Pb), manganese (Mn), pesticides, insecticides and fungicides. The input quality standard for sludge generated from sewerage system, however, has not been established yet, while the concerned bodies reportedly is starting the preparation works. In terms of the practice for landfill disposal, the MOSTE has indicated the guideline for MSW, regarding application of liner system, leachate collection, removal and treatment system, gas control system, storm water management system, water quality monitoring requirements[2], etc. Practical countermeasure has not been taken yet.

---

[1]: Notification of the Department of Industrial Works, issued under Notification of the Ministry of Industry No. 1 B.E 2531 (1988)

[2]: Regulation and Guideline of Municipal Solid Waste Management, by Pollution Control Department, MOSTE (1998).

As clarified from the above, BMA has not been prepared well to cope with increasing sludge generation at present, with respect to the provision of standards and regulations for landfill activities of sludge. In this regard, much effort is required to this matter from now on.

(3) Sludge Properties Required for Landfill Disposal

Standards and regulations, which set the qualities for landfill sludge, have not been provided in BMA. The experience of developed countries has indicated that, at least, the dehydration of sludge is essential for the transportation of sludge, handling at disposal sites, prevention of nuisances and orderly landfilling. Although digestion as well as incineration (including pyrolysis) is desirable in terms of sludge stabilization and volume minimization, they are not necessarily regarded as indispensable for the sludge treatment in BMA. Thus, as the minimum pre-requisite for the sludge disposal, the dewatered-type sludge with some 85 % moisture is desirable.

Concerning hazardous substance contents of sludge, like heavy metals, organic solvents, organic chlorides, etc., it is strongly recommended that certain adequate limits be enacted to enhance "Green Disposal".

7.2.4 Agricultural Use Scheme

(1) Prospect of Agricultural Use

1) General

A meeting organized by the Department of Agriculture Extension (DOAE) was held to explore the current status of organic fertilizer in Thailand. This revealed that the current policy of the Thai Government was to promote to the use of organic fertilizer as the organic matter content, which is critical in most agricultural soils in Thailand. It was further noted that low efficiency turnover by use of chemical fertilizer in a soil with low organic content required the indispensable use of organic fertilizer and, therefore, farmers should apply chemical fertilizer in combination with organic fertilizer.

Together, experience in developed countries has indicated that one of the most ideal and promising options of sludge beneficial uses is the utilization as an organic fertilizer or a soil conditioner for agricultural lands, because of its high organic and nutrient content. The term "Agricultural Uses" in this Study incorporates all kinds of activities on the wastewater sludge related to agriculture, gardening, forestry, planting in park as well as turf-keeping in golf courses. The application of sludge can reclaim the deteriorated land areas, which due to lack of nutrients, soil organic matter, low pH, and low water holding capacity can not support the plant vegetation.

a) Past Experience in Thailand

In Thailand, the use of organic waste in agriculture has been mainly practiced in rural areas since the old times, where farmers use raw and/or stabilized animal manure and septage from septic tanks and cesspools to cultivate their crops. BMA had experienced the compost production of MSW for agricultural utilization before, while being suspended at the present. The production and trade of organic fertilizer by using cow manure, chicken manure, etc. has been reportedly marketed, though no precise statistical data has been available. In terms of the sludge generated from wastewater in BMA, the sludge from the Si Phraya Central WWTP and the Huay Kwuang Community WWTP are being used for parks, nurseries, etc., mixed with ash, coconut husk, soil, etc. without composting treatment. The dewatered sludge from the NSTPs at Nong Khaem and On-Nut are also partly utilized for parks and agricultural land. Thus, BMA has practically experienced agriculture use of sludge to a certain extent.

b) Sludge Application Experiment by AIT

Using the sludge generated in BMA, the AIT had previously conducted a set of pot and field experiment studies for grass and sunflower as the principal crops with a basic purpose of evaluating the plant response to different nitrogen-based sludge application rates. Yield along with pathogens and heavy metals in the crops and the soil were monitored. Also, the experiments were carried out with flowers, ornamental plants, vegetables, etc. These experiments showed that the characteristics of wastewater sludge in BMA have no severe technical constraints towards the applicability of the sludge in agriculture.

2) Demand and Market Survey

The demand and market survey conducted by the JICA Study Team in this Study found that the agricultural use of wastewater sludge is basically acceptable for farmers, if it is processed safely. It also has revealed that the present market size of approximately 600 t DS/d compost in nearby 10 provinces is far beyond the some 300 t DS/d of projected total sludge generation as of 2020 in BMA.

3) Perspective and Constraint in BMA

Given the technical research conducted and the experience of BMA and the foreseen market demand for sludge fertilizer, as mentioned before, it is certainly concluded that BMA bears a brilliant future for agricultural use of sludge. As learnt by developed countries' history, the agricultural use of sludge, however, is not necessarily so easy as expected, without such proper measures, like:

- Mitigation against adverse effects to the natural environment and human health, such as offensive odor, bias feeling for wastes, toxic substances like heavy metals, pathogens, etc., detrimental effects on the growth of crops by encouraging phytotoxicity, etc.,
- Standardization and legislation of organic fertilizer's quality and application/monitoring method to produce a controlled quality fertilizer and to apply duly,
- Storage of organic fertilizer to cope with the seasonal fluctuation in consumption, and
- Community organizations to produce, market, distribute, and disseminate the sludge fertilizer.

(2) Standards and Regulations of Agricultural Use

To promote agricultural use of sludge fertilizer, sludge fertilizer must be regarded as a consumable product in the fertilizer market. Its quality standards and application/monitoring criteria should be defined by a certain authorized methodology so as to be extensively used by farmers. The following information and experience in developed countries will be much useful to BMA.

1) Japan

In almost all cases in Japan, sludge is used for agriculture in the form of sludge compost, after properly treated in a composting process. Basically, such compost fertilizer is required to have specific qualities so as: to promote the growth of crops and plants without adverse effects; to be easily handled through storage and land application; and not to contain such heavy metals and others that cause detrimental effects by accumulation in soils and crops.

Toxic substances:

The maximum contents of arsenic (As), cadmium (Cd) and mercury (Hg) are specified in the laws related to the fertilizer control as 50 mg/kg, 5 mg/kg and 2 mg/kg, respectively. Compost fertilizer, at the same time, must meet the values specified by the "Determination Criteria for Solid Waste containing Metal and Others" for solid waste, as shown in Table 7.2.3.1. Besides this, the maximum content of copper (Cu) and zinc (Zn) are applied as preferable values like 600 mg/kg and 1,800 mg/kg, respectively. These limitations were set up to protect the natural environment and public health against toxic substances.

General properties:

Not legally but voluntarily, compost producer specified the product as: 35 % organic matters to DS, less than 20 of C/N ratio, more than 1.5 % nitrogen to DS, more than 2 % phosphorus (P_2O_5) to DS, less than 25 % alkali of DS, less than 50 % moisture and less than pH 8.5. In addition, each producer or distributor controls their qualities, by using appearance, odor, BOD, particle size, etc.

Application and monitoring:

The Notification of Japanese Government sets the management standards, which specify less than 120 mg/kg zinc (Zn) in the soil to prevent the deposit of heavy metal in soil This is because zinc (Zn) is regarded as the most representative indicator of heavy metal deposit in the soil. Besides this, the environmental standards of soil must be observed, regarding heavy metals, organic chlorides, organic solvents, etc. Furthermore, each local government authority designates respective standards for the compost qualities and application/monitoring criteria correspondent to respective local sludge characteristics, local soil conditions, and categories of local crops and plant.

The guidelines issued by local governments in Japan for the sludge application on agricultural land are attached in the "SUPPORTING REPORT L", for reference.

2) United States

The regulations implemented by the US Environmental Protection Agency (US-EPA) set the criteria for sludge quality and outline management practices that must be observed in land application of sludge. The regulations have established two classes of sludge quality based on heavy metal levels and pathogen levels. Sludge with low heavy metal levels and pathogen levels can be freely land-applied as commercial fertilizer. Sludge, which does not meet these standards and gain an "exceptional quality" classification, has some restrictions placed on their reuse application.

The regulations shown in Table 7.2.4.1 provide numerical limits for the ten heavy metals, like:

- When sludge meets the "high quality" metal contents in column (C), it can be land-applied, provided that the application rate does not exceed annual pollutant loading rates (column (D)),
- When sludge does not meet the "high quality" limits but does not exceed the ceiling content limits (column (A)), the sludge can be land-applied, provided that the cumulative pollutant loading rates in the column (B) as defined in Table 7.2.4.1 are not exceeded the annual pollutant loading rate in the column (D). Besides heavy metals, the regulations also create two classes with respect to pathogen reduction.

The regulation specifies routine sludge analyses for land application purpose. Among the items to be monitored are pH, dry solids, total-N, NH_4^+-N, NO_3^--N, total P and K, heavy metals (Zn, Cu, Ni, Pb, Mn, Cr), and, at least initially PCB, halogenated hydrocarbons, polynucear aromatic compounds,

The regulations also create two classes with respect to pathogen reduction, Class A and Class B. These classes are defined both by technology-based requirements and indicator bacteria (fecal coliform or salmonella) testing requirements. Class A indicator standard is less than 1,000 fecal coliforms per gram of dry sludge solids and Class B indicator standard is less than 2 million fecal coliforms per gram of dry sludge solids. Technology-based requirements include time and temperature criteria, time and pH criteria and other process-related limits.

The sludge in Class B is restricted for use to crops, turf, etc. that cannot be harvested within a certain period. There are no use restriction placed on sludge that meets Class A requirements. In addition to meeting quality and pathogen reduction requirements, sludge must also meet vector reduction (VAR) requirement. These ensure that the land applied sludge does not attract flies, mosquitoes, rodent, or other potential vectors.

Table 7.2.4.1 Pollutant Limits for Land Application in the U.S.

Items / (Units)	Ceiling concentration limits (A) (mg/kg)	Cumulative pollutant loading rates (B) (kg/ha)	"High Quality" pollutant concentration limits (C) (mg/kg)	Annual pollutant loading rates (D) (kg/ha/year)
Arsenic (As)	75	41	41	2.0
Cadmium (Cd)	85	39	39	1.9
Chromium (Cr)	3,000	3,000	1,200	150
Copper (Cu)	4,300	1,500	1,500	75
Lead (Pb)	840	300	300	15
Mercury (Hg)	57	17	17	0.85
Molybdenum (Mo)	75	-	-	0.90
Nickel (Ni)	420	420	420	21
Selenium (Se)	100	100	36	5.0
Zinc (Zn)	7,500	2,800	2,800	140

Note: All weights are on a dry weight basis and ceiling concentration limits represent absolute values.

Source: Sewage Sludge Use and Disposal Regulations (Part 503 Standards), US-EPA.

3) Germany

The German regulation for sewage sludge provides the definitions and standards for use of sewage sludge in agriculture, gardening and forestry. The instruments and targets employed for soil protection in Germany consist of three key components: standards for sludge and soil, limitations of applied amounts, and, restrictions on the application of sludge to specific areas.

The standards for sewage sludge on heavy metals and toxic organic shown in Table 7.2.4.2 limits the application of contaminated sludge in agriculture. Limitation of application, that is, 5 tons of dry solids per ha for 3 years restricts the pollutant load in the land. In the standards for the limit of background concentrations on the soil, high risk for heavy metal mobilization at low pH and light soil are considered along with the maximum uptake of nutrients through plants and the minimization of groundwater contamination and surface water.

Table 7.2.4.2 Sludge Regulation for Agricultural Use in Germany

Items (Units)	Maximum content of sewage sludge (mg/kg)	Maximum content of land soil (mg/kg)
Cadmium (Cd)	10 / 5*	1.5 / 1*
Chromium (Cr)	900	100
Copper (Cu)	800	60
Mercury (Hg)	8	1
Lead (Pb)	900	100
Nickel (Ni)	200	50
Zinc (Zn)	2,500 / 2,000*	200 / 150*

Note:
1) * marked: Lower standards are applied for soils with pH 5 to 6.
2) All weights are on a dry weight
3) Besides these heavy metals, organic-persistence pollutants are specified in the regulation.

Source: German Sewage Sludge Regulation, 1992

The restriction of application to certain areas is defined to avoid particularly the exposure of pathogens. These areas include vegetable and fruit fields, food crops, grass lands, natural parks and resorts and forest, unless sludge is disinfected. The regulation also restricts the application of sludge in the soil with less than pH 5 and to turf and grass land without pretreatment.

4) Other Countries

The standards for heavy metal contents related to the agricultural use of sludge, which are set in developed countries, are aggregated in Table 7.2.4.3, for reference.

(3) AIT Study in BMA

For the sludge generated in BMA, AIT had performed an extensive study to find out the feasibility of agricultural use of sludge, including the application experiment for grass, flowers, ornamental plants, and vegetables. The findings of the Study were;

1) Observation of application test

- As for heavy metals, the residual concentrations in the soil and the accumulation in the crops were found within the safe limits,
- A higher nitrogen (N) application rates were essential, because of slower mineralization process of nitrogen (N) in sludge,
- Survival rates of pathogens were found longer than mentioned in other studies,

- Either composting or lime treatment of sludge ensured safety against pathogens,
- A higher growth and biomass yield of perennial plant was observed with mixture of sludge and soil than sludge and soil alone, and
- An annual sludge application rate of 5 t-DS/ha was recommended.

2) Standards and regulations for the application of sludge as well as the monitoring in BMA and its surroundings:

- The sludge should not be applied normally to the soil below pH 5. Extensive monitoring is essential for the soil below pH 5.
- Monitoring of soil and crop parameters such as pH, CEC, N, P, K and heavy metals of concerns must be carried out following every 5 years application.
- The concentration limits of heavy metals in sludge are tentatively given as: 20 mg/kg of cadmium (Cd), 1,000 mg/kg of chromium (Cr), 900 mg/kg of copper (Cu), 25 mg/kg of mercury (Hg), 200 mg/kg of nickel (Ni), 1,000 mg/kg of lead (Pb) and 3,000 mg/kg of zinc (Zn)[1].
- Sludge to be applied the crops for eating row, must be a pathogen free product (for example, composted or lime treated), and
- Sludge must be applied to soil before planting or seeding.

(4) Current Status and Issues in BMA

As for the current regulation available in Thailand, which is related to the sludge application for agricultural use, the Section 3 of the Fertilizer Act B.E. 2518 (A.D. 1975) defines organic fertilizer. In this regulation[2], organic fertilizer is defined as the one derived from organic material, which is produced through the process of moisture, chopping, grinding, fermenting, shifting or other method but not the chemical fertilizer. In addition, under the same Act, a commercial producer of organic fertilizer for trade is obligated to report the production information to the official.

As understood from the above, the standards and regulations related to agricultural use of sludge have not been furnished in Thailand. Proper standards and regulations must be furnished to promote the use of sludge fertilizer, and to protect the natural environment and the human health. The local practice and requirements, conditions, customs and constraints must be accommodated there

[1]: AIT has proposed the alternative standard limits in the Seminar on September 10th, 1999. They are 400 mg/kg for nickel (Ni) and 10 mg/kg for mercury (Hg).

[2]: Section 3, Government Gazette, Special Volume 92, Part 5, January 9, 1975.

adequately. In this regard, an extensive and expeditious action is called to tackle the following, including a variety of multi-institutional issues:

a) Quality control of raw sludge materials and product:

This includes the technical and/or administrative countermeasures for the mitigation of heavy metal and other toxic substance intrusion into sewerage from a certain industries and other wastewater sources. The periodical and continuous monitoring of sewage and sludge is needed.

b) Establishment of application and monitoring techniques of application results:

Users of sludge fertilizer like distributors, farmers, etc. must be well-informed of the relevant techniques for proper application, monitoring of produce, soil, water environment, etc.

(5) Sludge Properties Required for Agricultural Use

In case sludge is used for fertilizer, following four possible types will be considered: composted sludge, dried sludge, dewatered sludge, and incinerated sludge.

1) Composted sludge:

The easy-degraded organic substances and a certain part of water in sludge is decomposed and vaporized through composting treatment. As a result, sludge does not exert harmful influences to crops and plant and farmers, is not degraded rapidly in the soil. Likewise, it can be stored for a long time and is easy-handled in transportation and land application. The fermentation heat in the course of compost processing contributes to the removal of pathogens and parasites in sludge.

2) Dried sludge:

Drying can improve the handling performance of sludge in transportation, storage and application and remove pathogens and parasites. In undigested sludge, however, easy-degraded organic matters, which possibly cause a rapid degradation in the soil still remain. Accordingly, digestion is prerequisite for the land application of dried sludge.

3) Dewatered sludge:

The handling of dewatered sludge is rather difficult, most-likely giving-off offensive odor at the time of land application. Pathogens and parasites, and easy-degraded organic matters remaining in sludge may cause problems for plants in sludge application for agricultural land.

4) Incinerated sludge:

Almost all the organic matters contained in sludge are lost by incineration. Incinerated sludge, however, can provide remaining phosphorus (P), magnesium (Mg), iron (Fe), etc., which can be used for fertilizer.

To compare the four forms of sludge as fertilizer, the following evaluation items are set:

- Value in fertilizer (weighting point = 1):
  This is evaluated by the contents of organic components and nutrients (N, P, K, etc) contained in fertilizer. While these are essential components for fertilizer, wastewater sludge usually may be seen to contain the necessary quantity. Therefore, its weighting point is the lowest.
- Performance of handling and storage (weighting point =2):
  This is evaluated by the physical and chemical properties of sludge, like water content, size, physical strength, biological stability, etc. This is deemed as relatively important index for sludge fertilizer.
- Performance of production cost (weighting point = 2):
  This means the production cost necessary for transportation, processing, storage, distribution, etc. To realize a large-scale marketing of sludge fertilizer, this is seen as relatively important index.
- Influence to environment and public health (weighting point = 3):
  This means the influences, which may be caused by the agricultural use of sludge. For example, they are the negative impact to natural environment and public health, which result from toxic substances contained in sludge. To start and enlarge the use of sludge fertilizer, this should be regarded as the highest importance.

The four forms of sludge fertilizer are compared in Table 7.2.4.4. The composted sludge for sludge fertilizer is proposed as the best suitable sludge form in BMA.

Table 7.2.4.4 Evaluation of Sludge Forms for Sludge Fertilizer

Items	Weighting point	Composted sludge		Dried sludge		Dewatered sludge		Incinerated sludge	
		Raw	Total score	Raw	Total score	Raw	Total score	Raw	Total score
Value in fertilizer	1	4	4	5	5	5	5	2	2
Performance of handling and storage	2	5	10	5	10	1	2	3	6
Performance of Production Cost	2	4	8	2	4	5	10	1	2
Influence to environment and human health	3	5	15	5	15	1	3	5	15
Total		37		34		20		25	

7.2.5 Conceptualization of Ultimate Sludge Disposal

Based on the result of ultimate disposal priority, landfill disposal and agricultural use, the scheme for ultimate sludge disposal toward 2020 in BMA has been discussed quantitatively. The possibilities and constraints on the landfill disposal and the agricultural use of sludge clarified in subsection 7.2.3 and 7.2.4 have been incorporated into this examination.

As identified before, a number of uncertainties exist in BMA at the present. They are:

- Heavy metal contents of sludge in the future, although considerable heavy metal intrusion has been identified in this Study,
- Standards and regulations of sludge fertilizer concerning heavy metal contents, nutrient content, etc., which proscribe for uses on agricultural land,
- Standards and regulations for sludge qualities for landfill disposal with respect to toxic substance content like heavy metals, organic phosphorus, organic chlorides, etc., and
- Marketing demand of sludge fertilizer to possible generation.

To set out the ultimate sludge disposal, a number of assumptions have been made:

1) Heavy metal contents:

It has been assumed that the sludge in the higher risk ranked service areas of more than or equal to the middle place (8th:Si Phraya Central WWTP) is regarded as the "High-Risk Sludge", which cannot be used for sludge fertilizer, and the sludge generated from the lower risk ranked service areas of less than the middle place is regarded as the "Low-Risk Sludge", which can be used for sludge fertilizer. Under this assumption, total amount of the high-risk sludge reaches 114 t DS/d in 2020, which is roughly equivalent to the design treatment capacity of 120 t DS at the Nong Khaem Sludge Treatment Central (STC).

Night soil sludge is seen as the low-risk sludge as a rule. However, night soil sludge generated in the Ratburana Central WWTP is regarded as high-risk, because this is mixed and treated together with high-risk sewage sludge. Meanwhile, all the sludges from Community WWTPs are assumed as low-risk sludge.

A certain standards and regulations, which regulates the input quality of sludge for landfill disposal, is assumed to become effective after 2010 to promote environmental-friendly landfill.

2) Sales amount of sludge fertilizer:

Even though the large market demand for sludge fertilizer in and around BMA has been identified, the actual sales amount in the future may be uncertain. This is basically depends on the market principal of "Supply" and "Demand". This Study assumed only two cases to be expedient: all of the low-risk sludge is consumed in the market, and half of the low-risk sludge is consumed.

Under the assumption of the heavy metal contents and marketing of sludge fertilizer, the following three scenarios of ultimate sludge disposal are presented, as shown in Table 7.2.5.1:

- Scenario 1: (Full agricultural use)
  All the low-risk sludge will be consumed for sludge fertilizer,
- Scenario 2: (Incineration introduction)
  Incineration is introduced after 2010 for 25 % of high-risk sludge, and
- Scenario 3: (50 % agricultural use)
  Half of low-risk sludge will be consumed for sludge fertilizer.

Table 7.2.5.1 Scenario for Ultimate Sludge Disposal in BMA

Scenario	Risk Categories for Heavy Metal		Remarks
	Low-Risk Sludge	High-Risk Sludge	
Scenario 1 (Full Agriculture Use)	All the sludges are used for organic fertilizer after composting.	All the sludges are disposed to the landfill site after dewatering.	
Scenario 2 (Incineration Introduction)	All the sludges are used for organic fertilizer after composting.	Up to 2009: All the sludges are disposed to the landfill site after dewatering. After 2010: 75 % of sludge are disposed to the landfill site after dewatering. The rest (25 %) is incinerated.	The incineration of sludge is assumed to be called for the period afterward 2010, under the following situations: A: Regulations or standards for the landfill disposal of heavy-metal-containing sludge are applied, B: Ultimate sludge volume reduction or beneficial uses of sludge is needed.
Scenario 3 (50 % Agricultural Use)	50 % of sludge is used for organic fertilizer after composting. The rest (50 %) of sludge is disposed to the landfill site after dewatering.	All the sludges are disposed to the landfill site after dewatering.	The selling of sludge compost is limited to 50 % of usable sludge quantity.

In these three scenarios, it should be noted that:

- The share of the high-risk sludge (some 38 % in 2020) is of a tentative use, determined by the risk evaluation method as previously mentioned. This percent can be lowered by enforcing the proper counter measure to prevent heavy metal intrusion into sewerage,
- The portion of marketable sludge fertilizer is highly flexible by nature, depending on conditions like: the qualities and price of sludge fertilizer product, related technical and commercial promotions, etc. The institutions and organizations concerned are required to enforce the market promotion.

The mass balances for these three scenarios are shown in Figure 7.2.5.1.

7.2.6 Sludge Treatment Scheme

(1) Terminal Conditions for Sludge Treatment

As already mentioned in the subsection 7.2.3 and 7.2.4, the required sludge properties in respective ultimate disposal schemes are:

- Landfill disposal scheme: to be dewatered or incinerated,
- Agricultural use scheme: to be composted.

In light of these conditions as well as the qualitative and quantitative requirements of sludge, the treatment system for the sludge from wastewater treatment system has been examined.

(2) Sludge Treatment Process Options

Sludge generated from wastewater treatment system comprises water accounting for almost all portion as well as a few inorganic matters and organic matters. While the purpose of sludge treatment is generally seen as volume minimization, sanitization, and improvement for handling, sludge treatment has the following operations from the physicochemical point of view:

Sludge treatment is diversified in the world. Sludge treatment process, in almost all cases, is not in the form of a single unit but in the combination of a number of unit process so as to mainly attain the economic effectiveness. The general categories of unit process commonly applied are summarized here along with their input conditions and output performances:

1) Sludge Thickening

- Input sludge condition: Sludge concentration 0.5 to 1.5 % DS
- Thickened sludge concentration: 2 to 6 % DS
- Process features:
  The concentration of sludge entering sludge treatment system tends to be widely varied depending on the operating conditions of wastewater treatment system, from 0.5 to 1.5 %, hourly and daily. The main function of thickening is to make its concentration steady normally from 2 to 6 % DS so as to attain the effective operation in subsequent treatment stages.

2) Sludge Digestion

- Input sludge condition: Sludge concentration 3 to 6 % DS
- Removal ratio of organic matters: 40 to 60 % DS
- Process features:
  Digestion is performed in slurry status of sludge, and is a stabilization process where biological degradation of organic compounds occurs in anaerobic circumstance. A portion of easy degradable organic matters is converted into mainly methane gas and carbon dioxide. In general, digestion is operated in the mesophilic temperature range of 30 to 37 °C. The total hydraulic retention time of 20 to 30 days are commonly applied

to sludge digestion, consisting of primary and secondary digestion compartment. Cylindrical or egg-shaped structure is primarily applied for the digester construction. A digester is commonly equipped with a desulfurizer, a gas holder, a boiler, and a exhaust gas burner. A power generator also accompanies, when electricity is recovered.

3) Sludge Dewatering

- Process features: Input condition: 2 to 6 % DS
- Performance: 75 to 85 % moisture content after dewatering

  Dewatering is used to convert slurry-state sludge into solid-state cakes. While dewatering method, in general, consists of various types such as vacuum filtration, centrifuge separation, pressure filtration, etc., belt press type dehydration is the most prevalent at present. Belt press type dewatering normally accommodates the function to separate water and filter water under pressing force in the wake of coagulation by polymer electrolyte dosage.

4) Sludge Incineration

- Input Condition : 70 to 85 % moisture content sludge cake
- Performance Rate: 90 to 100 % removal of organic matters
- Process Features:

  Sludge incinerator can incinerate almost all organic matters in dewatered sludge. It is normally operated under the temperature of 700 to 900 °C. The commonly utilized systems for sludge incineration are fluidized-bed, rotary-kiln and multiple hearth types. Among them, a multiple-hearth type is the most prevalent for sewage sludge. An incinerator is accompanied by sludge feeding, emission gas treatment, ash treatment and fuel supply facilities.

5) Sludge Composting

- Input condition: 70 to 85 % moisture cake
- Performance: 45 to 65 % removal ratio of organic
  40 to 60 % removal ratio of incoming water
- Process features:

  Composting is a biological process of sludge stabilization in which microorganisms in the presence of oxygen decompose organic matters. The result of composting is a humus-like product that may be used as a fertilizer or a soil conditioner. Biological decomposition of volatile organic matters increase the temperatures up to 50 to 70 °C. This high temperature not only destroys pathogens and parasites but also evaporates water in sludge. Composting takes place commonly in a rectangular or a cylindrical tank equipped with the devices for forced aeration, addition of bulking agent, agitation and conveyance of sludge, storage yard, etc.

Apart from this treatment process, there are various kinds of processes, like drying, ozonization, wet oxidation, pyrolysis, and a certain kind of sludge conditioning and the likes. These processes, however, are very seldom employed and are not realistic in BMA from the viewpoint of technical reliability and economical efficiency. Therefore, they are not considered in this Study.

There is sludge conditioning process, which is in some ceases employed in developed countries, that includes sludge washing to reduce the chemical consumption in dewatering and improve the dehydration characteristics of sludge by removing colloidal particles and alkalinity in sludge. Provided that the priority in terms of coagulant dosing prior to dewatering is placed at the polymeric electrolyte usage, the effectiveness of sludge conditioning is very limited. So, this process is judged to be inappropriate in this Study.

(3) Selection of Sludge Treatment Process

Considering the terminal conditions for the ultimate disposal of either landfill disposal or agricultural use intended in this Study, both sludge thickening and the dewatering are required to treat sludge effectively and efficiently. The main points to be discussed in the selection of sludge treatment process are:

- Whether digestion process is feasible in landfill disposal and agricultural use, and
- Whether incineration process is feasible in landfill disposal.

Figure 7.2.6.1 shows total six options of possible sludge treatment process for the both landfill disposal (named by "L" of the first letter) and agricultural use (named by "A" of the first letter), incorporating digestion and incineration process, that is:

- Option L1: Sludge is disposed to a landfill site as ash from the sludge treatment facilities incorporating both of digestion and incineration,
- Option L2: Sludge is disposed to a landfill site after dewatering at the sludge treatment facilities incorporating digestion without incineration,
- Options L3: Sludge is deposed to a landfill site as ash after incineration without digestion,
- Option L4: Sludge is disposed to a landfill site as dewatered sludge without digestion and incineration,
- Option A1: Sludge is used for agricultural land after digestion, dewatering

and composting, and

- Option A2: Sludge is used for agricultural land after dewatering and composting.

To make the comparison between respective options, provisional sludge treatment facilities with the capacity of 20 t DS/d (2,000 m^3/d as 1 % slurry) has been assumed. The treatment capacity of actual sludge treatment facilities varies depending on respective Central WWTPs, the facilities with this capacity is seen as a representative one for the cost comparison. Table 7.2.6.1 and Figure 7.2.6.2 shows the mass transition and the course of sludge volume minimization, respectively, through the treatment of these provisional facilities.

These options have been compared economically by estimating relevant treatment costs including facilities construction, operation and maintenance cost and recovering cost. In the cost comparison, the expense for landfilling has been included in the operation and maintenance cost. Together, the recovering cost includes energy recovery in digestion and for sales revenue in the marketing of sludge compost. The results are shown in Figure 7.2.6.3 and Table 7.2.6.2, and are summarized in Table 7.2.6.3.

The employed costs in this comparison have been calculated by using the "Cost Calculation Basis" as indicated in Table 7.2.6.4. This table includes the cost functional equations used in Japan, making a necessary modification to meet the local economic conditions, and the present cost in Thailand investigated by the Study Team.

Table 7.2.6.3 Cost Comparison between Sludge Treatment Process Options (Summary)

Options		Total treatment expenses (US$/d)	Ratio
Option L1	Landfill of ash: after Digestion and Incineration	8,500	100
Option L2	Landfill of dewatered sludge: after Digestion	3,120	37
Option L3	Landfill of ash: after Incineration	9,965	117
Option L4	Landfill of dewatered sludge: Neither digestion nor incineration	3,540	42
Option A1	Agricultural use of compost: after Digestion	1,843	22
Option A2	Agricultural use of compost: No digestion	430	5.1

Note: The total treatment expenses include construction, O & M and the recovering costs in each treatment step.

As the results of the cost comparison, the following conclusions were obtained:

1) For landfill disposal:

From the comparison between Option L1 and Option L2, and between Option L3 and L4 Option, Option L2 is the most economical followed by L4, since incineration is highly costly. Meanwhile, the comparison between Option L2 and Option L4 make clear that digestion is more economical than direct disposal without digestion. Accordingly, Option L2 was selected as the optimum sludge treatment system for landfill disposal.

2) For the introduction of incineration in the future:

Incineration process is required due to environmental needs and possible beneficial uses in the future. Based on the economical comparison between Option L1 and Option L3, Option L1 was selected as the optimum sludge treatment process for the introduction of incineration.

3) For agricultural use:

As seen from the comparison between Option A1 and Option A2, Option A2 is more economical. Even though Option A2 does not accommodate sludge digestion, the sludge stabilization required for the decomposition of easy-degraded organic portions and the removal of pathogens and parasites takes place in composting process. Accordingly, Option A2 was selected as the optimum sludge treatment process for agricultural use.

(6) Unit Process Selection of Sludge Treatment

Diverse types are available for respective unit processes comprising sludge treatment facilities: thickening, digestion, dewatering, incineration and composting. Of them, a number of types, which are widely prevalent in many countries, have been extracted and compared in order to select the most suitable one for BMA.

1) Evaluation Method

The relative weighting point method has been applied for the evaluation of each type, by using the following parameters which are assessed by the raw point of 1 (inferior) to 5 (superior) by subjective types, the relative weight rating and, in the end, the weighting point, such as:

a) General Performance reliability (relative weight rating: 6)

This parameter is concerned with the extent of reliability in performance against the expected performance like the removal of water, organic matters, etc, which a certain type unit process has in the sense of the nature. Among all applied parameters, this is seen as the most important, considering that BMA has no experience in such sludge treatment operation.

b) Suitability for sludge properties in BMA (weight rating: 5)

This parameter means how it copes with sludge conditions in BMA like less-organic sludge, relatively high-temperature, etc.

c) Easiness of operation and maintenance (weight rating: 4)

Some type of unit processes request special skills and much experience in operation and maintenance. This parameter represents the degree of operation and maintenance.

d) Cost performance (weight rating: 3)

This parameter represents the extent of all cost required for construction and maintenance, etc.

e) Space requirement (weight rating: 2)

This parameter stands for the extent of land space required for installation, and operation and maintenance.

Apart from the evaluation parameters mentioned above, the environmental impact, which may be caused by respective unit processes, is an another significant parameter that should not be neglected. However, it has been not adopted here except for the composting process, since proper mitigation for negative impacts, if in existence, are assumed to be taken place on the job site of each unit process.

2) Selection of Unit Processes

a) Sludge thickening

Gravity, floatation and Central type are most prevalent as the unit process of sludge thickening.

i) Gravity thickener:

This is the method to separate sludge solids from water by natural gravity, storing sludge in a tank. Thickened sludge on the bottom is collected by a sludge collector and discharged to the outside. While this is the most prevalent type in the worlds, the high temperature in BMA may cause poor separation,

ii) Floatation thickener

This is the method to separate sludge solids by floating sludge particles on the water surface. Bulk density of sludge particles gets lower by being attached with fine air bubbles. This is classified into atmospheric and pressurized type by the method for fine air generation. Sludge of property unsuitable for gravity separation often applies a floatation thickener.

iii) Centrifuge thickener

This is the method to separate sludge solids by using centrifuge force. Sludge solids is separated in a bowl rotating at a high-speed and is discharged in the outside by a screw. The edge of screw may cause abrasion depending on the sludge properties and proper mitigation measure for noise is needed.

Table 7.2.6.5 Evaluation of Sludge Thickening Unit Process

Types	Weight rating	Points	Gravity	Floatation	Centrifuge
General performance	(6)	Raw point	5	5	3
		Total score	30	30	18
Suitability for sludge property	(5)	Raw point	1	5	3
		Total score	5	25	15
Easiness of O & M	(4)	Raw point	5	3	1
		Total score	20	12	4
Cost performance	(3)	Raw point	5	3	3
		Total score	15	9	9
Space requirement	(2)	Raw point	3	3	5
		Total score	6	6	10
Total score			76	82	56

These unit processes of sludge thickening have been compared in Table 7.2.6.5 by using relative weighting point method. From this, a floatation thicker is deemed as the most suitable one for BMA, surpassing gravity thickening prevalent usually. This is because a gravity thickener is concerned about possible poor-separation resulting from high-temperature in tropical climate.

b) Sludge digestion

Sludge digestion is classified into a mesophilic and a thermophilic digester. A mesophilic digester is overwhelmingly prevalent in the world, while a thermophilic digester is rarely used for sewage sludge.

i) Mesophilic digester

This is a kind of the anaerobic methods to stabilize sludge by converting organic matters into methane and carbon dioxide, etc. through organic acids, by the function of anaerobic bacteria like methane bacteria. A mesophilic digester is operated under the temperature of 30 to 35 °C.

ii) Thermophilic digester

A thermophilic digester, which is operated under the temperature of 53 to 57 °C, tends to show a high-rate performance in a certain condition. This, however, is seldom used for sewage sludge due to difficulty in operation.

Table 7.2.6.6 Evaluation of Sludge Digestion Unit Process

Types	Weight rating	Points	Mesophilic	Thermophilic
General performance	(6)	Raw point	5	2
		Total score	30	12
Suitability for sludge property	(5)	Raw point	5	2
		Total score	25	10
Easiness of O & M	(4)	Raw point	5	3
		Total score	20	12
Cost performance	(3)	Raw point	3	5
		Total score	9	15
Space requirement	(2)	Raw point	3	5
		Total score	6	10
Total score			90	59

These unit processes of sludge digestion are compared in Table 7.2.6.6 by using relative weighting point method. From this, a mesophilic digester is deemed as much more suitable than a thermophilic digester for BMA, indicating clearly that a thermophilic is not realistic in practical uses.

c) Sludge dewatering

The unit processes of sludge dewatering in use widely are the types of belt press filter, pressure filter, centrifuge separator, and vacuum filter.

i) Belt press filter

A belt-press filter is equipped with many of rolls and sludge is pressurized and filtrated by filter cloths running between the rolls. This usually comprises the section of gravity separation, pressure dehydration and compression dehydration. The filter cloths are washed continuously to prevent clogging.

ii) Pressure filter

A pressure filter is equipped with a large number of filtration chambers constructed by filtration cloths. Sludge is filtrated in the chamber by pump pressure and then compressed through diaphragms by hydraulic and/or pneumatic pressure. The operation, which is fully computerized normally, takes place by an automatically sequential-batch system. Usually, not organic but inorganic coagulant is applied to a pressure filter.

iii) Centrifuge separator

This is the method to dewater sludge by using centrifugal force being 1,500 to 3,000 times gravity, usually. Sludge solids is separated in a bowl rotating at a high-speed and is discharged into the outside by a screw. The edge of screw may cause abrasion depending on the sludge properties and proper measures are necessary for noise issue. Proper mitigation measure for noise is needed in site.

iv) Vacuum filter

This type is to make the inside of a drum covered by filter cloth vacuum and to absorb and dehydrate sludge on the surface of filter cloth. Two kind of vacuum filter: belt and drum type, are used. The drum is partitioned into the three zones: adsorption, dehydration, and exfoliation zone and the Vacuum pressure is kept to some 600 mmHg at the adsorption zone and about 300 mmHg at the dehydration zone. Inorganic coagulant being aided by lime is usually applied to sludge to be treated by this filter.

These unit processes of sludge dewatering have been compared in Table 7.2.6.7 by using relative weighting point method. As understood from this, aside from the vacuum filter, the belt-press filter appears the most suitable, followed by the pressure filter and the centrifuge separator which appears to become possibly realistic in a certain condition.

Table 7.2.6.7 Evaluation of Sludge Dewatering Unit Process

Types	Weight rating	Points	Belt-press	Pressure	Centrifuge	Vacuum
General performance	(6)	Raw point	*4*	*5*	*4*	*3*
		Total score	24	30	24	18
Suitability for sludge property	(5)	Raw point	*5*	*5*	*3*	*3*
		Total score	25	25	15	15
Easiness of O & M	(4)	Raw point	*5*	*4*	*4*	*3*
		Total score	20	16	16	12
Cost performance	(3)	Raw point	*5*	*2*	*5*	*4*
		Total score	15	6	15	12
Space requirement	(2)	Raw point	*5*	*4*	*5*	*2*
		Total score	10	8	10	4
Total score			94	85	80	61

d) Sludge incineration

Sludge incineration being used prevalently is classified into multi hearth, fluidized bed, and rotary kiln type.

i) Multiple hearth incinerator

A multiple hearth incinerator consists of furnace beds with usually 6 to 12 stages, furnace wall, central shaft with collector arms and teethes, and auxiliary combustion device, etc. Sludge supplied from the top of incinerator is dried, burned and cooled in order, falling down to the bottom of furnace with being mixed on respective furnace beds.

ii) Fluidized bed incinerator

A fluidized bed incinerator, usually in the shape of vertical cylinder, comprises window box, fluidized bed and free board, and its furnace main is of steel-made lined by fireproof bricks. Fluidized media is fiercely mixed like "boiled" by the supply of air and heated by the combustion gas of fuel. The majority of sludge fed into the inside is dried and burnt out in a few moments in the fluidized bed. The remaining combustible portion of sludge is completely burnt out in the free board zone.

iii) Rotary kiln incinerator

A rotary kiln incinerator consists of mainly the rotating horizontal furnace cylinder lined with fireproof materials and the fixed portion equipped with the feeding hood and the combustion hood. Sludge supplied from the feeding hood is transported in the cylinder by its inclination and rotary movement, and dried and brunt out in order.

Table 7.2.6.8 Evaluation of Sludge Incineration Unit Process

Types	Weight rating	Points	Multiple Hearth	Fluidized Bed	Rotary Kiln
General performance	(6)	Raw point	5	5	4
		Total score	30	30	24
Suitability for sludge property	(5)	Raw point	5	5	5
		Total score	25	25	25
Easiness of O & M	(4)	Raw point	3	3	4
		Total score	12	12	16
Cost performance	(3)	Raw point	4	4	4
		Total score	12	12	12
Space requirement	(2)	Raw point	4	4	3
		Total score	8	8	6
Total score			87	87	83

These sludge incinerators have been compared in Table 7.2.6.8 by using relative weighting point method. As understood from this, no significant difference among these unit processes can be seen within a general assessment. Accordingly, the selection of the incinerator type should be more precisely and carefully taken place based on the specific conditions like: purpose of incineration, sludge characteristics, site conditions, preparedness of operators, requirement for environmental countermeasures, etc. For reference, it may be notable trend that, in Japan, the installation of fluidized bed type has greatly increased recently, while the multiple hearth type still comprises the majority of installations.

e) Sludge composting

Composting can make sludge easy-handling and can prevent offensive odor emission. In most cases, some bulking materials are added to the sludge to improve the physical properties and C/N ratio of sludge, prior the fermentation While there are many kinds of composting facilities working for actual production, the sludge compost may be divided into three categories in terms of the type of fermenter: pile-up type, horizontal type, and vertical type.

i) Pile-up type

A pile-up type composting is the method to simply stack and pile sludge on the floor, usually without air supply. Sludge is piled with 2 to 3 m height or so and sometimes is mixed and turned by vehicles. Because fermentation is left to nature, it usually takes 2 or to 4 months to get composted.

ii) Horizontal type

A horizontal type composting takes place in a horizontally rectangular tank made of concrete. Many of them are equipped with a certain type of windowing device that can travel on the top of fermenters to mix and turn over sludge. Usually, air for fermentation is supplied from the bottom of fermenters by using blowers and the primary fermentation days is designed as 15 to 30 days.

iii) Vertical type

A vertically cylindrical fermenter, which is closed to the outside and usually partitioned by multiple horizontal devices with paddles, is a highly mechanized composting plant. Sludge, which is fed from the top, falls down to the bottom in 10 to 15 days, being mixed properly, through multiple chambers. Air supply by using a blower is conducted continuously.

These sludge-composting types have been compared in Table 7.2.6.9 by using relative weighting point method. Unlike other unit process evaluation mentioned before, the parameter of the environmental influence is accounted exceptionally. This is because the counter measure for environmental problem of offensive odor is regarded as a key factor to assess the composting unit processes. Based on the evaluation result, the horizontal type is most suitable for BMA, while the selection of suitable unit process for composting is likely to be predominated by the installation location.

Table 7.2.6.9 Evaluation of Sludge Composting Unit Process

Types	Weight rating	Points	Pile-up type	Horizontal type	Vertical type
General performance	(6)	Raw point	2	4	4
		Total score	12	24	24
Suitability for sludge property	(5)	Raw point	3	4	4
		Total score	15	20	20
Easiness of O & M	(4)	Raw point	5	4	3
		Total score	20	16	12
Cost performance	(3)	Raw point	4	3	2
		Total score	12	9	6
Space requirement	(2)	Raw point	1	4	5
		Total score	2	8	10
Environmental influence	(6)	Raw point	1	4	4
		Total score	6	24	24
Total score			67	101	96

3) Selected Unit Processes

The rough configurations of the selected unit process of sludge treatment are shown in Figure 7.2.6.4.

In the end of this section, the most suitable ones for BMA in respective unit processes for sludge treatment has been summarized like:

- Floatation thickener for thickening,
- Mesophilic digester for digestion,
- Belt-press dehydrator for dewatering,
- Multiple hearth or fluidized bed incinerator for incineration, and
- Horizontal fermenter for composting.

These conclusions, however, should be regarded as an exemplary direction, which is induced based on general conditions in BMA. It is highly recommended that the selection of unit processes in the actual cases take place on the basis of substantial and specific conditions and requirements of respective schemes.

7.2.7 Sludge Transportation

(1) General

As mentioned before, a daily total of some 1,500 t as 80 % moisture cakes is projected to be generated, every day and unceasingly, from BMA in 2020. Given around daily 250 t as of today, the sludge amount in 2020 is a significant volume. Therefore, the efficient logistic measures must be established for the sludge transfer between each sludge source and landfill site, and composting plant sites.

While the important requisites for sludge transportation is to transfer sludge effectively, economically and environmental-friendly, of them, the emission of offensive odor is likely to be serious concerns in BMA. People concerned in sewerage, however, should understand that "fresh sludge" does not stink of decomposition, and offensive odor generated from sludge can be controlled to a certain extent by a number of a small contrivance before transportation phase, like:

- To keep the aeration tank in the higher dissolved oxygen (DO),
- To keep sludge in the storage tank aerated enough,
- Not to storage dewatered sludge for a long time, and
- To keep sludge handling facilities and rooms always clean.

The countermeasure for offensive odor like lime dosing or application of odor-proof agent should be taken, unless other measures are effective.

(2) Overview of Sludge Transportation Alternatives

Generally, sludge in the form of liquid or solid-like cake is transported by different ways like trucks, pipeline pumping, barge and rail cars. Of them, however, only a limited number of alternatives are logistically realistic for the sludge generated in BMA, in light of the physical state of sludge, the origin and destination point, the sludge volume to be handled and, most importantly, the existing situation of transportation infrastructure.

1) Truck transportation

The use of trucks is the most secure and suitable alternative to transport sludge from small volume to large volume, not depending on the origin and the destination transportation points, etc. Despite notorious traffic congestion in Bangkok, the truck transportation probably continues as a major method for a while. The sludge transportation mode by trucks, however, should be carefully planned so as to avoid the traffic congestion as much as possible, for example, introducing hauling in the nighttime.

2) Pipeline pumping

Pumping through pipeline can transport sludge, unless it is solid-state. The unique characteristics of sludge, however, may cause special different problems in the course of transportation like clogging in pipeline, corrosion/erosion of piping materials, the likelihood of environmental pollution resulting from possible leakage, etc. This transportation has been substantiated in several cities in Japan with the longest pipeline length of some 15 km for about 1 % concentration slurry as shown Table 7.2.7.1.

Given the habitual traffic congestion in Bangkok, pipeline pumping appears very promising. This method, however, has been known as a cost-consuming. Accordingly, careful study should be undertaken, also including the possible risk at the time of a system breakdown or the stoppage in an emergency. In the subsection 8.3.4 and 8.4.3, a number of pumping transportation alternatives has been compared economically.

Table 7.2.7.1 Pipeline Sludge Transportation System in Japan

Items \ Locations	Tokyo Metropolitan	Yokohama City	Osaka City	Kagoshima City
Pipe diameter (mm)	700	500	350 x 2 trains	200
Material of pipe	Ductile cast iron (mortar lining)	Ductile cast iron (mortar lining)	Ductile cast iron (mortar lining)	Ductile cast iron (mortar lining)
Total length (km)	15.2	13.9	9.9	10.3
Average velocity (m/sec)	1.2	1.0	0.6	0.6
Total head (m)	50	51	43	75
Sludge concentration (%)	1.0	1.0	0.5	0.5
Type of pump	Sludge pump with screw	Sludge pump with screw	Horizontal Non-clogging pump	Horizontal Non-clogging pump

Source: Sewerage Design Standards in Japan, Japan Sewage Works Association.

3) Barge transportation and rail transportation

In general, these logistic measures are economically beneficial, especially for the hauling of bulky volume of sludge, provided that the origin and destination are fixed. The rail transportation in BMA, however, appears to be difficult with the current scarcity of rail networks.

Bangkok is endowed with the densely arranged networks of khlongs. Although sludge transportation using barges through these khlongs may be one alternative, actual assessment on this transportation is rather difficult for the time being. There are a number of uncertainties, like:

- All the Central WWTPs are not necessarily facing khlongs,
- There are no khlongs leading to final sludge destinations and, so, relay transportation by truck is needed.

Therefore, barge transportation is not regarded as primary measures in this Study. Nevertheless, in the subsection 7.3.4, a rough study of barge transportation has taken place just for referential use.

Based on these results, both truck and pipeline-pumping alternatives has been dealt with in the comparison in the subsection 7.3.4

7.3 Sludge Treatment Plan for Landfill Disposal

7.3.1 General

Of sludge generated from BMA, the sludge assumed as the high-risk for heavy metal intrusion is ultimately disposed off for the landfill site. As mentioned in the subsection 7.2.5, the sludge generated from the following Central WWTPs up to the 8th place risk ranking is tentatively regarded as the high-risk sludge:

- Existing and ongoing: Nong Khaem, Ratburana (including night soil), Ratanakosin, Si Phraya,
- Planned and proposed: Khlong Toey East, Khlong Toey West, Huay Kwuang, and Thonburi South.

Meanwhile, the optimum sludge treatment process for landfill disposal thereof has been clarified in the subsection 7.2.6, as:

(Raw sludge) - [Thickening] - [Digestion] - [Dewatering] --------------(Landfill)

In reality, on the other hand, the Sludge Treatment Center (STC) at Nong Khaem has already been ongoing toward the completion in 2001. Its preliminary design has been completed as of today, with the treatment plan for the sludge generated in the ongoing Phase 1 to the Phase 4 Projects, namely: Nong Khaem, Si Phraya, Ratanakosin, Yannawa, Din Daeng and Chatuchak. Such aggregation to the Nong Khaem STC of sludge treatment is conceived to result from the shortage of the land spaces for digestion in respective job sites of Central WWTPs and the economical effectiveness. Because this is equipped with the digestion process, which is essential for the optimum sludge treatment process for landfill disposal, all of the high-risk sludge is assumed to be transported and treated at the Nong Khaem STC.

The following items for high-risk sludge sources are dealt with in this section:

- Thickener, dehydrator and their relative facilities at respective Central WWTPs,
- The treatment facilities in the ongoing Nong Khaem STC,
- Incinerator and their relative facilities at the Nong Khaem STC, and
- Landfill disposal facilities.

7.3.2 Planning Conditions

According to the preliminary design, the sludge transportation to the Nong Khaem STC is planned by trucks after dewatered at respective Central WWTPs. The sludge treatment facilities for landfill disposal, therefore, are separately installed in respective Central WWTPs as well as the Nong Khaem STC. The planning conditions thereof are summarized as follows:

- Sludge quantity in 2020:
  - Sludge from Central WWTPs: Total 11,400 m^3/d (as 99 % moisture content), (114 t DS/d)
  - Inlet Sludge to incinerator: 120 t/d (as 80 % moisture content) (equivalent to 25 % of dewatered sludge after 2010 in the Scenario 2)
- Sludge composition: VS 43 to 48 %
- Process performance:
  - VS removal in digestion 50 %
  - Dewatered sludge moisture content: 80 %
  - Digestion gas generation: 0.6 Nm^3/kg-Removed VS
  - Generated heat: 5,000 kcal/ Nm^3
  - Gas engine efficiency: 35 %
  - Power generation efficiency: 95 %

7.3.3 Sludge Treatment Facilities at Central WWTPs

Based on the results mentioned in the subsection 7.2.6, employing floatation thickeners and the belt press filter, sludge is treated to form sludge cakes. The following design parameters has been applied to determine their main dimensions:

- 130 kg DS/m^2/d of surface loading for a floatation thickener, and
- 150 kg DS/m/h of filtration rate for a belt-press filter.

The sludge treatment facilities in Central WWTPs consists of thickener mains, dehydrator mains, sludge storage tanks, chemical dosing systems, cake conveyance systems, cake hoppers, and other appurtenances. The main dimensions of sludge treatment facilities in the planned and proposed Central WWTPs schemes have been determined as shown in Table 7.3.3.1. Cylindrical-shape floatation thickener and standard-type belt-press filter are applied to these. These sludge treatment facilities will be constructed step-wisely in line with the development plan of respective schemes.

Table 7.3.3.1 Main Dimensions of Sludge Treatment Facilities in Planned and Proposed Central WWTPs

Processes / Central WWTPs	Generated sludge (t DS/d)	Floatation thickener		Belt press filter	
		Required nr.	Diameter (m)	Required nr.	Filter width (m)
Khlong Toey East	15.6	2	9.0	2	2.5
Khlong Toey West	17.9	2	9.5	2	2.5
Huay Kwuang	16.6	2	9.2	2	2.5
Thonburi South	24.1	2	11	3	2.5

Notes : This table shows the main dimensions correspondent to the capacity in 2020.

7.3.4 Nong Khaem Sludge Treatment Center (STC)

(1) Main Specifications

The preliminary design has delineated the following outline of the ongoing Nong Khaem STC:

- Inlet sludge quantities: Total 120 t DS/d: 80 % moisture content, VS ratio 53 % (The sludge from the Nong Khaem Central WWTP is in the state of slurry)
- Slurry preparation system:
  - Sludge holding tank: Total 324 m^3
  - Gravity belt thickener: 2 units
  - Sludge cake holding tank: Total 15,000 m^3
  - Sludge mixing tank: Total 46 m^3
- Anaerobic digester: Total 45,000 m^3 (2 units)
- Belt press filter: 2.5m Width x 5 units
- Boiler and heat exchanger: Total 4,000 kW

High-risk sludge of total 114 t DS/d (in 2020) will be treated in these facilities. As seen from Figure 7.3.3.1, in light of the efficiency in the financial investment, the facilities of the Nong Khaem STC should be constructed in the two phases (the daily capacity of 300 and 600 t Dewatered Sludge) in line with the treated sludge quantities. Moreover, the entire facilities like digesters, sludge dewatering, etc.

should be separated into four complete lines at least so as to make its operation and maintenance securer and more flexible.

Figure 7.3.3.2 shows the flow diagram of the Nong Khaem STC based on the preliminary design, additionally attached by the incinerator being planned after 2010 and the digestion gas recovery system. While the preliminary design does not consider the power generation using digestion gas, this should be installed from the viewpoint of economical efficiency as well as energy saving.

(2) Sludge Transportation Alternatives

Although the Nong Khaem STC scheme has already adopted the truck haulage for the sludge transportation from respective Central WWTPs, the pipeline pumping may be seen as the alternative for sludge transportation. In terms of sludge transportation to the Nong Khaem STC, the alternatives being described hereunder have been examined as detailed in Table 7.3.3.2:

1) Alternative T1: Truck Transportation (ongoing scheme)

(Raw Sludge)-[Thickening]-[Dewatering]-Truck Transp-[Nong Khaem STC]

The sludge in the form of cake from seven (7) Central WWTPs except for the Nong Khaem Central WWTP is transported to the STC by trucks.

2) Alternative T2: Pipeline Transportation

(Raw Sludge)-Pipeline Transp-[Nong Khaem STC]-[Thickening]-[Treatment]

The sludge in the shape of liquid with about one (1) % concentration from all the Central WWTPs is transported to the STC by pipeline pumping.

3) Alternative T3: Barge Transportation

(Raw Sludge)-[Thickening]-[Dewatering]-Barge Transp-[Nong Khaem STC]

The sludge in the shape of cake from seven (7) Central WWTPs except for the Nong Khaem Central WWTP is transported to the STC by barges.

Table 7.3.3.3 shows the cost comparison between the three transportation alternatives. Both truck transportation and barge transportation include the daily expenses for the sludge treatment system, which consists of floatation thickeners and dehydrators. The pipeline transportation alternative, on the other hand, does not contains such sludge treatment facilities, since it can handle directly the sludge derived from wastewater treatment facilities.

Table 7.3.3.3 Summarized Cost of Sludge Transportation Alternatives

Items	Alternatives		
	Truck (T1)	Pipeline (T2)	Barge[1] (T3)
Daily expense (US$/d)	15,600	13,500	15,300
Ratio	100	86	98

Note:
1) The expense of barge includes only the net barge transportation except for other related costs.

The expenses of the pipeline alternative needs are less than the truck alternative. Truck alternative includes the cost for the thickening and dewatering in the respective Central WWTPs, so that the entire transportation cost of the pipeline alternative is lower than that of the truck alternative. If the pipeline transportation is realized instead of the ongoing truck transportation, the following issues should be analyzed and solved:

- In the pipeline transportation, a certain risk in the operation and maintenance of sewerage system exists. Namely, in case some troubles in the pipeline system cause the stoppage liquid transportation, the entire sewerage system may be constrained not to work,
- The treatment system's treatability of the STC should be examined, considering the concentration of sludge transported by pipeline may fluctuate in the rage of 0.7 to 1.5 %,
- The construction cost of the pipeline should be elaborated more specifically, especially about the crossing with the Chao Phraya River,
- A part of the facilities of thickening and dewatering for respective Central WWTPs have already worked or been ordered. These facilities must be beneficially used for other purposes to offset the cost of pipeline transportation system.

Although the cost of the barge alternative appears almost equal to that of the truck transportation, more elaborate study is necessary, because it should include other costs like on-loading/off-loading facilities, the modification work of canal courses, etc.

Because its fundamental scheme has been already endorsed by BMA, the sludge transportation by trucks in the Nong Khaem Project will go ahead at the moment. However, the pipeline transportation should be studied in detail in the future.

7.3.5 Power Generation by Digestion Gas

In the ongoing scheme of the Nong Khaem WWTPs, the beneficial utilization of digestion gas has been beyond consideration. Meanwhile, the result in the subsection 7.2.6 justifies the introduction of the power generation by digestion gas. The Study Team recommends that the following facilities be installed to recover energy from digestion gas:

- Digestion gas generation: 16,100 Nm^3/d (in 2020)
- Gas holder: 8000 m^3 x 2 units
- Gas engine output: 1,370 kW (in 2020)
- Generated power: 700 kW x 2 units (in 2020)
- Power output: 1,300 kW

When the power generation takes place, the exhaust heat will be used to heat raw sludge prior to digesters.

7.3.6 Sludge Incineration

As described in the subsection 7.2.5, in Scenario 2 of sludge disposal, the sludge equivalent to 25 % quantity of the treated sludge at the Nong Khaem STC is incinerated on the assumption that:

- Regulations or standards for the landfill disposal of heavy-metal-containing and toxic substances-containing sludge are enforced for the period afterward 2010. As a result, incineration is required as a suitable treatment for final disposal or a pretreatment for further processing, and
- Beneficial uses of sludge such as the utilization for construction materials and the likes are promoted, starting from the period of 2010.

The incinerator may be either multiple hearth or fluidized bed type, as judged in the subsection 7.2.6. This study has assumed fluidized-bed type incinerator, which is utilized most widely throughout the worlds. In the design of the incinerator, special attention for exhaust gas should be paid to prevent the air pollution derived from dust, sulfur oxide (SO_x), nitrogen oxide (NO_x), etc. The main dimensions of sludge incinerator are delineated as follows:

- Fluidized-bed type furnace: 2 units
  Capacity 60 t Dewatered Sludge/d x 2 units
  Combustion temp. 700 to 900 °C
- Auxiliary facilities: Sludge feed equipment,
  Auxiliary combustion equipment,
  Fuel supply equipment,
  Ash storage hopper,
  Exhaust gas treatment equipment.

The construction schedule of the incinerator is shown in Figure 7.3.3.1.

7.3.7 Landfill Disposal Facilities

(1) Sludge Quantities for Landfill Disposal

The quanties of sludge to be disposed off landfill site are projected in Table 7.3.7.1, assuming that all of the ash from incineration in Scenario 2 of sludge disposal are disposed to landfill. Also, Figure 7.3.7.1 shows the transition of these sludge quantities by years. These sludge are expected to be disposed at the landfill site at Kampansaem where MSW is also disposed off.

Table 7.3.7.1 Sludge Quantities of Landfill Disposal in 2020

Sludge Categories	Disposed Sludge in 2020			Sludge Sources
	Scenario 1	Scenario 2	Scenario 3	
Dewatered Sludge after Digestion	443 t Wet/d	332 t Wet/d	443 t Wet/d	Nong Khaem STC
Ash after Incineration	0	16.6 t Wet/d[1)]	0	Nong Khaem STC
Dewatered without Digestion	0	0	470 t Wet/d	Central WWTPs, NSTPs, Community WWTPs
Total	443 t Wet/d	349 t Wet/d	913 t Wet/d	

Note:
1) This sludge will be disposed to landfill site or destined for beneficial uses.

(2) Landfill Disposal Facilities

As clarified in the subsection 7.2.3, BMA should have adequate regulations for the input condition of sludge containing toxic substances, and proper standards of landfill manners for sludge to be disposed to landfill site.

Because the landfill site in BMA likely deals with not only sludge but also MSW, it should be prepared for the safe structure and practices against both solid waste and sludge. At least, sludge should be disposed in the manner of separated-layer with proper depth using cover soil, since it contains a large portion of water and organic matters. As shown in Figure 7.3.7.2, the landfill disposal for sludge should be well equipped with the following facilities so as to prevent the possible negative environmental problems and human-health hindrances:

1) Access road:

- Connect the landfill site with the outside,
- Constructed as an essential component of the landfill site.

2) Leachate treatment facilities:

- Collect rainwater and other water discharged through waste layers
- Consist of leachate drain pipes and a treatment plant including a control tank, a biological treatment process, a sedimentation tank, a sand filter, etc.

3) Rainwater drainage:

- Collect and discharge rainwater which run on the ground surface and is not contaminated,
- Consist of collection ditches, a retention pond and discharge facilities,

4) Enclosure dikes:

- Made of soil to limit the range of landfill areas,
- Placed along with the landfill site boundary.

5) Divider dikes:

- Made of aged waste or clay to limit the range of landfill areas,
- Placed on the boundary of the partition for the demarcation of operation scheme.

6) Landfill area:

- The place where waste is disposed and installed with on-site roads,
- Covered with a seepage control liner employing clay or membrane sheet.

7) Gas vent:

- Installed vertically through a waste layer and a cover soil layer to strip gas generated by waste degradation,
- Consist of plastic pipes with small holes and cages utilizing bamboo woods.

8) Water quality-monitoring system:

- To monitor surface water discharge from landfill site and underground water,
- Consists of monitoring well, and measurement and analysis equipment.

9) Administration facilities:

- Consists of building and other miscellaneous facilities including weighing equipment for incoming wastes, maintenance and repair equipment for vehicles,
- Contains the administration function by operation staffs,

7.4 Sludge Treatment Plan for Agriculture Use

7.4.1 General

Of sludge generated from BMA, the sludge assumed as the lower-risk for heavy metal intrusion is used as organic fertilizer for agricultural use in the vicinities of BMA. As mentioned in the subsection 7.2.5, the sludge generated from the following Central WWTPs beyond the 9th risk ranking. is tentatively regarded as the low-risk sludge:

- Ongoing schemes: Yannawa (including night soil), Din Daeng, Chatuchak, and
- Planned and proposed schemes: Thonburi Central, Bung Kum, Wang Thong Lang, Thonburi North, Bang Sue,

The optimum sludge treatment process for agricultural use thereof has been clarified in the subsection 7.2.6, as:

(Raw sludge) - [Thickening] - [Dewatering] - [Composting]----(Organic fertilizer)

The sludge derived from NSTPs (2 places) and Community WWTPs (14 paces) are, also, seen to be dehydrated by existing facilities in respective treatment sites.

As stated in the subsection 7.2.5, in Scenario 1 and 2, all of the low-risk sludge are assumed to be used as organic fertilizer for agricultural use. In Scenario 3, on the other hand, 50 % of the low-risk sludge is assumed to be marketed as organic fertilizer and the rest disposed to landfill site after dewatered.

Accordingly, the following items for the low-risk sludge generated from Central WWTPs are dealt with in this section:

- Thickener, dehydrator and their relative facilities, and
- Sludge composting facilities.

7.4.2 Planning Conditions

The planning conditions for the treatment facilities for the low-risk sludge are summarized as follows:

- Sludge quantity in 2020
  - Generated sludge form Central WWTPs: Total 14,300 m^3/d (as 99 % moisture content)
  - Generated sludge from NSTPs: Total 185 t/d (as 80 % moisture content)
  - Generated sludge from Community WWTPs: Total 36.5 t/d (as 80 % moisture content)
- Sludge composition: VS 50 to 60 %

- Process performance:
  - Dewatered sludge moisture content: 80 %
  - VS reduction at composting content: 50 %
  - Water evaporation: 50 %

7.4.3 Sludge Treatment Facilities at Central WWTPs

(1) Alternatives for Sludge Treatment

Almost all of the Central WWTPs in BMA are constrained to install their facilities within very limited land spaces. Aggregated sludge treatment facilities, which consist of thickener and dehydrator, can save the land space necessary for respective Central WWTPs and may reduce the treatment cost by the scale-up effect. From such conception, the following alternatives for the sludge treatment facilities including sludge transportation have been examined from the viewpoint of economical feasibility:

- Alternative C1: Individual Treatment

(Raw Sludge) - [Thickening] - [Dewatering]--------------------(Dewatered Sludge)

The sludge treatment facilities are installed in individual Central WWTPs sites (total 8 places).

- Alternative C2: Aggregated Sludge Treatment Facilities

(Raw Sludge)--Pipeline Transp---[Thickening]-[Dewatering]--(Dewatered Sludge)

The aggregated sludge treatment facilities are assumed to be installed at certain place close to the Nong Khaem STC. The sludge generated in respective Central WWTPs is transported to the aggregated sludge facilities by pipeline pumping and then thickened and dewatered.

Table 7.4.3.1 shows the cost comparison between the truck transportation and the pipeline transportation. The individual treatment alternative is by far more advantageous than the aggregated treatment alternative. This indicates that the scale-up effect is not so significant, in case the aggregated facilities are limited to only thickening and dewatering. The individual sludge treatment at respective Central WWTPs is recommended in this Study.

(2) Main Specification of Sludge Treatment Facilities

Based on these results, employing floatation thickeners and belt press filters, sludge is treated to form sludge cakes at the individual Central WWTP. The following design parameters has been applied to determine their main dimensions:

- 130 kg DS/m^2/d of surface loading for a floatation thickener, and
- 150 kg DS/m/h of filtration rate for a belt-press filter.

The sludge treatment facilities in Central WWTPs consist of dissolved air floatation thickeners (DAF), dehydrator mains, sludge storage tanks, chemical dosing systems, cake conveyance systems, cake hoppers and other appurtenances.

Table 7.4.3.1 Cost of Sludge Treatment Alternatives for Agricultural Use

Items / Central WWTPs	Sludge generation (t DS/d)	Transport distance (km)	Alternative C1: Individual		Alternative C2: Aggregated		
			Thickening (US$/d)	Dewatering (US$/d)	Pumping (US$/d)	Thickening (US$/d)	Dewatering (US$/d)
Yannawa	22.1	24	1,034	3,168	1,811		
Thonburi Central	16.7	16	504	1,554	797		
Bung Kum	15.5	43	474	1,464	2,736		
Wang Thong Lang	15.1	35	464	1,434	2,288		
Thonburi North	9.8	19	326	1,026	833		
Bang Sue	15.1	27	464	1,434	1,843		
Din Daeng	35.8	27	1,265	3,893	2,030		
Chatuchak	13.3	29	315	994	1,913		
Aggregated Facilities	143.4					3,627	11,674
Total			19,812		29,552		
(Ratio)			(100)		(149)		

Note : The costs are computed by using the basis mentioned in Table 7.2.6.4.

The main dimensions of sludge treatment facilities in the planned and proposed schemes have determined as shown in Table 7.4.3.2. assuming cylindrical-shape floatation thickeners and standard-type belt press filters. These sludge treatment facilities will be constructed in line with the sewerage development plan of the respective schemes.

Table 7.4.3.2 Main Dimensions of Sludge Treatment Facilities at Planned and Proposed Central WWTPs

Processes / Central WWTPs	Generated sludge (t DS/d)	Floatation thickener		Belt press filter	
		Required nr.	Diameter (m)	Required nr.	Filter width (m)
Thonburi Central	16.7	2	9.5	2	2.5
Thonburi North	9.8	2	7.0	2	1.5
Bang Sue	15.1	2	8.8	2	2.0
Wang Thong Lang	15.1	2	8.8	2	2.0
Bung Kum	15.5	2	9.0	2	2.3

Notes : This table shows the main dimensions required in 2020.

7.4.4 Sludge Composting Facilities

The sludge generated in Central WWTPs regarded as the lower-risk for heavy metal intrusion, NSTPs and Community WWTPs is composted after dewatered. The sludge quantity in 2020 has been foreseen 940 t Wet/d in Scenario 1 and 2, and 470 t Wet/d in Scenario 3.

Apart from the composting of only sludge, garbage in MSW (mono-composting) may be composted after mixed with sludge (co-composting). Department of Public Cleansing (DPC) has been already endowed with the marketing of the compost product produced from garbage, while suspending the operation due to an unknown reason, at this moment. Garbage generated from kitchens in households and from markets is seen as raw material suitable for compost, on the condition that they are collected separately from other non-organic refuses and, then, are segregated from foreign materials by suitable equipment before composted. There technically appears no significant obstacle in such co-composting. At the same time, however, co-composting unlikely has a special benefit from the technical and economical viewpoint of the sewerage side, as compared with mono-composting. Therefore, the co-composting of sludge with garbage should be studied mutually between the sectors concerned, whether it is feasible and beneficial from the viewpoint of the institutional aspect.

In general, composting facilities are characterized as a rather space-consuming process. Almost all of the Central WWTPs unlikely can allocate the land space to install such bulky facilities within their sites. Accordingly, the following choice may be emerged:

- To construct an aggregated composting plant in a certain suitable place within /outside BMA, which collect and process sludge from Central WWTPs and other sources,
- To install dispersively a number of composting plant in the inside or the outside BMA, where is the consumption area for sludge fertilizer.

Given that the transportation expense for dewatered sludge and chaff to be used as bulking material accounts for a significant portion of compost product cost, this Study has assumed tentatively to select the following dispersive scheme, envisaging that the actual places should be decided at the implementing stage:

- North Plant: in the northern area of BMA,
- East Plant: in the eastern area of BMA, and
- West Plant: in the western area of BMA (including Nong Khaem).

These plant sites are expected to be located in the areas where a large volume of organic fertilizer are consumed and chaff and the likes as bulking materials are easily available. Together, the site of composting plant should keep the proper distance from residence areas to avoid offensive odor and traffic problems. Table 7.4.4.1 shows the tentatively allocated production capacity of composting plants.

Table 7.4.4.1 Production Capacity of Sludge Composting Plants

Name	Dewatered Sludge Input in 2020 (and Output in 2020)		Sludge Sources
	Scenario 1 and 2	Scenario 3	
North Plant	334 t Wet/d (334 t Product/d)	167 t Wet/d (167 t Product/d)	Bang Sue Chatuchak Din Daeng Community WWTPs
East Plant	218 t Wet/d (218 t Product/d)	109 t Wet/d (109 t Product/d)	Bung Kum Wang Thong Lang On-Nut (Night soil) Community WWTPs
West Plant	389 t Wet/d (389 t Product/d)	195 t Wet/d (195 t Product/d)	Thonburi North Thonburi Central Nong Khaem (Night soil) Yannawa (Sewage) Yannawa (Night soil) Community WWTPs

The horizontal-type fermenter attached by travelling paddle windrow devices is recommendable for the sludge composting for BMA from the viewpoint of the compost quality and economical efficiency, based on the results in subsection 7.2.6. The chaff and the likes are used as bulking material at the weight rate of (dewatered sludge) : (chaff) = 1 : 0.5, so as to improve sludge properties in related to aeration in the fermenter. Table 7.4.4.2 and Figure 7.4.4.1, Figure 7.4.4.2 show the outline of the proposed composting plant for BMA.

Figure 7.4.4.3 shows the production amount in the time-wise from three composting plants. Figure 7.4.4.4 represents the inlet sludge quantities to the composting plants, indicating that each plant will be constructed at the two phases.

Table 7.4.4.2 Main Dimensions of Sludge Composting Plants

Items	Quantity	Main Specification	Remarks
Sludge Feeding Yard	1 set/train	Size: 20 mWidth x 40 mLength Appurtenances: Sludge mixing equipment, Sludge stock area, Bulking material stock area, Conveyers.	
Fermenter	4 sets/train	Size:4 mWidth x 80 mLength Appurtenances: Sludge auger, Aeration fan, Exhaust fan, and Odor absorber, Conveyers.	Fermentation time: about 14 days (effective)
Maturation Yard	1 set/train	Size: 20 mWidth x 100 mLength Appurtenances: Compost product area, Packaging equipment, Conveyers.	Fermentation time: about 20 days (effective)
Auxiliary Facilities	1 lot	Workshop, Control room	

Notes: Required quantities of facilities in the target year of 2020 as follows:
Scenario 1 and 2: North Plant; 10 trains, East Plant; 6 trains, West Plant; 10 trains.
Scenario 3: North Plant; 5 trains, East Plant; 3 trains, West Plant; 5 trains.

7.5 Proposed Sludge Treatment/Disposal Scheme in BMA

7.5.1 Overall Sludge Treatment/Disposal Flow

Based on the three Scenarios of ultimate sludge disposal, which was conceptualized in the subsection 7.2.5, Figure 7.5.1.1 shows the entire scheme and its mass flow quantities in 2020.

The three Scenarios have emerged under the consideration for the critical parameters, which are needed for the sludge treatment/disposal and for the extent of demands in beneficial uses. These parameters are the standards for agricultural use of sludge and for the input quality for landfill sludge, the demand for beneficial uses and the demand for sludge compost as shown in Figure 7.5.1.2.

In Scenario 1, which is named "Full Agricultural Use", all the sludges meeting the standard quality (62 % of total generated sludge) are used for agricultural use. The rest of the sludge (38 % of total generated sludge) is disposed to landfill site. In Scenario 2, which is named "Incineration Introduction", out of the landfill disposal sludge, some 10 % of total generated sludge (equivalent to 25 % of the landfill sludge) is incinerated after 2010. The need of maximum volume reduction or diverse beneficial uses of sludge and/or the enforcement of the input quality standard for landfill sludge are assumed to justify the introduction of incineration.

In Scenario 3, which is named "50 % Agricultural Use", only 50 % of the sludge with suitable quality for agricultural use, which is equivalent to 31 % of total generated sludge, are used for sludge compost. This is the case which actual marketing of sludge compost would be constrained less than the expected demand. The rest of sludge is disposed to landfill site and total landfill sludge together with the sludge of non-suitable quality for agriculture use is 69 % of total generated sludge.

The sludge dynamic lines from the sludge sources to ultimate disposal sites are delineated in Figures 7.5.1.3, 7.5.1.4 and 7.5.1.5, indicating the spatial moving lines of sludge for Scenario 1, 2 and 3. While all the sludge transportation will be done by truck after dewatering, the pipeline transportation from Central WWTPs to the Nong Khaem STC is the subject for future detail study.

7.5.2 Proposed Treatment/Disposal System for Landfill Disposal Sludge

The landfill disposal sludge, which is tentatively assumed high-risk sludge, is proposed to be treated and be disposed by the system summarized in Table 7.5.2.1 for Scenario 1, 2 and 3. In this system, the sludge generated in respective Central WWTPs is centralized to the Nong Khaem STC after dewatered and then goes to the Kampangsaen landfill site after treated. When night soil is treated after mixed with high-risk sludge in Central WWTP, the night soil sludge is regarded as high-risk sludge.

The Nong Khaem STC, which is under the ongoing status, is equipped with cake receiving and storage, sludge dilution, sludge digestion and sludge dehydration facilities. Its capacity is scheduled to be 120 t DS/d. As described in the sub-section 7.3.4, the Study Team recommends that the Nong Khaem STC be equipped with the power generation units (expected total output 1,400 kW) utilizing digester gas form the economical point of view.

Table 7.5.2.1 Proposed Treatment/Disposal System for Landfill Disposal Sludge

No.	Activities / Treatment	Locations	Facilities and Works	
			Scenario 1 / Scenario 3	Scenario 2
L-1	Sewage sludge thickening and dewatering	Central WWTPs (8 places)	[L-1]: Thickeners and dehydrators	
L-2	Sludge transport by trucks	Central WWTPs →Nong Khaem STC	[L-2]: Transport of dewatered sludge (quantity: 571 t Wet/d in 2020)	
L-3	Sludge dilution, digestion, dewatering and incineration	Nong Khaem STC	[L-3A]: Dilution equipment, digester and dehydrator (capacity: 120 t DS/d in 2020)	[L-3B]: Dilution equipment, digester and dehydrator (capacity: 120 t DS/d in 2020) [L-3C]: After 2010: Incineration added (capacity: 120 t Wet/d in 2020)
			[L-3D]: Power generator (capacity: 1400 kW in 2020)	
L-4	Sludge transport	Nong Khaem STC →Kampangsaen landfill site	[L-4A]: Transport of dewatered sludge (quantity: 443 t Wet/d in 2020)	[L-4B]: Transport of dewatered sludge (quantity: 332 t Wet/d in 2020) [L-4C]: After 2010: Transport of ash (quantity: 16.6 t Wet/d in 2020) added
L-5	Landfill disposal	Kampangsaen landfill site	[L-5A]: Controlled landfill disposal (quantity: 443 t Wet/d in 2020)	[L-5B]: Controlled landfill disposal of dewatered sludge (quantity: 332 t Wet/d in 2020) [L-5C]: After 2010: e.g. controlled landfill disposal of ash (quantity: 16.6 t Wet/d)

Note: The numbers marked by [ ] stand for the item number to specify a certain facility or work in this system.

In the beginning, the sludge transportation by trucks will take place from Central WWTPs to the Nong Khaem STC in accordance with the ongoing scheme. However, the pipeline transportation under the slurry status should be studied for economical transportation in the future, as described in the subsection 7.3.4.

Scenario 2 is featured by the introduction of incinerator with the capacity of 120 t Wet/d after 2010, which is aimed as a mitigation measure for toxic materials like heavy metals, etc. correspondent to the implementation of the input quality control of landfill sludge. In this case, ash from incinerator will be disposed in strictly controlled-type or controlled-type landfill site. Ash may need to receive the solidification process before disposal, depending on the quality standard to be enforced. Incinerator is, also, anticipated to play the role for the maximum volume reduction or the pre-treatment for some perspective sludge beneficial uses.

As for the landfill disposal, the Study Team has clarified that BMA has to prepare an adequate input control for sludge disposed in landfill site. Also, setting up a proper practice for sludge landfilling to be dedicated to wastewater sludge is needed, as detailed in the subsection 7.2.3 and 7.3.6.

7.5.3 Proposed Treatment/Disposal System for Agricultural Use Sludge

The agricultural use sludge, which is tentatively assumed low-risk sludge, is proposed to be treated and be disposed by the system summarized in Table 7.5.3.1 for Scenario 1, 2 and 3. The sludges from respective Central WWTPs, NSTPs and Community WWTPs are dewatered at the job-sites and are transported into the composting plants.

Total quantity of sludge compost will be around 940 t Product/d in 2020 in Scenario 1 and 2. In Scenario 3, its quantity will be limited to some 470 t Product/d in 2020 due to the restriction of compost marketing and the rest of low-risk sludge will go to the kampangsaen landfill site, directly from respective sludge sources.

The composting plants are tentatively sited at the three locations: the North Plant, the East Plant and the West Plant. The actual location of the composting plant, however, should be studied more specifically prior to the implementation stage in light of the distance from compost consumption areas, the availability of bulking materials and operation staffs, and the environment conditions of the neighborhood.

Table 7.5.3.1 Proposed Treatment/Disposal System for Agricultural Use Sludge

No.	Activities / Treatment	Locations	Facilities and Works	
			Scenario 1/ Scenario 2	Scenario 3
A-1	Sewage sludge thickening and dewatering	Central WWTPs (8 places)	[A-1]: Thickeners and dehydrators	
A-2	Sludge transport by trucks	Central WWTPs, NSTPs, Community WWTPs→ Composting Plants (3 places)	[A-2A]: Transport of dewatered sludge to North Plant (quantity: 334 t Wet/d in 2020)	[A-2D]: Transport of dewatered sludge to North Plant (quantity: 167 t Wet/d in 2020)
			[A-2B]: Transport of dewatered sludge to East Plant (quantity: 218 t Wet/d in 2020)	[A-2E]: Transport of dewatered sludge to East Plant (quantity: 109 t Wet/d in 2020)
			[A-2C]: Transport of dewatered sludge to West Plant (quantity: 389 t Wet/d in 2020)	[A-2F]: Transport of dewatered sludge to West Plant (quantity: 195 t Wet/d in 2020)
		WWTPs, NSTPs, Community WWTPs→ Kampansaen landfill site	None	[A-2G]: Transport of dewatered sludge to Kampangsaen (quantity: 470 t Wet/d in 2020)
A-3	Composting	Northern area	[A-3A]: North Plant (Capacity: 400 t Wet/d in 2020)	[A-3D]: North Plant (Capacity: 200 t Wet/d in 2020)
		Eastern area	[A-3B]: East Plant (Capacity: 240 t Wet/d in 2020)	[A-3E]: East Plant (Capacity: 120 t Wet/d in 2020)
		Western area	[A-3C]: West Plant (Capacity: 400 t Wet/d in 2020)	[A-3F]: West Plant (Capacity: 200 t Wet/d in 2020)
A-4	Selling of sludge compost	From 3 composting plants	[A-4A]: Product 941 t Wet/d in 2020	[A-4B]: Product 471 t Wet/d in 2020

Note: The numbers marked by [ ] stand for the item number to specify a certain facility or work in this system.

The composting plant consists of sludge stockyard, fermenter, maturation yard and odor control facilities. Among various type of composting process, the Study Team deems the horizontal type to be the most suitable for BMA, as the results of comprehensive comparison including performance, easiness of O and M, space requirement, etc. Bulking materials such as chaff necessary for sludge composting will be collected and be transported to the composting plants from the nearby areas.

7.6 Recommendations

In the course of the examination and planning of the sludge treatment/disposal in BMA, a number of the issues to be solved have been identified. These are summarized here and should be tackled to attain the target of this development plan.

(1) Management of Sewage Inflow

Considering either the landfill disposal or the useful use of sewage sludge, the quality of sewage inflow must be observed and controlled. As seen from the sludge qualities measurement and analysis conducted by the JICA Study Team, a certain extent of heavy metal intrusion has been identified in the present system in Central WWTPs and even NSTPs.

In agricultural use of sludge, adequate standards of sludge fertilizer should be first established beforehand. To observe such standards, the quality of sludge to be originated from respective sources should be judged in the course of the planning stage and also the operation stage of sewerage, as shown in Figure 7.6.1.1.

Meanwhile, to assess actual status of such intrusion level precisely and address such hindrances including the possible inflow of other toxic substances, the following actions are called for:

1) Countermeasure for Possible Sources of Toxic Substances

While BMA has already been equipped with the regulations for the control of industrial effluent, some small-scale industries reportedly continue to discharge wastewater beyond the limitation, mainly due to their financial constraint. To establish the thorough control of wastewater discharge, adequate measures should be addressed in cooperation with industrial sectors concerned.

Other than industries, hospitals and laboratories in educational institutions and research and development centers may be possible sources of toxic substances. To address the possible intrusion properly and effectively, the inventory of such suspicious sources should be furnished.

As seen from the above, massive inter-sectorial cooperation are called for to attain this scheme.

2) Monitoring of Inflow and Sludge

The monitoring of sludge quality as well as the incoming sewage and night soil quality on the regular base is essential by respective service areas. As for sewage quality monitoring, the location, frequency and the subjective items of measurement should be decided, depending on the conditions of each catchment area. Among these conditions are the topographic conditions, the distribution of possible toxic sources, and the categories of possible toxic source, etc. which may determine the background concentration and to assess occasional inflow of toxic substances.

(2) Establishment of Environment-Friendly Landfill

Landfill disposal will continue to be one of major ultimate methods necessary for the sludge disposal in BMA. The regulation and standards for proper landfill activities of sludge, however, have not been furnished in BMA, yet. The following matters should be prepared to promote the environmental-friendly landfill disposal:

- To enact the regulations which specify the quality of landfill sludge, so as to prevent hazardous substances in sludge like heavy metals, organic chlorides, etc. from being discharged into the environment,
- To establish the standards in which proper landfill practice dedicated to sludge become prevalent to promote safe and hygienic disposal.

(3) Marketing of Compost

Experience in many countries has shown that the marketing of sewage sludge compost is not so easy as expected. Major reasons for such difficulties have been the scarcity of information on how to use safely and effectively the compost and the imperfection of market-oriented organization on how to sale the compost. From such context, much of efforts must be made based on the inter-sectorial activities between concerned sectors, especially agricultural sector, in BMA to tackle these issues, for example:

1) Establishment of Organization of Production and Distribution System

In many countries, the combined system with public and private bodies are involved in the production and distribution of the sludge compost, as shown in Table 7.6.1.1. BMA should be prepared for the establishment of system suitable for the local conditions to produce competitive products and to market them securely. Proper storage facilities and functions through the production and marketing are required to cope with the seasonal fluctuation of the demand, also.

Table 7.6.1.1 Possible Organization Options for Compost Production and Distribution

Mode classifications	Compost production and distribution system		
	Sludge transportation	Compost production	Distribution
All public mode	(Public)	(Public)	(Public)
Public initiative mode	(Public)	(Public)	*[Private]*
Private initiative mode	(Public)	*[Private]*	*[Private]*
All private mode	*[Private]*	*[Private]*	*[Private]*

2) Setting up of Standards and Regulations

The quality of sludge compost, which covers the limitation of toxic and hazardous substances like heavy metals, pathogens and parasites, etc., should be regulated to protect the public health and present environmental pollution. Meanwhile, to provide guideline for proper utilization and monitoring of organic fertilizer, standards or guidance for land application should be formulated. Such regulations and standards must incorporate local requirements, conditions and constraints, for example, soil characteristics, climate, surrounding environment, categories of produces, agricultural practice, etc.

3) Training and Dissemination

To promote the agricultural use of organic fertilizer originated from sludge, massive activities for training and dissemination of not only farmers and bodies concerned with agriculture but also public are essential. These activities should cover the following, at least:

- Education to promote awareness and social acceptance of public for sludge compost,
- Training of sludge application techniques for farmers to properly use compost according to soil conditions and crop types,
- Training of technical analyses and nutrient management for agricultural experts to monitor soil conditions, heavy metals, pathogens, etc., on the regular basis.

(4) Study on Sludge Generation from WWTPs

The precise projection of sludge quantity generated in WWTPs is a key pre-requisite in sludge treatment/disposal planning. In this Study, a number of parameters for operation conditions and biological characteristics were assumed to estimate the sludge generation quantity. To make more precise estimation of the sludge quantity by setting suitable parameters, a continuous monitoring and assessment through actual operation of WWTPs should be carried out.

(5) Reassessment of Generated Sludge Quantity and Construction Schedule

The step-wise construction schedule of sludge treatment/disposal facilities is described in the Chapter 10. This is based on the sludge quantity projected in this Study. Meanwhile, actual sludge quantity generated by year in the future is varied directly depending on the implementation of sewerage development. Therefore, the reassessment of the sludge quantity by year and the construction schedule of facilities is needed in the course of the implementation stage.