5.4.4 Enforcement of Legislation

Discussions with senior officials and academics suggest that enforcement of environmental legislation is poor although the law and regulations are generally adequate. A particular problem, especially in districts, appears to be the reliance on the police to enforce environmental law when they have insufficient interest or knowledge for the purpose. An apparent anomaly is that the Environmental Law is considered to be either not well enough known or not strong enough to be effective, as mentioned in 5.4.3 above.

5.5 Privatization

In the wastewater and night soil treatment and disposal sector the state has relied significantly on private sector participation (PSP) with fairly simple mechanisms. The main types of participation used (see Table 9.4.1.1 for type details) are discussed below:

i) Service contracts are widely used for such work as plant and equipment installation and repair, survey and design work by consulting engineers, canal and retention pond dredging, transportation of solid waste to landfill sites, in most DDS and DPC divisions.

ii) Management contracts are less common, but are being considered for wastewater treatment plants and water treatment plants.

iii) Concession contracts are rare. MWA has granted a concession to the private sector to produce, distribute and supply water to a new town in Samut Prakan province by extending the MWA service. Some other small water supply projects have also been set up under concessions.

5.6 Training Facilities and Needs

The main organizations with responsibilities for staff training and development in areas relevant to the Study are the Institute of BMA Officers Development (a division in the Department of the BMA Permanent Secretary) and the Training Center for Sewerage Works. In addition, several universities in Bangkok and in the provinces contain facilities for research and dispensing information on wastewater treatment technology.

Training needs appeared to be modest, except for: some district offices which required extensive training at all levels, including management; pumping station O&M; and unskilled staff, especially in DDS.

CHAPTER 6 PLAN OF FUTURE WASTEWATER AND NIGHT SOIL TREATMENT AND DISPOSAL

6.1 Establishment of Future Wastewater Disposal System

6.1.1 Establishment of Design Basis

(1) Flows and Loads

1) Approach

In this Study wastewater flows and loads are determined separately for domestic, commercial and institutional, and industrial wastewaters:

i) Domestic flows and loads are determined from unit per capita flows and loads and population forecasts.
ii) Commercial and institutional flows and loads are determined from the numbers, types and sizes of commercial and institutional premises derived from the 1993 PCD BMR Wastewater Management Master Plan.
iii) Industrial flows and loads are determined from wastewater records of the Ministry of Industry.

This approach was adopted in the 1993 PCD BMR Wastewater Management Master Plan and the 1998 Wastewater User Charge Study.

The ongoing wastewater scheme projects are designed for flows calculated from forecast populations and per capita unit flows which allow for all non-domestic wastewater. Pollution load concentrations are assumed for all wastewater flows. This is considered less appropriate as it does not account for differences in commercial, institutional and industrial wastewaters in different areas.

2) Domestic Wastewater

a) Domestic Flows

Metered water consumption is used to forecast domestic wastewater flow in this Master Plan. Some water consumed will not result in wastewater and wastewater flow will be increased by infiltration. These are assumed to be approximately equivalent and so no loss nor gain is predicted from the water supply. Per capita water consumption is difficult to predict due to uncertainties in the population per meter connection. Nevertheless MWA currently adopt a per capita flow of 376 l/c/d in their planning to 2017 which includes 256 l/c/d for domestic consumption and 120 l/c/d for non-domestic use. The later ongoing BMA wastewater schemes adopt this unit flow.

Other studies have proposed unit flows ranging from 190 to 599 l/c/d as indicated in Table 6.1.1.1. The survey of water consumption of the 38 apartment blocks draining to the Huay Kwuang Community WWTP undertaken by the Study Team and described in Section 4.1.2 found a consumption of 183 l/c/d but a lower than average consumption would be expected from this area.

A unit domestic wastewater flow of 256 l/c/d is adopted throughout the period of this Master Plan. This is consistent with BMA current wastewater scheme design specifications but excludes an allowance for non-domestic use which are better assessed separately for each scheme area.

b) Domestic Loads

Previous studies have adopted unit domestic loads ranging between 30 and 50 g/c/d of BOD as indicated in Table 6.1.1.1. 43 g/c/d is given as a typical value for South East Asia in a standard text book, Sewage Treatment in Hot Climates by D. Mara. This is similar to the unit load derived from the Huay Kwuang WWTP catchment of 45 g/c/d described in Section 4.1.2 where the contributing population was determined, although this catchment is served by a separate foul sewerage system without private septic tanks not typical of most of Bangkok. A BOD reduction of the toilet wastes treated in the septic tank may typically be 9 g/c/d (assuming 40 % of a typical toilet waste BOD of 22 g/c/d is lost from the tank effluent). This would suggest a value of 34 or 36 g/c/d but a higher value is considered appropriate since Bangkok has a higher quality of life than many parts of Southeast Asia, and the Huay Kwuang WWTP service area is poorer than average. Unfortunately it was found that the values determined from the Study Team's survey described in Section 4.2 could not readily be utilized in the assessment of domestic unit load due to uncertainties in the contributory populations. A rather higher per capita BOD load is therefore considered appropriate and 40 g/c/d is proposed initially and assessed with wastewater quality.

The load of 40 g/c/d in the per capita flow of 256 l/c/d derived above is equivalent to a domestic wastewater BOD concentration of 156 mg/l which is close to 150 mg/l specified in the current scheme contracts. A unit BOD load of 40 g/c/d is therefore generally consistent with BMA current design practice although it does not take account of the much lower measured BOD concentrations in the wastewater. This is accounted for later in this section. A value of 40 g/c/d is therefore adopted at the entry to the drain for the purposes of this Master Plan throughout the planning period.

Table 6.1.1.2 indicates the arrangement of toilet and other domestic wastes before entry to the drain and gives ranges of BOD loads to suit different types of property.

3) Commercial and Institutional Wastewater

The 1993 PCD BMR Master Plan investigated the extent of commercial premises in each district and applied unit flows and loads researched by the 1988 Water Quality Management study as indicated in Table 6.1.1.3. These were converted to the new districts in the Wastewater User Charge study. Increases in these flows and loads are forecast to be in proportion to the increase in population.

Table 6.1.1.3 Wastewater Discharges from Commercial Premises

Establishment	Unit	Unit Flow (l/unit/d)	Unit BOD (g/unit/d)
Office	m^2	3.4	0.09
Hospital	Bed	566	94
Hotel	Room	885	123
Department Store	m^2	4.3	0.27
Market	m^2	16	21
Restaurant	m^2	74	53

There is concern that no unit flows are provided for other institutions, especially schools and colleges. It is, therefore, proposed to make an assumption that 20 % of the population is at school or college and will produce a typical flow of 40 l/c/d. This adds significantly to the commercial and institutional flows but the addition to the total wastewater flows is small. No allowance is made for additional BOD load on the assumption that this is included in the domestic load allowance described above.

4) Industrial Wastewater

a) Industrial Flows

The 1993 PCD BMR Master Plan investigated the extent of wastewater producing industries in each district to establish industrial wastewater flows in 1990 and assumed that these would increase in proportion with Gross Domestic Product (GDP) forecast to be 3.33 % pa throughout the period 1990 - 2020. The 1996 PCD BMR Plan estimates industrial wastewater in the BMA region to be very much less than in those of the earlier plan and is considered less reliable.

GDP in the manufacturing sector has been growing faster than predicted in the 1993 Master Plan, and is forecast to increase at an average rate of 5.52 % pa over the 30 years from 1990 to 2020. For several economic and planning reasons industrial wastewaters are likely to increase at a lower rate than GDP, and wastewater flows are forecast to increase at half this rate or 2.76 % pa. GDP growth rates in the manufacturing sector and reasons for adopting a lower rate are described in Supporting Report B.

b) Industrial Loads

The 1993 PCD BMR Master Plan assumes that industries will treat their wastewaters at source to remove 70% of their pollution load. This produces an average industrial effluent qualities of between 95 mg/l of BOD in Phrakhanong district and 168 mg/l in Thonburi district in their forecasts for the planned and proposed wastewater scheme areas proposed for implementation within the Master Plan planning horizon.

The later 1996 Plan estimates very much higher industrial pollution loads with no reference to treatment at source and is not considered in this assessment.

The 1993 PCD BMR Master Plan assumption that 70 % of industrial wastewater pollution load will be removed at source is equivalent to 70 % of industrial wastewaters being fully treated at source, and the remaining 30 % requiring to be treated in BMA facilities. This is considered to be a reasonable expectation and the 1993 PCD BMR Master Plan assumptions on industrial loads, adjusted by reductions in flow forecasts described above, are proposed to be adopted in this Master Plan.

5) Load Reduction in Drainage System

a) Causes of BOD Reduction

The sluggish flows in the large flat combined drains allows wastewaters to become septic and putrefy (anaerobic decomposition) as is evident from the black color of the wastewaters and frequent release of sewer gas (hydrogen sulphide) from the drains in the city. This will reduce the BOD in the wastewater to a significant but unknown extent. A recent preliminary study by a resident JICA expert indicates that BOD concentration in the drains may halve in two days, and the many observations of stagnant wastewater in the drains by the Study Team suggest that much of the wastewater remains in the drains for long periods during dry weather. BOD will also be reduced by dilution with groundwater infiltration into the drains through leaks in the pipes or unsealed septic tanks, and through inflows from the khlongs. These

factors explain the relatively low wastewater strength measured at the inlet to Si Phraya WWTP and elsewhere.

b) Review of Wastewater Quality Data

The only extensive wastewater quality data from the combined drainage system is that from the records of incoming sewage to Si Phraya WWTP over a period of 41 months from October 1995 to April 1999 given in Data Book M which indicates an average BOD concentration of 61 mg/l.

Other wastewater quality data obtained by the Study and Counterpart Team and from previous investigations shows the wastewater to be generally very weak, and often variable upstream in the drainage system. In order to fully assess the available wastewater quality data and its variability, all available analyses of wastewater from the combined drains are presented in Figure 6.1.1.1 which indicates the distribution of BOD concentrations within discrete ranges. This shows normal weather wastewater analyses in columns and storm event analyses separately as a graph.

c) BOD Reduction Factor

The domestic unit load parameter proposed above is considered as appropriate at the point of entry to the drain, but a BOD Reduction Factor is applied to account for the reduction in wastewater BOD as it passes through the drainage system and interceptor sewer to the WWTP. For the purposes of this Study, the following definition is adopted:

$$\text{BOD Reduction Factor} = \frac{(\text{BOD at entry to the drain} - \text{BOD at WWTP})}{\text{BOD at entry to the drain}} \times 100\ \%$$

d) Evaluation

Figure 6.1.1.1 indicates that the Si Phraya Central WWTP wastewater quality is typical of other wastewaters in combined drains in other parts of the city although there is more variation. The figure indicates that about 90 % of the wastewater has a BOD of less than 110 mg/l. On this basis 110 mg/l is taken to represent the normal maximum wastewater BOD in the drains.

The Si Phraya Wastewater Scheme interceptor chambers have been found not always to be successful in separating wastewater. The interceptor sewers of the new wastewater schemes should significantly improve the collection and transfer of wastewater drawing down the flows in the combined drains and so increasing wastewater flow velocities and reducing residence times in the drains. The drain outfalls are to be controlled to avoid back flows from the

khlongs. These expected changes in the operation of the combined drains are shown diagrammatically in Figure 6.1.1.2. It is therefore expected that the new wastewater schemes will achieve better wastewater separation and the Si Phraya WWTP data should, therefore, not be taken as typical of future schemes.

It is proposed that the average wastewater quality from the future wastewater schemes will be equivalent to that of the normal high strength wastewaters found in the drains at present. This assumes that the present normal high strength wastewaters are representative of future wastewaters transported more effectively in the drains when connected to interceptor sewers and that back flows from the khlongs will be minimal.

In the forecasts of future flows and loads for the proposed future schemes described in Section 6.1.2 and presented in Table 6.1.3.1, total DWF from these areas in 2020 is estimated to be 1,306,000 m^3/d and total BOD load, 209 t/d, equating to an average BOD concentration of 160 mg/l, rather higher than the 156 mg/l calculated for domestic wastewater alone. Adopting 110 mg/l as the average future wastewater quality at the WWTP inlet, this gives a BOD Reduction Factor of $\frac{160-110}{160} = 31\ \%$.

This compares with a much lower Reduction Factor of $\frac{156-61}{156} = 61\ \%$

calculated from the Si Phraya records data assuming only domestic wastewater.

A BOD Reduction Factor of 30 % is therefore adopted in this Study. However, when the new wastewater schemes in Yannawa and Ratanakosin are commissioned new actual wastewater quality data at the Central WWTP inlets drawing from the combined drains and interceptor sewers will be available and allow the BOD Reduction Factor to be re-assessed from actual rather than derived data.

6) Proportion of Wastewaters Collected

The major wastewater schemes are required to collect all the wastewaters from the BMA drains before discharge to the khlongs. They are not required to collect wastewater flows from direct house connections to the khlongs from adjacent properties nor from private sewers. The scheme contractors are required to locate all BMA drain outfalls but it is likely that some will be missed. However, it is the intention of BMA to make further connections to

collect all wastewaters in future both from missed BMA drains and from private sewers and khlong connections.

Although it is unlikely that all wastewaters will be collected, it is assumed that the proportion of wastewater not collected by the new schemes will be small and may be neglected for the purposes of this Study

(2) Size of Wastewater Service Systems

The options available range between:

i) very small pre-fabricated WWTPs for each property
ii) small community separate sewerage systems and Community WWTPs
iii) large public wastewater schemes comprising major sewerage and Central WWTPs serving major areas of the city
iv) very large public wastewater schemes comprising major sewerage and WWTPs such that two or three schemes would serve the whole of the city

These are discussed in Supporting Report C in which it is recommended to continue the current program of major wastewater schemes arranged such that each scheme will realize immediate environmental benefits.

(3) Type of Sewerage

The main choice lies between continuing with the interceptor sewerage system adopted in the current wastewater schemes, or the construction of new independent separate foul sewerage systems. These options are discussed in Supporting Report D.

In view of the nature of the existing drainage systems, the separate sewer system is preferred for all new development. However, the continued use of the combined drains is a much lower cost option and is therefore recommended subject to:

i) improvements in the hydraulic operation in sensitive areas to establish effective and consistent flow patters, and continuous falls in drain level,
ii) subsequent conversion to separate sewerage in particular sensitive locations where, despite efforts, the drains fail to convey wastewaters satisfactorily and sewer gas release continues,
iii) improved maintenance of the drainage system and renovation where necessary,
iv) improved operation and regulation of septic tanks and use of grease traps.

(4) Peak Flow Capacity

Variations in wastewater flow are accommodated by providing capacity for a multiple of average Dry Weather Flow (DWF). For all the current ongoing schemes, a Peak Flow Factor of 5 x DWF has been selected. Peak Flow Factors

are discussed in Supporting Report E and it is proposed that consideration be given to selecting a lower factor. This will require more storm event monitoring to be undertaken, measuring both flow and quality as the first flush load is critical to the choice of the factor. Nevertheless a factor of 5 x DWF is adopted for the provisional interceptor sewer designs included in Section 6.1.4.

(5) Wastewater Treatment

1) Treatment Capacity

The current wastewater schemes all require preliminary treatment (screening and grit removal) of all incoming flows of up to 5 x DWF and full biological treatment of up to 1.5 x DWF initially with provision for accommodating 2.5 x DWF in future. The lower initial capacity of the initial biological plant is appropriate especially in view of the uncertainties in initial flows and loads. These capacity requirements are recommended for future schemes as discussed in Supporting Report G.

2) Extent of Treatment

Full biological treatment in these schemes includes nutrient removal which is required to limit eutrophication in the khlongs. The required treated effluent standards are set out in Table 6.1.1.4.

Table 6.1.1.4 BMA Current Project Treated Wastewater Effluent Quality Standards

Parameter	Average Effluent Quality Standard (mg/l)
BOD	20
Suspended Solids	30
N (total)	10
N (NH_3)	5
P	2
DO	5

The main treatment requirement is to protect the khlongs and Chao Phra River from wastewater pollution. At present, the majority of khlongs are highly polluted as indicated in Data Book G. However, in the initial stages of implementation of the new wastewater schemes, the proportion of wastewater collected and the efficiency of its transfer to the WWTP may be more critical to khlong water quality than the extent of treatment. Normal biological treatment to a 30/20 quality (mg/l BOD/suspended solids) is considered to be the first priority.

Nutrient removal is required to avoid eutrophication and weed growth in the khlongs and is considered of secondary importance. It requires additional activated sludge plant and sophisticated plant control or expensive chemical treatment.

Sludge treatment is discussed in Section 7.4.

A review of the options for the extent of wastewater treatment is included in Supporting Report G.

6.1.2 Establishment of New Wastewater Schemes

(1) Strategic Wastewater Plan

1) Planning Approach

In Section 6.1.1 it is proposed that future wastewater schemes should be generally of the same size as those of the current ongoing projects, and this is generally in accordance with the 1993 PCD BMR Wastewater Management Master Plan proposals.

A long term Strategic Plan is proposed as an ultimate target to meet perceived needs but its main purpose is to provide a framework for selecting schemes to be implemented during the Master Plan period.

2) Criteria for Service Area Selection

The main criterion for the selection of new areas requiring public wastewater facilities must be the degree of urbanization as indicated by forecasts of population density and planned development. The planning information evaluated by the Study Team include:

i) population forecasts for each district available from the Wastewater User Charge Study, 1998,
ii) the future Land Use Plan prepared in 1997 for 1999-2019 from the BMA City Planning Department,
iii) the PCD BMR Wastewater Management Master Plan, 1993 which identified future proposed wastewater service areas,
iv) current development as indicated on the 1994 City Plan 1:20,000 maps.

Population forecasts from the Wastewater User Charge study are described in Section 2.2.1, and future land use by City Planning in Section 2.2.2. The 1993 PCD BMR Wastewater Master Plan is described above.

The selection of areas for public wastewater services to be included in the Strategic Plan is as follows:

i) It is assumed that areas with forecast populations of less than 50 persons/ha will generally remain essentially rural and that public wastewater services are considered low priority in these areas.
ii) Other areas are generally considered to require public wastewater services in due course, especially those where strategic development is planned by City Planning.
iii) Several low density districts are planned to have pockets of development which would warrant public wastewater services.
iv) Although sewerage and sewage wastewater treatment will not be provided to all areas within the BMA region, Night Soil collection from septic tanks and community WWTPs will be required in all areas.
v) Priority is given to areas with major khlongs suffering from wastewater pollution.

3) Service Areas in Strategic Wastewater Plan

Thirteen new areas are selected on this basis, parts of which are considered to warrant the installation of sewerage and wastewater treatment in due course. Other areas are not considered to require public wastewater services for the foreseeable future and well after the 2020 planning horizon. Needs for these areas should be re-appraised in due course .

These proposed serviced areas have been selected on the basis of 2020 forecast population densities exceeding 50 persons/ha from the Wastewater User Charge study, and areas of high growth identified and strategic transport and industry which will encourage growth as identified in the BMA Land Use Plan.

Consideration has been given to the wastewater zones proposed in the 1993 PCD BMR Master Plan but area boundaries have been adjusted to the likely limits of more intensive urban development and to follow khlongs, district boundaries, and main roads as considered appropriate. Several of the key roads are raised and these together with the khlongs form natural catchments, although the region is generally flat. More smaller areas are proposed than in the 1993 PCD BMR Master Plan with serviced populations generally in the range of 200,000 to 500,000 as this is considered more suitable for management and incremental development.

The 13 proposed new areas are indicated in Figure 6.1.2.1. Names to these areas are mostly given to the main new district in which they lie.

The Wastewater User Charge study population projections, extrapolated to 2020 by the Study Team, are used for the basis of population forecasts in

each proposed area. These are derived as indicated in Data Book E and generally assume the uniform population density within the districts and making adjustments for the changed proposed district boundaries.

These new areas together with the planned schemes for Khlong Toey and Thonburi and the ongoing wastewater projects comprise a proposed Strategic Wastewater Plan for the BMA region. This represents a long term plan looking beyond to Master Plan 2020 planning horizon since implementation of wastewater schemes in all areas cannot be expected to be accomplished within the 2020 planning horizon of this Study.

(2) Priority Areas for Implementation During Master Plan Period

1) Selection Procedures

Priority areas for public wastewater services are determined on the development forecasts described above.

Table 6.1.2.1 sets out a numerical analysis based on ratings for forecast population density and planning.

Scores are given for forecast population density in 2020 population density, land use taking into account types of residential development, transport plans and industrial zones, and for khlong water quality where available as indicated in the table. Analyses from the khlong surveys are included in Data Book G.

These total scores are then ranked in priority order and placed in 3 categories for implementation: the current planned schemes, proposed schemes to be implemented within the 2020 planning horizon, and those to be implemented later. The schemes proposed to be implemented during the Master Plan period are indicated on Figure 6.1.2.2.

No special consideration was given to improving the Khlong San Sap. Should this become a government priority, the Eastern Corridor and Non Jok wastewater schemes should also be included.

2) Selected Service Areas for Master Plan

This analysis justifies the priority for schemes in the Khlong Toey and Thonburi areas but not for the Nong Bon scheme. It is therefore proposed not to include the Nong Bon scheme in the Master Plan implementation program as discussed with BMA despite its inclusion in the Bangkok Metropolitan Development Plan (1997 - 2001). The Khlong Toey and Thonburi schemes are already planned and placed in the first category of

priorities. Arrangements are being made for the detailed study and funding of the Khlong Toey scheme.

Second priority is given to newly proposed schemes in Bang Sue, Huay Kwuang, Wang Thong Lang, and Bung Kum, and these are proposed to be implemented within the Master Plan period.

The other identified areas will generally have population densities of about 100 per ha or less, and are not proposed for implementation before 2020. These are given third category priority status. However, the northern areas near the airport, Don Muang, and Lak Si, are expected to have higher densities of around 120 persons/ha but have not been identified as key development areas in the Land Use Plan.

3) Comparison with 1993 PCD BMR Wastewater Management Master Plan

The Study Team's Master Plan proposals for new wastewater schemes to be implemented within the 2020 planning horizon are similar to the 1993 PCD BMR Master Plan group of first priority areas. However:

i) the PCD BMR Master Plan also includes the Lak Si, Lat Phrao and City South West areas not recommended as priority areas in this Study,
ii) the Bung Kum area proposed as a priority area in this Study is not identified as a priority area in the PCD BMR Master Plan,
iii) Nong Bon scheme is also not given priority in the PCD BMR Master the Plan.

(3) Proposed Implementation

It is proposed that the ongoing schemes are developed and the proposed new schemes constructed over the Master Plan period to 2020 broadly at the present rate of investment. Although many changes to this program may be expected, and the sequence of scheme implementation changed, the program serves to provide a basis for sludge generation from the Central WWTPs essential for this Master Plan in Section 7.1.3.

Many of the schemes are proposed to be developed in phases to allow for increasing demands for these services over the Master Plan period and for incremental investment. Phased development will facilitate adjustment of the schedule should service demands differ from those forecast and allow for limitations on investment funds. For the purposes of this Study it is assumed that the initial stages of the schemes will allow for the flows and loads predicted in 2000 and that the later stages will allow for those forecast in 2020. The first stages of the Thonburi and Khlong Toey schemes are proposed to be implemented by

2010, with the second stages proposed in the following decade. The second stages of the ongoing schemes are proposed to be implemented five years before they were predicted to reach design capacity. The new schemes proposed in this Master Plan are each proposed to be implemented in a single stage to their planned 2020 capacity during the period 2012 to 2018. This program is set out in Table 6.1.2.2.

6.1.3 Wastewater Treatment Plants

(1) Wastewater Flows and Loads

Wastewater flows and loads are forecast for the planned and proposed schemes in Table 6.1.3.1 on the basis of criteria described in Section 6.1.1.

Domestic flows are calculated from the forecast population at 256 l/c/d, and domestic loads at 40 g/c/d of BOD. Population forecasts in each area are derived from the 1998 BMA Wastewater User Charge study.

Commercial and institutional flows and loads are derived from the 1993 PCD BMR Wastewater Management Master Plan with an addition for educational establishments of 40 l/c/d for 20 % of the population but no additional load. These are assumed to increase in proportion to population growth and have been adjusted from the previous Master Plan population projections to those used in this Study. In Table 6.1.3.2, commercial and institutional flows and loads are established for 2000 which are transferred to Table 6.1.3.1.

Industrial flows and loads are derived from the 1993 PCD BMR Wastewater Management Master Plan. These are assumed to increase at 50 % of GDP growth in the manufacturing sector as forecast by NESDB and have been adjusted from those in the previous Master Plan. Table 6.1.3.3 establishes industrial flows and loads for 2000 which are transferred to Table 6.1.3.1.

Flows and loads from these sources are added to give total forecast flows and loads discharged to the drainage system.

BOD is will be reduced in the drainage system and a Reduction Factor of 30 % is assumed to account for BOD reduction for all forecast BOD loads between entry to the drains and delivery at the WWTP.

Table 6.1.3.1 has been extended to forecast sludge production at an assumed rate of 1.0 kg sludge solids per kg BOD. This is discussed in Section 7.1.3

(2) Treatment Plant Size and Location

BMA have difficulty in acquiring sites for WWTPs and this has necessitated compact multi-story housed plants with a small footprint for most of the ongoing schemes requiring air management and odor control. Investigations concerning

Central WWTPs for the planned and proposed schemes indicate that most of these will require similar types of plants although single level WWTPs are preferred wherever possible.

Supporting Report H describes these investigations and proposes WWTP sites mostly on private property. These are assumed for the provisional design of the interceptor sewers and WWTPs proposed in this section and Section 6.1.4.

(3) Treatment Plant Processes

The choice of treatment processes in the ongoing projects is proposed by the bidder and approved by BMA during bid evaluation before awarding the contract. The process streams must satisfy the assumed wastewater quality, and the treated wastewater and sludge quality standards specified in the contract. This procedure ensures that the selected processes are cost-effective. This is particularly appropriate in relation to nutrient removal as processes are currently being rapidly developed and bidders will search for the most cost-effective process. Proposals for WWTP processes in this Master Plan are therefore provisional.

Treatment process options are discussed in Supporting Report I and a provisional process plant selection is shown schematically in Figure 6.1.3.1.

(4) Treatment Plant Arrangements

1) Process Plant Sizing

Numbers and sizes of the mainstream process units have been determined for each of the planned and proposed Central WWTPs in Table 6.1.3.4 assuming the processes listed above.

The following process design parameters have been assumed based on accepted design practices. These are discussed in Supporting Report I.

i) Coarse bar screens with a maximum flow velocity between the bars of 0.9 m/s together with a stand-by unit,
ii) Fine drum screens with 5 mm apertures based on manufacturers' unit capacities together with a stand-by unit,
iii) Vortex grit separators based on manufacturers' unit capacities,
iv) Modified Sequential Batch Reactor Activated Sludge Plant (SBR ASP) basins assuming a Food to Micro-organism ratio (F/M) of 0.09 kg BOD/kg MLSS. Mixed Liquor Suspended Solids (MLSS) concentration of 2,500 mg/l and 2.0 h settling/decant time.

Sludge thickening and de-watering at the Central WWTPs is discussed in Section 7.3.3

The modified SBR ASP process has been proposed as it is one of the simpler biological nutrient removal activated sludge processes and is adopted in the Yannawa Central WWTP. Biological nutrient removal is preferred to chemical treatment for large WWTPs in view of the costs of chemicals.

2) Central WWTP Plant Layouts

Typical WWTP arrangements are shown in Figures 6.1.3.2 and 6.1.3.3 for a single level compact plant and for one with SBR ASP basins on two floors. These are sized for the proposed Thonburi South wastewater scheme WWTP and include a 20 m buffer zone around the plant. This sizing is used as a basis for the areas required for WWTPs for the other proposed schemes considered in Supporting Report II.

6.1.4 Wastewater Collection Systems

(1) General Description

The wastewater collection systems will comprise new interceptor chambers close to the outfalls to the khlongs on the existing drainage system, and interceptor sewers to convey the diverted wastewater to the Central WWTP. The proposed scheme arrangements require no pumping stations on the sewer system upstream of the WWTPs

1) Interceptor Chambers

Interceptor chambers or diversion chambers will be required at each drain outfall or pair of outfalls to the khlong.

Hydraulic control in the current schemes is provided by a simple orifice plate restricting flows to the interceptor sewer and rectangular weir plates for the overflows to the khlongs. Back flows from the khlongs are avoided by provision of flap valves. Manually cleaned coarse screens are also provided and these will present a major maintenance task and will restrict flows if blocked.

Hydraulic control of the diverted flow could be improved by the installation of Hydrobrakes instead of orifice plates. These are devices which control the diverted flow with relatively little variation under a range of storm flow conditions.

The current design specifications require screening of flows in the chambers with manual cleaning. This is considered impractical and may increase the risk of flooding if not properly maintained. Mechanically raked screens would

be very costly and over-topping manually cleaned screens would increase flooding. Screens are ,therefore, not recommended on either the diverted wastewater flow or the storm overflow. However, baffle plates at the water surface level are proposed to trap floating solid matter from spilling into the Khlongs allowing the storm water overflow to pass beneath. These may be located either in the interceptor chambers or at the outfall to the Khlong whichever is the more convenient for maintenance.

2) Manholes

Manholes are required for access for maintenance. The current BMA wastewater scheme specification requires manholes to be located at each change in direction, pipe diameter or gradient, at intervals not exceeding:

i) 80 m for sewers equal or less than 800 mm diameter,
ii) 120 m for sewers between 800 and 1500 mm diameter,
iii) 200 m for 1500 mm diameter and larger sewers.

These criteria are generally considered appropriate but manhole spacing should also be determined to suit the sewer maintenance equipment which may allow greater distances between manholes.

(2) Plans of Main Interceptor Sewers

The arrangement of the main interceptor sewers is shown in Figures 6.1.4.1 to 6.1.4.9. These are shown draining to the preferred option Central WWTP sites proposed in Section 6.1.3.

(3) Hydraulic Design

The hydraulic design of the main interceptor sewers uses the Manning formula for pipe friction losses with a roughness coefficient of 0.01.

The current BMA wastewater scheme specification requires wastewater flow velocities to exceed minimum values required for "self cleansing" to avoid solids deposition.

i) 0.8 m/s for sewers equal or less than 600 mm diameter,
ii) 0.7 m/s for sewers greater than 600 mm up to 1200 mm diameter,
iii) 0.6 m/s for sewers larger than 1200 mm diameter.

The current BMA specification also requires that wastewater velocities do not exceed 3.0 m/s. These are generally accepted wastewater velocity criteria for sewer design.

The main interceptor sewers have been sized to accommodate peak flows of 5 x DWF forecast in 2020 in accordance with current BMA policy. However, it is suggested that consideration be given to adopting a lower peak factor as discussed in Section 6.1.1. For the purposes of this Study it has been assumed that the flows will be generated uniformly across the service area. Data Book I presents the areas and flows in each sub-catchment, and the required sewer diameter, length, peak flow velocity, and gradient.

(4) Sewer Materials and Construction

1) Sewer Pipes

Methods Interceptor sewers will be spun or pre-cast reinforced concrete pipes. The strength of the pipes will generally be determined to suit the method of construction discussed below. Plastics linings will be required to resist acid attack from hydrogen sulfide gas released from septic sewage except where the sewer will always be operating under surcharged conditions.

2) Sewer Construction

The majority of interceptor sewers will be constructed in tunnels to avoid traffic disruption and because the downstream sewers will be too deep for economic open cut construction.

The Bangkok soils comprise soft clays overlying medium and stiff clays as described in Section 2.1.4. These are well suited to tunneling and there is considerable experience of tunnel construction in Bangkok. A variety of tunneling techniques may be used appropriate to the pipe size.

i) Micro-tunneling for pipes up to 250 mm diameter,
ii) Slurry Shield Pipe Jacking for pipes between 300 mm and 800 mm diameter,
iii) Earth Pressure Balance Pipe Jacking for pipes between 900 mm and 2600 mm diameter,
iv) Slurry Shield Tunneling for pipes greater than 2500 mm diameter.

6.2 Plan of Future Night Soil Treatment System

6.2.1 Planning Conditions

(1) Generation Rate of Collected Night Soil

To determine the per capita night soil generation rate in BMA, past record were reviewed, as shown in Table 6.2.1.1. The range of 0.77 to 0.85 l/c/d for the night soil generation rate was derived from this analysis. Meanwhile, for the purpose of

future projection of night soil quantities from BMA, 1.0 l/c/d has been practically and conventionally adopted, containing a certain allowance for actual analyzed rates. Thus, the night soil generation rate of 1.0 l/c/d has been applied to this Study.

(2) Total Population in BMA

Total population in BMA based on Table 2.2.1.3 is projected to be 11,856,000 in 2020.

(3) Quantity of Collected Night Soil

The quantity of night soil collected in the whole of BMA has been computed, assuming that the collection ratio of night soil would attain 20 % in 2020, on the basis of population number. As shown in Table 6.2.1.2, this has resulted in daily 2,445 m^3 of collected night soil in BMA in 2020, with the stepwise increases of collection ratio, like 16 % in 2005, 17 % in 2010 and 18 % in 2015.

Table 6.2.1.2 Collected Night Soil Quantity in BMA

Items	Units	Years				
		2000	2005	2010	2015	2020
Total Population	(x 1000)	8,007	8,778	9,664	10,681	11,856
Collection Rate	(%)	15.0	16.0	17.0	18.0	20.6
Served Population	(x 1000)	1,201	1,404	1,643	1,923	2,445
Collected Night Soil	(m^3/d)	1,201	1,404	1,643	1,923	2,445

(4) Characteristics of Collected Night Soil

Night soil characteristics vary widely due to a number of factors. Among these factors are the type of property from which the night soil is originated, food habits of the people, form of receiving treatment equipment at sources (septic tank, cess pool, etc.), and the extent of digestion taking place. As shown in Table 6.2.1.3, a number of studies in the past regarding characteristics of the night soil from BMA have been performed. The survey results of Thammrat Koottatep, et al. are likely to be the representative ones for BMA, because the survey extended to as many as 90 septage samples. Thus, this Study has regarded the characteristics being represented by 18,600 mg/l of total solids as the design basis of collected night soil, depending on the survey results of Thammrat Koottatep, et al.

Table 6.2.1.3 Characteristics of Collected Night Soil

Items / Data source	Total solids (TS) (mg/l)	Suspended solids (SS) (mg/l)	Volatile suspended solids (mg/l)	BOD (mg/l)	COD (mg/l)
Rattasuk Klinsokoa (1977) for BMA	1,806 - 35,260	9,200 - 21,600	1,204 - 25,926	-	-
Arifin (1982) for BMA	30,000 - 160,000	15,000 - 21,000	10,000 - 21,000	1,260 - 4,800	9,600 - 68,800
Culalangkorn (1986) for BMA	26,640	20,381	19,534	4,889	45,410
EPA recommended design basis	40,000	15,000	7,000	6,000	30,000
AIT recommended basis for BMA	40,000	18,000	15,000	4,500	40,000
Thammrat Koottatep, et al.[1] for BMA	18,600	13,400	11,000	2,700	16,900

Note:

1) Septage Treatment by a Vertical-Flow Constructed Wetland, Thammarat Koottatep, Chaong Pongrak Polprasert, and Nguyen T. Kim Oanh, August 5, 1998, Proceeding of Workshop, Low-cost Septage Treatment.

2) Other data were originated from Final Report of AIT Master Plan Study on Treatment and Disposal of Domestic Sewage Sludge including Night Soil and Oil and Grease Residues for Bangkok Metropolitan, AIT (1995).

6.2.2 Expansion Plan of Night Soil Collection and Treatment System

(1) Expansion Scheme

In 2020, the service area of night soil collection and treatment in BMA will be divided into four service areas: Nong Khaem, On-Nut, Yannawa, and Ratburana, as shown in Figure 6.2.2.1. This division of service areas has been planned in light of the location of NSTPs, their treatment capacity and the served population number in respective districts. The main features of respective service areas in 2020 are forecast as follows:

1) Nong Khaem services area:

Land area: 432.0 km^2,
Population: 2,843,000,
Collection ratio: 18.1 %,
Quantity of collected night soil: 516 m^3/d

2) On-Nut services area:

Land area: 724.1 km^2,
Population: 2,773,000,

Collection ratio:	20.8 %,
Quantity of collected night soil:	578 m^3/d

3) Yannawa services area:

Land area:	319.0 km^2,
Population:	4,494,500,
Collection ratio:	21.4 %,
Quantity of collected night soil:	963 m^3/d

4) Ratburana services area:

Land area:	94.0 km^2,
Population:	1.744,700,
Collection ratio:	22.3 %,
Quantity of collected night soil:	389 m^3/d

The targeted collection ratio of respective districts in 2020 are detailed in Table 6.2.2.1. Highly urbanized areas like the center of BMA area are given higher collection ratios. The following targets by districts correspond to the population density are proposed, except for districts, where the targets have been already exceeded:

- 30 % collection ratio for districts with higher than 30,000 people/km^2,
- 20 % collection ratio for district between 30,000 and 10,000 people/km^2, and
- 10 % collection ratio for districts with lower than 10,000 people/km^2.

(2) Expansion of Collection Services and Treatment Plant

The number of vehicles and workers for night soil collection and hauling to the treatment plants should be gradually increased to meet the intended quantity of collected night soil, in both the DPC and in the districts.

The collected night soil in BMA area will be treated in the NSTPs at Nong Khaem and at On-Nut, which are dedicated to night soil treatment and in the Central WWTPs at Yannawa and Ratburana, which treat night soil in mixing with sewage sludge. The existing NSTPs at Nong Khaem and On-Nut are proposed to be rehabilitated to achieve their original capacity of 600 m^3/d to meet the quantities of collected night soil shown in Table 6.2.2.2.

Table 6.2.2.2 Night Soil Quantities to Treatment Plants

Service areas \ Years		2000	2005	2010	2015	2020
Non Khaem NSTP	(m^3/d)	409	430	503	589	516
On-Nut NSTP	(m^3/d)	409	430	503	589	578
Yannawa WWTP	(m^3/d)	382	401	469	549	963
Ratburana WWTP	(m^3/d)	0	143	168	196	389
Total	(m^3/d)	1,200	1,404	1,643	1,923	2,446

The combined treatment of night soil in the Yannawa Central WWTP and in the Ratburana Central WWTP, which are in the ongoing and planned status, should be proceeded according to the following time-schedule planned by BMA:

- Yannawa Central WWTP:
  - 500 m^3/d in 2000,
  - 1,000 m^3/d in 2016,

- Ratburana Central WWTP:
  - 260 m^3/d in 2002,
  - 400 m^3/d in 2016,

Figure 6.2.2.2 shows the transition of the collected night soil quantities and the construction schedule of NSTPs and the combined-sludge treatment facilities in the Central WWTPs.

6.3 Plan of Reclaimed Wastewater Reuse

6.3.1 Evaluation of Present Condition and Identification of Key Issues

As described in Chapter 4, questionnaire and inventory surveys on reclaimed wastewater reuse were carried out in the course of this Study. The following are the results of evaluation and presentation of the key issues.

(1) Road Plant Watering/Road Cleaning

Reclaimed wastewater as well as public supply water and river water from the Chao Phraya River is used for plant watering and road cleaning by the district offices. When river water includes saline in dry season, public water supply is generally used. When wastewater treatment plants have been completed in future, uses of reclaimed wastewater is envisaged to increase.

(2) Building Miscellaneous Water

Provision of septic tanks to individual households and on-site plants for the building is an obligation according to the regulation. Buildings consuming large quantities of water have their own wastewater treatment plants in conformity with Class A of Building Effluent Standards. The facilities are operated and controlled by stationed engineers and operators, and the treated water quality is reported to the pollution control office once a month. The treated wastewater quality is the same level as that of public sewage treatment plants.

Therefore, necessary amount of reclaimed wastewater can be easily. In addition, parallel piping is required when obtained in these facilities, and treated wastewater from the Central WWTP may not be requested to a large extent. Treated wastewater is utilized in the building. As a conclusion, reuse system may be applied to new developing towns, but not in the existing city area.

(3) Plant Watering (Parks, Golf course etc.)

Treated wastewater can be used for parks, golf courses, etc. The water consumption for these is considerably large using rain water, groundwater, and river water. In general, high quality water is not required for these use and reclaimed wastewater can be used in place. When treated wastewater is used for this purpose, a great amount of groundwater can be saved.

(4) Purification of Khlong

With the development of sewerage system in the city, pollutants currently being discharged into khlong will decrease, and water quality in the khlong will be improved. The khlong network will be accelerated in the future extending to surrounding areas.

However, in some cases, the khlongs will continue to be polluted. The water purification effect of using treated wastewater as khlong purification water is to be considered in a case study (see 6.5.5(4)).

(5) Agricultural Use

At the present time, the use of treated wastewater for irrigation is evaluated as follows:

- Because ongoing and planned wastewater treatment plants are located in the center of Bangkok, removed from the surrounding agricultural areas, transport would pose difficulties.
- Treated wastewater cannot be used as it is. Special hygienic and safety precautions must be taken.

- If treated wastewater is discharged as a means of preventing the salt water intrusion, an equivalent amount could possibly be used for irrigation from the discharge water (good quality) from the Chao Phraya Dam (according a representative of the RID).
- Inside Bangkok city, particularly inside the King's Dike, there is little agricultural land and the demand for water for agriculture is not great.
- If agricultural land in the suburban areas near the city is converted to urban land, the demand for agricultural water will disappear.

From these considerations, it is the conclusion of this study that use of treated wastewater for irrigation would be premature for the study's target year, 2020.

(6) Industrial Use

At the present time, the use of treated wastewater for industrial purposes is evaluated as follows:

- Currently, companies have access to large volumes of inexpensive, good quality groundwater for industrial use, so there is no incentive to use lower quality treated wastewater.
- There is great demand for processing water, but the water quality requirements are strict.
- Industrial development is progressing in areas such as the north of Bangkok, where land and water are easily obtained. There is not much demand for industrial use water in the city of Bangkok.
- Many factories use well water. Due to restrictions on the use of groundwater, factories are beginning to implement water conservation and rationalization programs of water use. It is predicted that there is still room for water savings to be made, so the level of water consumption is not expected to grow much.
- Expansion of the area served by public water is progressing well, so public water will be easily accessible.

From these considerations, it is the conclusion of this Study that use of treated wastewater for industrial use would be premature for the study's target year, 2020.

Focussing on the issue of drought mitigation, it is necessary to mention the possibilities of reusing wastewater for agricultural and industrial uses. Several problems currently exist, such as shortages of irrigation water and the subsidence caused by the use of groundwater for industrial purposes. There is potential demand here for reclaimed wastewater. There is, however, a need to resolve a lot of issues, so reuse in these areas cannot be achieved immediately. Accordingly, this Study positions agricultural use and industrial use as long-term objectives.

Taking into account of this consideration, the following four items will be selected as the possible alternatives for the reclaimed wastewater reuse plans :

i) Road Plant Watering/Road Cleaning
ii) Building Miscellaneous Water
iii) Plant Watering (Parks, Golf course etc.)
iv) Purification of Khlong

6.3.2 Policy for Prioritization

In order to realize effectively the reclaimed wastewater reuse plan, the following policies are set up here.

1) Since the public water supply plan established by MWA has been progressing efficiently and quantitative prospects for future development of water supply are hopeful, establishment of extensive pipe reticulation for reclaimed wastewater will not be considered in this Study. However, in the light of unusual condition in a drought period and saline water intrusion in the Chao Phraya River in dry season, reclaimed wastewater will be considered as an approach for a back-up measure.
2) In accordance with the survey results, viability of treated wastewater reuse has a comparatively large need in limited fields. However, as it is to be organized and implemented by public authorities, realization of the reclaimed wastewater reuse plan should be primarily a common use and contribute to a public benefit.
3) Development of a reclaimed wastewater reuse plan shall be considered in view of social needs of Bangkok City, life style of people and policies of BMA. In this regard, importance shall be given to ease of realization, viability and sustainability.

On the basis of these policies, the four items on reclaimed wastewater reuse are judged in light of, i) future demand (potential), ii) viability, and iii) public as summarized below.

Items	Future Demand	Viability	Public	Priority
A	◎	◎	◎	1
B	◎	X	X	2
C	O	X	X	3
D	X	X	X	4

Note:
A: Road Plant Watering/Road Cleaning
B: Building Miscellaneous Water
C: Plant Watering (Parks, Golf course etc.)
D: Purification of Khlong

A has a large viability and an implementation plan is worth preparing due to having much potential use. B and C have some difficulty in implementation due to needs of additional pipe installation in the existing building for the case of B, and needs of selling to the users for the case of C. Therefore, these could be applied conditionally. While C has further difficulty on the application. It should be coordinated with Main Drainage System Development Division in implementing programs in the future.

6.3.3 Reclaimed Wastewater Quantity

(1) Road Plant Watering/Road Cleaning

Road Plant Watering/Road Cleaning should be undertaken by all the district offices that possess public wastewater treatment plants and its neighboring districts. Road Watering shall be done at night and preferably twice a day and once a day in rainy season and dry season respectively. Sprinkling for Road Cleaning should be carried out in the daytime once a week.

Plant Watering should be basically the same as current average volume of 30 m^3/d/100ha carried out by the neighboring district offices of Si Phraya wastewater treatment plant. On the other hand, sprinkling for road cleaning may be somewhat different depending on the condition of the city development and population increase. In this Master Plan, existing sprinkling for road cleaning does not excess 10 m^3/d/100ha.

The amount of reclaimed wastewater reuse for each treatment plant will be the total volume used by the nearest district office. The maximum projected volumes to be used, by treatment plant, are presented in Table 6.3.3.1. In the year 2000, the total will be 9,608 m^3/d (7,206 m^3/d for plants, 2,402 m^3/d for roads). In the year 2020, the total will be 20,600 m^3/d (15,450 m^3/d for plants, 5,150 m^3/d for roads). This water volume represents about one percent of the 2,290,500 m^3/d that is the total wastewater treatment capacity. The supply area for each treatment plant is indicated in Figure 6.3.3.1.

Reclaimed wastewater quality for plant watering and road cleaning should be basically BOD 10 mg/l and SS 6 mg/l.

The volume of water for watering roadside plants with reclaimed wastewater from private buildings (2020) is calculated as follows:

Private sector roadside plant watering like the Rama IV Project would be promoted. According to the BMA City Planning Division, the extension of roads is 991 km as of 1999 (based on 394 roads). If the project is implemented on 2 % of this, the extension is: 20 km (=991 km x 0.02). Assuming watering units 36 m^3/d/km, the reclaimed wastewater reuse amount is calculated to be 720 m^3/d (= 20 km x 36m^3/d/km).

(2) Building Miscellaneous Water

Application for this purpose will be given to toilet flushing water, floor cleaning etc. for public and private buildings. The transportation from the treatment plants concerned will be made by tanker and/or pipelines. Due to stable supply by the public water supply authority in the future, and urgent increase of supply water amount will not be demanded according to the existing programs and ongoing schemes of Metropolitan Waterworks Authority. The water quality to meet the requirement for miscellaneous use, BOD 5 mg/l, SS 3 mg/l and COD 30 mg/l shall be the target for the future implementation.

Trial calculations for the amount of reclaimed wastewater for miscellaneous use in buildings (2020) are as follows:

According to the MWA Annual Report 1997 the water consumption for the item (Business, State Enterprise, Government Agency and Industrial) was 349.9 million m^3 in 1990 and 471.1 million m^3 in 1997. These figures reveal an increase in water consumption of 4.42 % over the period. It is predicted that the rate of increase in water consumption will slow in the future, so a rate of 2 % is assumed. Accordingly, the water consumption for the year 2020 is predicted to be:

743 million m^3 (=349.9 x $(1.02)^{(2020-1997)}$).

The increase from 1997 is 272 million m^3 (=743- 471).

If seaward areas (414.8 km^2 in 2020) are expected to represent 30 % of the area served by the public water supply in 2020, water consumption will be:

223,000m^3/d (=272,000,000 x 0.30 / 365 days).

If it is assumed that reclaimed wastewater will be used for 10 % of this total the reclaimed wastewater reuse amount is calculated as:

22,000 m^3/d (=223,000 x 0.10).

The amount of water for miscellaneous use in buildings provided by reclaimed wastewater from private buildings (2020) is calculated as follows:

It is possible to reuse the treated wastewater from the on-site plants in hotels and hospitals. The average volume of wastewater for any one such plant is 200 m^3/d. If 30 % of this volume is used, and there are assumed to be 300 such plants in 2020, the reclaimed wastewater reuse amount is calculated to be:

18,000 m^3/d (=200m^3/d x 0.30 x 300 buildings).

(3) Plant Watering (Parks, Golf course etc.)

Transportation of reclaimed wastewater to tanks or ponds for storage in the parks and golf courses will be carried out by tankers, pipeline, through khlong. Detail method for sprinkling will be considered by the users appropriately on each site for use. In this Study, fundamental frames for implementation of reclaimed wastewater will be given, for example, as 30 $m^3/d/ha$ in the dry season for sprinkling in the golf course. The recommended water quality shall be BOD 10 mg/l or less and SS 6 mg/l or less in order to maintain sanitary conditions accompanied with work.

The amount of reclaimed wastewater (2020) to be used for plant watering (public parks and golf courses) is calculated as follows:

Currently, there are 12 public parks, with a total area of 286.5 ha. Five additional parks (total area 84 ha) are planned. There are 10 golf courses, with a total area of 600 ha. The total green area is 970 ha. If it is assumed that reclaimed wastewater is supplied to 10 % of this and the unit quantity is 40 $m^3/d/ha$, the reclaimed wastewater reuse amount is calculated as:

3,900 m^3/d (= 970 x 0.10 x 40 $m^3/d/ha$).

The amount of reclaimed wastewater from private buildings used for plant watering (2020) is calculated as follows:

It is assumed that the average amount of wastewater is 10 m^3/d, with 200 sites for implementation in 2020. The reclaimed wastewater reuse amount is calculated to be:

2,000 m^3/d (=10m^3/d x 200 buildings).

(4) Purification of Khlong

All water discharged from treatment plants is considered to have the potential for use in khlong purification.

Table 6.3.3.2 shows the results of analyzing each potential of demand for reclaimed wastewater in terms of drought mitigation, environmental improvement (green area

expansion and water environmental purification) and land subsidence prevention. The results are graphically expressed in Figure 6.3.3.2.

6.3.4 Reclaimed Wastewater Quality

(1) Water quality standards for reclaimed wastewater reuse

These standards are divided into the following three stages, corresponding to the purpose for which the treated wastewater is to be reused: secondary effluent (BMA Treated Effluent Requirements), Class 1 (for plant watering, etc.) and Class 2 (for miscellaneous water uses in buildings etc.). The proposal is in Table 6.3.4.1. Table 6.3.4.2 shows Japanese figures for reference.

The selection of water quality standard items and the setting of standard values were based on the following considerations. The required characteristics and the relevant water quality standard items that apply if reclaimed wastewater is to be used for plant watering and miscellaneous uses in buildings and so on are as follows:

- A stable level of water quality and stability in storage: BOD, SS
- Hygienically safe for human beings: Number of coliform groups
- Aesthetic and not unpleasant for the user: Odor, Color
- Not causing corrosion, blockage or other functional problems to facilities and equipment: pH, SS

In the area of using reclaimed wastewater as a supplement to municipal water, Japan can be considered an advanced nation, so Japanese standards are provided for reference. In Japan, standards have been determined based on experience, through conducting resident opinion polls, etc. As it is not expected that there will be much difference between the way people feel about water in Japan and in Thailand, values obtained through experience in Japan are provided for reference.

(2) Irrigation Standards for Reclaimed Wastewater Reuse

The big problem with using treated wastewater for irrigation is water quality. Irrigation Standards for Reclaimed Wastewater reuse are proposed as material for consideration as possible water quality standards. Aspects of water quality that present problems in irrigation are the odor, pathogens, parasites, seeds, etc., that occur in human waste. It would be necessary to add these items to the irrigation standards.

In Japan, there is little use of treated wastewater for irrigation, and there are no prescribed standards. In the United States, on the other hand, there are many examples of treated wastewater being used for irrigation, and there are detailed standards. Accordingly, the American figures are provided for reference. The

proposed water quality standard for treated wastewater for irrigation purposes is the RID irrigation standard plus an item to deal with pathogens. The FAO-Guideline will serve as a standard for each crop. Standard values are presented in Table 6.3.4.3.

(3) Industrial water quality standards for reclaimed wastewater

Each factory requires a different high level of water quality. If treated wastewater is to be used, it needs to be treated to match the required high water quality level. From the Japanese experience, we propose that Secondary Treated Effluent is provided to factories as raw water, with the Industrial Estate providing advanced treatment before using the water. The water quality would be the same as the BMA Treated Effluent Quality Requirements.

(4) Miscellaneous (Color, Salt)

1) Color

In the Japanese experience, the color of activated sludge treated wastewater is in the range of 10-50 and is normally 30-40. Even with no special treatment, Standards Class 1 (Color: 40 or less) can be achieved. To achieve Standards Class 2 (Color: 10 or less), usually an activated carbon filter is added. In the United States, it is reported that 5 can be achieved with an activated carbon filter following a sand filter. Table 6.3.4.4 below shows the relationships between treatment and color.

Table 6.3.4.4 Treatment Achievable with Various Secondary and Additional Treatment Processes

Secondary Treatment	Additional Treatment	SS (mg/l)	BOD (mg/l)	Color
Activated sludge process	None	20-30	15-25	15-80
	Granular-medium filtration	5-10	5-10	15-60
	Granular-medium filtration, Carbon column	3	1	5

Source: Water Reuse (Second Edition), WPCF Manual of Practice SM-3

2) Salt

Normally, the concentration of chlorine ions in treated wastewater is about 100 mg/l when the treated wastewater is recycled, the chlorine concentration rises proportionately with the number of times recycled. This leads to corrosion of pipelines and other problems.

The Study showed that rate of recycling treated wastewater for miscellaneous use in buildings is about 1 % of the volume of treated wastewater from

wastewater treatment plants, and the recycling of building miscellaneous use water in private firms is about 10 % of the treated wastewater volume. There is little problem of salt concentration due to recycling. When the water is used for irrigation, if the chlorine ion concentration is less than 350 mg/l it may be used for growing rice, and if the concentration is less than 600 mg/l it may be used for growing vegetables. If treated wastewater is to be used for irrigation, there is no problem with regard to salt concentration.

(5) Disinfection

If treated wastewater is to be reused, it needs to be hygienically safe. Possible treatment methods for this purpose include chlorination, ozonation, ultraviolet radiation, and the polishing pond system. The most orthodox method is chlorination, and this is employed at the Si Phraya WWTP. The polishing pond method uses sunlight and is simple. Other methods present problems such as expense or complicated equipment requirements.

For the following reasons, simple disinfection methods are highly recommended:

- Because it is a sewerage system without human excreta, there is little danger of pathogens in the wastewater.
- Pathogens are eliminated with the activated sludge treatment process and additional treatment measures (e.g., sand filter, activated carbon).
- There are many ponds which might be used as polishing ponds. The season for supplying water for watering plants is the dry season, when the weather is good, so the polishing ponds works effectively.
- It is the custom in Thailand to spread something on the ground when using grassy spaces.
- Chlorination is a cheap and commonly used method of disinfection, but there are concerns about the effect of chlorine by-products on ecosystems.

The minimum possible disinfection is recommended. Table 6.3.4.5 shows the quality standards, additional treatment, and disinfection for each item.

Table 6.3.4.5 Disinfection for Each Item

Item	Quality Standards	Additional Treatment	Disinfection
Road Plant Watering	Class 1	Sand Filter	No disinfection
Building Miscellaneous	Class 2	Sand Filter Activated Carbon	Disinfection (Chlorination)
Plant Watering	Class 1 + Exception	Sand Filter	Disinfection (Polishing pond)
Khlong	BMA Requirement	No additional Treatment	No disinfection

It is necessary to consider carefully the disinfection methods to be used for irrigation water in terms of the particular purposes for which the water is to be used. The use of sunlight for ultraviolet radiation is a good potential method of disinfection. There are many ponds in the suburbs that may be used in a polishing pond system. With three days to a week of sunlight, water can be suitably disinfected for irrigation use.

6.3.5 Alternative Reuse Plan and Recommendation

(1) Road Plant Watering/Road Cleaning

The facilities needed for this use are additional treatment facilities, water supply facilities and tankers for watering.

1) Additional Treatment Facilities

These facilities are sand filters for achieving the target water quality and pumps. The required treated wastewater amount is shown in Table 6.3.3.1 as stated previously, and the subsequent required number of sand filters are given in Table 6.3.5.1.

2) Supply Facilities

The supply facilities are to supply water to the tanker for watering. These facilities comprise storage tanks, pumps, and service tanks. As for the additional treatment facilities, at least one unit of a package type with a capacity of 300 m^3/d is needed.

The following are three plans for installing supply facilities:

Plan A : Install supply facilities at each treatment plant yard.
Plan B-1 : Install relay supply facilities at two places besides the treatment plant and transport will be made by tanker.
Plan B-2 : Install relay supply facilities at two places besides the treatment plant and transport by pipeline.

Plans B-1 and B-2 assume the installation of relay supply facilities at two locations located about 3 km apart from each treatment plant. Transport of reclaimed wastewater to these relay facilities would be by tanker or by pipeline and thereafter distributed by tankers.

3) Tanker for Watering

To distribute 300 m^3/d, 8 tankers (6 m^3) are required for watering.

Possible system diagrams of the three plans are presented in Figures 6.3.5.1 to 6.3.5.3.

(2) Building Miscellaneous Water

The facilities needed for this use are additional treatment and transport facilities.

1) Additional Treatment Facilities

To bring secondary treated and target quality water, additional treatment involving sand filters and activated carbon filter is required. The necessary facilities comprise pumps, sand filters, activated carbon filters, storage tanks, pumps and supply tanks (for the case of transport by tanker). One unit of a package type with 900 m^3/d capacity is recommended.

2) Transport Facilities

These are facilities to transport reclaimed wastewater to the sites where ti is needed. For this purpose, two systems are considered:

Plan A: Pipeline transport plan
Plan B: Tanker transport plan

The reclaimed water will be transported to the new town development area by pipeline or by tanker. The cost per unit volume varies greatly with transportation distance and water quantity. In the interest of calculating a practical unit cost, cost comparisons will be made for the possible combinations of transportation (1 km - 5 km) and volumes (900 m^3/d, 1,800 m^3/d, 2,700 m^3/d).

Possible system diagrams of the plans are provided in Figures 6.3.5.4 and 6.3.5.5.

(3) Plant Watering (Parks, Golf course etc.)

The facilities needed for this use are additional treatment facilities, supply facilities and transportation facilities.

1) Additional Treatment Facilities

The facilities required are the sand filters and pumps needed to get required water quality. One unit of a package type with a capacity of 300 m^3/d is suggested.

2) Supply Facilities

These facilities are comprised of storage tanks, pumps, and supply tanks. As was suggested for the additional treatment facilities, one unit of a package type with a capacity of 300 m^3/d is suggested.

3) Transport Facilities

The volume to be used is variable depending on the seasons and location. For this reason, pipelines are not considered for transport method and only two tankers (12 t) are considered.

A possible system diagram is provided in Figure 6.3.5.6.

(4) Purification of Khlong

The Khlong Toey East Catchment Area will be taken as a case study to examine the purification effect of treated wastewater in the khlongs. The following two cases are considered: Case 1: Khlong Pollution due to the load that flows from the sewer pipes when it rains. Case 2: Khlong Pollution from a portion of sewage that flows directly into the khlongs (estimated to be about 5 % of the total sewage volume).

Case 1: Khlong Pollution due to the load that flows from the sewer pipes when it rains.

1) Current condition of the case study area

In the Khlong Toey East Catchment Area, there are many polluted khlongs because many have little flowing water or are blocked off, and there is sewage drainage into the khlongs. In southern khlongs such as the Khlong Bang Na and the Khlong Bang Oa etc., projects such as the Khlong Water Quality Improvement Project, System 4 (water dilution by Chao Phraya River water, installation of aerators) are underway to improve water quality.

The khlongs in this area are shown in Figure 6.3.5.7. They are provisionally divided into routes 1-6, each representing a drainage system of branch and trunk khlongs. The total length of the khlongs is 26.9 km (see Table 6.3.5.2).

2) Khlong purification strategy using treated wastewater

In a combined sewer system, some sewage overflows to the khlongs when it rains. When the rain stops, this wastewater stagnates in the khlongs. To improve this water quality, purification water will be added to the flow from upstream. In one day, a volume of treated wastewater equal to the volume of

the khlongs will be released into the khlongs, pushing the sewage stagnating in the khlongs further downstream. With this method, the quality of the water in the khlongs is improved to the level of treated wastewater.

Of the 6 routes, routes 1 and 2 are being improved by the Khlong Water Quality Improvement Project, System 4. Routes 3 and 5 are small-scale and therefore not considered here. Treated wastewater will be supplied to routes 4 and 6 to improve khlong water quality as follows: 12,300 m^3/d for Route 4; and 12,600 m^3/d for Route 6.

3) Facilities for providing treated wastewater

Details of the facilities are provided below.

Route 4:
- Pump well 65 m^3 x 1
- Pump 5 m^3/min x 22 kW x 2
- Transportation Pipeline (dia 400 mm) 2.9 km

Route 6:
- Pump well 65 m^3 x 1
- Pump 5 m^3/min x 30 kW x 2
- Transportation Pipeline (dia 400 mm) 3.8 km

4) Cost

Costs of the facilities are provided in Table 6.3.5.3. The initial total cost is 116 million Baht, the total annual O & M cost is 3 million Baht.

Case 2: Khlong Pollution from a portion of sewage that flows directly into the khlongs (estimated to be about 5 % of the total sewage volume).

1) Current condition of the case study area

In the Khlong Toey East Catchment Area, there are many polluted khlongs because there are many khlongs with little flowing water or that are blocked off, and there is sewage drainage into the khlongs. In southern khlongs such as the Khlong Bang Na and the Khlong Bang Oa etc., projects such as the Khlong Water Quality Improvement Project, System 4 (water dilution by Chao Phraya River water, installation of aerators) are underway to improve water quality.

The khlongs in this area are shown in Figure 6.3.5.7. They are provisionally divided into routes 1-6, each representing a drainage system of branch and trunk khlongs. The total length of the khlongs is 26.9 km (see Table 6.3.5.2).

Once a sewage system (intercepting trunk line, WWTPs) is in place, sewage will no longer drain to the khlongs. However, in a few areas, it is predicted that sewage will still drain directly into the khlongs. The amount of sewage draining to the khlongs is assumed to be about 5 % of the total sewage amount for calculation purposes. The forecast DWF for the Khlong Toey East Catchment Area is 185,400 m^3/d, and 5 % of that is 9,270 m^3/d. The proportional distribution of 9,270 m^3/d over the length of the Khlongs is shown in Table 6.3.5.4.

2) Khlong purification strategy using treated wastewater

The water quality of the wastewater draining into the khlongs is BOD 146 mg/l (average water quality of the Khlong Toey East Catchment Area). Treated wastewater for khlong purification is assumed to be BOD 10 mg/l (the estimated average water quality of treated wastewater). Comparing dilution ratios (the ratio of treated wastewater to sewage) of 5, 10, 13, 15, 20 times, the khlong BOD becomes 32.7, 22.4, 19.7, 18.5, and 16.5 mg/l, respectively. At a dilution ratio of 13 times, the khlong water is found to improve to 20 mg/l or less.

Of the 6 routes, routes 1 and 2 are being improved by the Khlong Water Quality Improvement Project, System 4. Routes 3 and 5 are small-scale and therefore not considered here. Treated wastewater will be supplied to routes 4 and 6 to dilute the khlong water to BOD 20 mg/l or less. Details are provided below.

Route 4: 18,369 m^3/d
Route 6: 18,811 m^3/d

In both cases, treated wastewater amounts to about 10 % of the khlong water volume.

3) Facilities for providing treated wastewater

Details of the facilities are provided below.

Route 4:

- Pump well 100 m^3 x 1
- Pump 5 m^3/min x 22 kW x 3
- Transportation Pipeline (dia 500 mm) 2.9 km

Route 6:

- Pump well 100 m^3 x 1
- Pump 5 m^3/min x 30 kW x 3
- Transportation Pipeline (dia 500 mm) 3.8 km

4) Cost

Costs of the facilities are provided in Table 6.3.5.5. The initial total cost is 146 million Baht, the total annual O & M cost is 5 million Baht.

6.3.6 Facilities Plan and Cost Comparison

(1) Road Plant Watering/Road Cleaning

Assuming a service life of 20 years, the construction costs and operation and maintenance costs for each plan (see Table 6.3.6.1) are as follows:

Plan A : 25 Baht/m^3
Plan B-1 : 49 Baht/m^3
Plan B-2 : 30 Baht/m^3

Plan A, which installs water supply facilities only at the treatment plants, is selected as being the most economical.

(2) Building Miscellaneous Water

Each combination of transport distance L = 1 to 5 km and volume Q = 900 to 2,700 m^3/d is provided in Tables 6.3.6.2 and 6.3.6.3 (see Table 6.3.6.4(1)-(3) and Table 6.3.6.5(1)-(3)). The costs for the unit volume calculated for each plan are as follows:

Table 6.3.6.2 Unit Cost of Plan A (by Pipeline)

Unit : Baht/m^3

Case	Reuse Quantity		
	900 m^3/d	1,800 m^3/d	2,700 m^3/d
Case 1km	4.4	3.9	3.7
Case 2km	4.9	4.5	4.2
Case 3km	5.3	5.0	4.6
Case 4km	5.7	5.6	5.2
Case 5km	6.2	5.9	5.4

The unit cost of Plan A is 4 to 6 Baht/m^3.

Table 6.3.6.3 Unit Cost of Plan B (by Tanker)

Unit : Baht/m³

Case	Reuse Quantity		
	900 m³/d	1,800 m³/d	2,700 m³/d
Case 1 km	23.0	22.7	22.6
Case 2 km	25.4	25.1	25.0
Case 3 km	27.8	27.5	27.4
Case 4 km	30.2	29.9	29.8
Case 5 km	32.6	32.3	32.2

The unit cost of Plan B is 23 to 33 Baht/m³.

If the system can be established with the unit cost less than the public water tariff (14.31 Baht/m³ for commercial use of more than 201 m³/month), it will become feasible.

(3) Plant Watering (Parks, Golf course etc.)

Assuming a service life of 20 years, construction and operation and maintenance cost come to 28 Baht/m³ in case of transportation from the Central WWTP to site by tanker (see Table 6.3.6.6).

If the system can be established at less than the groundwater tariff (currently 3.5 Baht/m³), it will become feasible.

6.3.7 Conclusion and Recommendation

(1) Road Plant Watering/Road Cleaning

The objective for this reclaimed wastewater reuse is to water plants along the streets and clean the roads, which are currently being carried out by the public cleaning division of district offices.

The planning sites are 33 districts for which the 16 existing, ongoing, and proposed wastewater treatment plants can provide reclaimed wastewater.

The method of distributing reclaimed wastewater is to deliver the water to the watering sites by tankers operated and managed by the district offices after being supplied from the nearest treatment plant.

The capacity of the production facilities of reclaimed wastewater is planned as given in Table 6.3.5.1, and 347 m³/d to 2,520 m³/d is the planned supply capacity for reuse. Supply units of 1 to 8 with the capacity of 300 m³/d for one unit will be procured, and 8 tankers will be provided with 6 working shifts for distribution.

Watering shall begin when the treatment plant nearby starts to operate and further detail will be decided at the time of detail design and construction implementation.

(2) Building Miscellaneous Water

The objective for this is to use reclaimed wastewater for miscellaneous water use for the buildings.

The target areas shall be the new town developing areas near the planned wastewater treatment plant. For these areas, two separate systems comprising public water supply by MWA and miscellaneous water supply by reclaimed wastewater reuse system will be established. The distribution of the reclaimed wastewater will be made by pipelines.

The treated wastewater in this system will be applied to toilet flushing water, car washing, and sprinkling gardens, etc. after additional treatment by sand and activated carbon filters to raise the water quality.

The supply capacity of this method shall be 900 m^3/d in one package.

Initial construction and subsequent operation and maintenance of the treatment plant and subsequently collecting the wastewater charge from the users will be carried out by BMA.

The implementation period will be decided when new town schemes are proposed and will not be determined in this Study stage.

(3) Plant Watering (Parks, Golf course etc.)

The objective of this water use is to water plants and golf courses in the vicinity of the wastewater treatment plants.

Water is supplied out by tanker, pipeline, or through khlong. The amount of treated wastewater production for this use shall be 300 m^3/d with one package facilities.

Initial construction of the treatment plant and subsequent collection of wastewater user charge will be carried out by BMA.

Detail facility planning and implementation plan will be carried out at the time of request from the users.

(4) Purification of Khlong

The problem of khlong purification will be fundamentally resolved with the installation of sewerage systems, but problems remain. These problems cannot be solved on the side of the sewerage system alone. As it is not easy to transport

water within the urban area, every effort must be made to use nearby water sources and to recycle water locally. There needs to be a comprehensive, all-encompassing strategy.

A comprehensive khlong purification project is proposed below. It is necessary to create a plan that organically links wastewater treatment plants, khlongs, and urban ponds. The plan should include the following items:

- Supplying treated wastewater to khlongs (discharge directly from points of treatment plant or transport by pipeline for discharge to khlongs)
- Links to the Khlong Water Quality Improvement Project (introducing river water at a rate of 35 m^3/s)
- Reconnection of filled-in khlongs and replacing the water
- Links to ponds in public parks and college campuses, etc., and to wells
- Where sewer lines cannot be laid, use of khlongs as sewer trunk lines, with sewage treatment of the complete volume at the end and subsequent use of the treated wastewater as khlong purification water

(5) Agricultural Use

Though it will depend on the progress of sewer completion, there is a possibility that treated wastewater from outlying wastewater treatment plants could be used in the future for irrigation. There are several examples of treated wastewater being transported up to about ten kilometers in other developing countries. If a survey of the demand for irrigation water in the area is conducted, the feasibility of arranging supply can be evaluated.

Although it is outside the scope of the current investigation, it is reported that there are many farms in the Samut Prakarn Province, south of Bangkok, that have been abandoned due to the salt water intrusion. The possibility exists that these farms might be returned to fertility by supplying treated wastewater from the city of Bangkok. This too is something to be considered for the future.

(6) Industrial water

Wastewater treatment plants are an urban water source that can provide a year-round constant supply of water, unaffected by droughts. It is possible that in the future, when sewers are completed and many wastewater treatment plants are completed, these plants will be able to supply industrial water to some factories scattered throughout the city. It is possible that the use of treated wastewater will become feasible if restrictions on the abstraction of well water are strengthened in the future due to stricter controls of the use of groundwater (such as increases in the groundwater tariff) and if prices for public water rise significantly. It depends on an economic comparison of the unit costs for groundwater or public water and

reclaimed wastewater. It may also be predicted that at some time in the future it will be reasonable to consider a exclusive pipeline for industrial use water in the city of Bangkok.

CHAPTER 7 DEVELOPMENT PLAN OF SLUDGE TREATMENT/DISPOSAL

7.1 Frameworks of Sludge Treatment/Disposal Development

7.1.1 Goal and Basic Strategies

The target year for the sludge treatment/disposal development in this Study is set for the year of 2020. It is targeting the establishment of safe, economically efficient and environment-friendly sludge treatment/disposal system to cope with the increasing sludge generation along with the sewerage development in BMA.

The sludge generated from wastewater may give negative and the positive influence on environmental aspects. The sludge, which is continuously generated in sewerage operation at a certain rate, must be removed and discharged so as to properly sustain the function of sewerage. If BMA fails to establish an adequate final destination for the sludge, sewerage system will be deteriorated and the sludge will cause negative environmental and health issues. The sludge, on the other side, may be a useful resource, in light of its organic substances, inorganic substances as well as nutrient elements contained at a certain level.

Thus, the goal of sludge treatment/disposal should be achieved well-coordinated manner, taking into account quantitative and qualitative properties of sludge and the status of its receivers. The basic strategies to attain the goal of the sludge treatment/disposal development are categorized into:

1) The short-term (to attain within the first quarter term of the targeted period):

   The development of safe and sound treatment/disposal system to secure the function of sewerage systems, and

2) The long-term (to attain within the target year):

   The inauguration and implementation of "*green disposal*" and beneficial uses of sludge.

7.1.2 Service Area for Sludge Treatment/Disposal

Sludge treatment/disposal development concerns the sludge generated from three (3) sources in BMA: the central wastewater treatment system, the community wastewater treatment system and the night soil treatment system, as shown in Figure 7.1.2.1 and outlined below:

1) Central wastewater treatment system: (based on the proposals in section 6.1)
   - Service area: 41,480 ha (divided into 16 catchment areas in 2020)

- Served population: 7,175,000 people in 2020 (equivalent to about 60 % coverage)
- Sewage flow: 3,403,000 m^3/d in 2020 (based on DWF)

2) Community wastewater treatment system: (as described in subsection 3.1.1)
   - Service area: located in 14 small communities
   - Served population: total 133,400 people in 2020
   - Sewage flow: 25,700 m^3/d in 2020 (based on DWF)

3) Night soil treatment system: (based on the proposals in section 6.2)
   - Served area: 157,000 ha (equal to the entire BMA)
   - Served population: 2,445,000 people in 2020 (equal to some 20 % coverage)
   - Collected night soil: 2,445 m^3/d (in 2020)

7.1.3 Projection for Sludge Generation

The quantities of sludge generated from the three sources in BMA have been projected according to the following methodology:

(1) Sludge from Central WWTPs

The Central Wastewater Treatment Plants (Central WWTPs) in BMA basically employ a diverse type of biological processes. Some of these include nitrogen (N) and phosphorus (P) removal system to prevent eutrophication in receiving water bodies. Accordingly, sludge to be derived from Central WWTPs may be classified into biological treatment sludge and phosphorus removal sludge.

1) Biological Treatment Sludge

Sludge amount generated from biological treatment widely varies depending on different factors such as sewage characteristics, the type of biological process as well as its operation conditions. In particular:

- The organic and inorganic concentration in sewage,
- The category of substrates consisting of organic,
- The organic removal rate in the treatment system,
- The oxygen supply rate in biological system, and
- The sludge retention time in biological system.

Given the biomass generated from biodegradation, biomass lost in self-digestion, inorganic solids in influent and effluent, the sludge generation rate

per the incoming BOD (R_1, kg-DS/kg-BOD) may be presented in the equation below[1]:

$$R_1 = W / G$$
$$= (a \times F \times S_o - b \times MLSS \times T + M_i - M_f) \times 1/S_o \quad \text{.....} (1)$$

Where,

R_1	: Sludge generation rate per incoming BOD (kg-DS/kg-BOD)
a	: Coefficient of removed BOD converted into biomass (-)
b	: Coefficient of biomass reduced by self-digestion (-)
F	: BOD removal ratio (-)
G	: Incoming BOD load (kg/d)
S_o	: Influent BOD concentration (mg/l)
MLSS	: Biomass concentration (mg/l)
T	: Hydraulic retention time (d)
M_i	: Influent suspended inorganic solids (mg/l)
M_f	: Effluent suspended solids (mg/l)
W	: Generated sludge (kg-DS/d)

To calculate R_1 for the sludge generation in BMA, typical and common operation and performance figures in wastewater treatment system, which more or less represents the sewerage system in BMA, are assumed as follows:

F: 0.85,	MLSS: 2,000 mg/l,
T: 0.2 days,	M_f: 15 mg/l,
M_i: 40 % of S_o (mg/l)	

The representative value of influent BOD (S_o) is assumed to be 110 mg/l, which is derived from the discussion in the section 6.1. As for "a" and "b", they are regarded to range from 0.63 to 0.77 and from 0.04 to 0.06, respectively, depending on BOD constituents. For the range of "a" and "b", equation (1) gives the sludge generation rate (R_1) of 0.58 to 0.77 for the influent BOD of 110 mg/l.

2) Phosphorus Removal Sludge

A number of processes, which ranges from biological adsorption to physicochemical separation, will be likely introduced in wastewater treatment schemes to prevent receiving water bodies from eutrophication.

[1] : Tesuo Ide, et al., Water Treatment Technology, Gihoudou Publication Ltd. 1978.

In order to calculate the sludge quantity generated from phosphorus removal, phosphorus removal using dosage of aluminum coagulant has been assumed. This removal process is commonly used and is being applied to the Nong Khaem Central WWTP. In the removal process, the following chemical reaction may be expressed

$$Al_2(SO_4)_3 \cdot 18H_2O + 2PO_4^{3-} = 2AlPO_4 + 3SO_4^{2-} + 18H_2O$$

Therefore, the sludge consisting of aluminum phosphate of 3.9 mg/l per 1 mg-P/l (= 122 / 31 = 3.9) is induced. To calculate the sludge generation, 110 mg/l of BOD used above and 7 mg/l of phosphorus in representative sewage in BMA, as seen from the design report for the Nong Khaem WWTP, have been used as representative ones. Thus, the sludge generation rate (R_2) in phosphorus removal process is estimated at 0.25 (= 7 x 1/110 x 3.9 = 0.25) kg-DS per kg-BOD_{inlet}.

3) Total Sludge Generation Rate from Central WWTPs

From the above discussion, the overall sludge generation rate ($R = R_1 + R_2$) in planned and proposed schemes, has been computed as 0.83~1.02 (= (0.58~0.77) + 0.25) kg-DS/kg-BOD_{inlet} including both biological and phosphorus treatment sludge. Based on this examination, "1.0 kg-DS/kg-BOD_{inlet}" of sludge generation rate (R) has been adopted in this Study.

Meanwhile, the ongoing Central WWTPs in BMA have been found to adopted different sludge generation rates (R) ranging from 0.6 to 1.3 kg-DS/kg-BOD, according to their design reports and related documents. The sludge generation has been calculated by using these rates in the ongoing schemes.

(2) Sludge from Community Wastewater Treatment Plants

For the Community WWTPs at Huay Kwuang, the sludge generation rate of 36 g-DS/cap/d has been adopted, based on its current sludge generation rate. For all other Community WWTPs, 60 g-DS/cap/d has been adopted as assumed in the AIT Feasibility Study[1]. These values are considered reasonable, in view of small catchment areas with the separated-system.

[1]: Final Report of Master Plan Study on Treatment and Disposal of Domestic Sewage Sludge including Night Soil and Oil and Grease Residues for Bangkok Metropolitan, AIT, (1995).

(3) Sludge from Night Soil Treatment Plants

The Night Soil Treatment Plants (NSTPs) at Nong Khaem and On-Nut consist of sedimentation with chemical coagulation and aerobic biological degradation for the supernatant liquor. Night soil will also be treated in the Central WWTPs at Yannawa and Ratburana, together with sewage sludge. The sludge generated from night soil treatment may therefore be regarded as the suspended solid in the night soil and the surplus sludge, which is generated in biological treatment system for supernatant. There will also be a small amount of metal hydrate resulting from coagulant.

The characteristics of collected night soil in BMA are reported as shown in Table 6.2.1.3. On the average, suspended soils (SS) and BOD are 13.4 g/l and 2.7 g/l, respectively, although they are widely varied.

To calculate the night soil sludge generation rate, 1.0 l/c/d of the collected night soil rate as stated in the section 6.3 has been adopted. In addition, 100 % for the removal of SS and 50 % the biomass generation from BOD_{inlet} have been assumed. The sludge generation rate from night soil treatment is then calculated as 14.8 g DS/c/d (13.4 + (2.7 x 50/100) = 14.8). In view of the large fluctuation in the characteristics of collected night soil, a further 20 % allowance has been added and, finally, the rate of 18 g DS/c/d (14.8 x 1.2 = 17.7, say 18) has been derived.

Although the AIT Master Plan implicated 26 g DS/c/d of the sludge generation from night soil treatment[1], it appears relatively high, considering the characteristics of collected night soil in BMA. Thus, 18 g DS/c/d of the generation rate is adopted in this Study.

(4) Overall Sludge Generation in BMA

These evaluations of sludge generation rates from various sources concludes the following:

- kg-DS/kg-BOD_{inlet} for Central WWTPs except for the existing and ongoing schemes,
- 60 g DS/c/d for Community WWTPs except for the Huay Kwuang Community WWTP, and
- 18 g DS/c/d for NSTPs.

Sludge quantities generated from Central WWTPs are shown in Table 7.1.3.1. In this table, the sludge quantities in the planned and proposed schemes are calculated by applying the generation rate of 1.0 kg-DS/kg-BOD_{inlet} as determined

[1]: Final Report of Master Plan Study on Treatment and Disposal of Domestic Sewage Sludge including Night Soil and Oil and Grease Residues for Bangkok Metropolitan, AIT, (1995)

above. Meanwhile, the sludge quantities for the existing and ongoing schemes are based on their operation records, and design or related reports. The 30 % reduction in BOD in the influent of Central WWTPs, as described in the subsection 6.1.1, has been accounted.

Table 7.1.3.1 Sludge Generation from Central WWTPs in 2020

Service Areas	Phase	Year of Completion	Design Target Year	Incoming BOD Load (t BOD/d)	Sludge Generation in 2020 (t DS/d)
Existing and Ongoing Scheme					
Si Phraya		Existing	2009		1.0
Ratanakosin		1998	2011		5.6
Din Daeng (BMA Stage 1)	Phase 1	2000			23.9
	Phase 2	2010	2011		11.9
Yannawa (BMA Stage 2)	Phase 1	1999			16.8
	Phase 2	2015	2020		5.3
Nong Khaem		2001	2020		14.4
Ratburana (BMA Stage 3)	Phase 1	2001			5.7
	Phase 2	2015	2020		6.3
Chatuchak (BMA Stage 4)		2003	2020		13.3
Planned and Proposed Scheme					
Thonburi South	Phase 1	2005	2020	20.0	20.0
	Phase 2	2015	2020	4.1	4.1
Thonburi Central	Phase 1	2006	2020	13.9	13.9
	Phase 2	2016	2020	2.8	2.8
Thonburi North	Phase 1	2007	2020	7.7	7.7
	Phase 2	2017	2020	2.1	2.1
Khlong Toey West	Phase 1	2008	2020	13.9	13.9
	Phase 2	2018	2020	4.0	4.0
Khlong Toey East	Phase 1	2009	2020	9.5	9.5
	Phase 2	2019	2020	6.1	6.1
Bang Sue		2012	2020	15.1	15.1
Huay Kwuang		2014	2020	16.6	16.6
Wang Thong Lang		2016	2020	15.1	15.1
Bung Kum		2018	2020	15.5	15.5
Total					251

Notes:

1) For Si Phraya, adjusted actual sludge amount is used.

2) For ongoing schemes, the sludge amounts described in their design or related reports are used, applying 30 % BOD reduction into account, as a rule.

3) For planned and proposed schemes, 1.0 kg-DS/kg-BOD of sludge generation rate as well as 30 % BOD reduction are applied.

Table 7.1.3.2 shows the sludge generation in Community WWTPs based on the design population.

Table 7.1.3.2 Sludge Generation from Community WWTPs in 2020

Wastewater Treatment Plants	Design Population Served	Year Completed	Generation Rate (g DS/c/d)	Sludge Generation (t DS/d)
1. Huay Kwuang	16,800	1975	36	0.6
2. Bang Na	8,280	1981	60[1)]	0.5
3. Khlong Chan	32,190	1979	60[1)]	1.9
4. Ram Indra	4,060	1978	60[1)]	0.2
5. Tung Song Hong 1	15,015	1984	60[1)]	0.9
6. Tung Song Hong 2	5,555	1984	60[1)]	0.3
7. Hua Mark	2,940	1978	60[1)]	0.2
8. Phibun Tatana	2,060	1979	60[1)]	0.1
9. Khlong Toey	7,200	1983	60[1)]	0.4
10. Tasai	7,095	1978	60[1)]	0.4
11. Rom Klao	19,150	1985	60[1)]	1.1
12. Bon Kai	1,900	1983	60[1)]	0.1
13. Bang Bua	6,070	1980	60[1)]	0.4
14. Din Daeng	5,100	1978	60[1)]	0.3
Total	133,415			7.6

Notes:

1) These are assumed as values included in 1998 AIT Feasibility Study on Agricultural Use and Land Application of Sewage and Night Soil Sludge for Bangkok.

The sludge quantities generated from night soil in 2020 are indicated in Table 7.1.3.3. The time-wise sludge generation in BMA has been projected for each sludge sources, as shown in Table 7.1.3.4. Figure 7.1.3.1 shows the transition of the sludge generation from 2000 to the target year of 2020.

Total sludge generation is projected to reach 302 t DS/d in 2020, equivalent to daily 30,200 m^3 at 1 % concentration. The sludge generated from the Central WWTPs is forecast to account for 83 % of total sludge in BMA in 2020, indicating the gradual-increasing correspondent with the development of sewerage. The night soil sludge quantity that occupies 42 % at present is forecast to decrease to 15 % in 2020. The current Community WWTPs is expected to remain almost constant sludge generation by year, occupying only 4 to 7 % of the total sludge.

7.1.4 Sludge Characteristics

(1) Sludge Solids Contents

Moisture, total solids and volatile solids of dewatered sludge discharged from existing sources were analyzed in this Study, as stated in the subsection 4.3.3. The volatile solids ratio (VS ratio) of the sludge at the Si Phraya WWTP was found to be almost 50 %. The extremely light-loading rate in the biological treatment system at the present might account for the relatively low VS ratio.

The VS content of sewage sludge will be further reduced in future as new sewerage plants come into operation, due to aluminum or other metal hydrate sludge generated in phosphorus removal processes.

Measured water contents of dewatered sludge ranging from 75 to 85 % indicate that dehydrators are operating under normal expected performance.

(2) Nutrient Elements

The carbon (C), nitrogen (N), phosphorus (P), and other nutrient concentrations of the sludge currently produced were determined in this Study, as described in the subsection 4.3.3. The C/N ratio, carbon content and other items shows that all the sludges are almost suitable range for agricultural use.

(3) Heavy Metal Intrusion into Sewage

1) Results of Measurement and Analysis

The measurement and analysis of heavy metals in the sludge generated at present was undertaken in this Study, as stated in the subsection 4.3.3.

When the measured figures are compared with the current Japanese Standards, mercury (Hg) in all sludge from BMA and copper (Cu) in the Si Phraya WWTP are beyond the limits on the average basis. The sludge from the Si Phraya WWTP exceeds the limit of nickel (Ni) as well as copper (Cu) on the average basis in the comparison with the tentative standards proposed by AIT. Furthermore, mercury (Hg) in the sludge from the NSTPs is beyond the limit set by AIT on the maximum basis.

2) Possible Causes for Heavy Metal Intrusion

In the planning of either landfill disposals or beneficial uses, it is important to limit the contents of heavy metals in the sludge. They possibly can exert irreversible and significant influences to the environment and human health, through water, soil, and groundwater contamination.

BMA has been provided with a strict regulation to control the discharge of toxic heavy metals into water bodies. This regulation, at the present, is similarly being applied to the discharge into sewerage without any exception, even after the completion of sewerage system. Despite such legal enforcement, the Si Phraya Central WWTP, which is the only one being operated now, has been known to show a certain extent of heavy metal intrusion into the sewerage system.

The heavy metal intrusion into sewerage is reported to be caused by relatively small-scale industries, which might discharge heavy metals due to the inferiority of treatment facilities and their maintenance/operation. Meanwhile, the heavy metal intrusion into night soil appears to result in occasional or, in some cases, intentional discharge of the waste from industrial or business firms into septic tanks. Together, laboratories in hospitals, universities, certain fields of research and development institutions, etc. have been suspected as possible mercury sources without obvious evidence.

3) Risk Evaluation of Heavy Metal Intrusion

As seen from the possible causes mentioned before, there is no proper way to define the extent of heavy metal intrusion into sewerage. Nevertheless, this should be assessed in order to examine the future sludge disposal and sludge reuse. The following risk evaluation method has been applied to evaluate the likelihood of possible inclusion of heavy metals in the catchment areas concerned.

An assessment on the heavy metal intrusion into sludge produced from the various catchment areas has been performed. This assessment has been undertaken using criteria such as the volume of industrial wastewater generated, the total number of industrial factories, likely loads from polluting industries[1], toxicity indicators and the future potential growth in this type of industrial sector. The results identified by this methodology therefore can only provide an indication of where these sludge with the high-risk for heavy metal are likely to be discharged.

Out of all industries, factories likely to discharge heavy metal-containing wastewater in each district were extracted and allocated into each catchment area of sewerage. The Six most probable heavy metal-generating industries were selected and evaluated as shown in Table 7.1.4.1.

[1]: The data of existing industries were originated from "Location of Industrial Factory (in 1996)" issued by Factory Sanitary Section Environmental Healthy Department of BMA (1998).

The procedure for the risk evaluation is briefly outlined as follows:

- Six typical factories (dyeing, machinery, electroplating, cosmetics/tooth paste, battery and printing), which are likely to handle and discharge heavy metals, are selected out of all the factories and the "Relative Weighting Points" from 1 to 5 are given depending on the possible probabilities of discharge of heavy metals. The weighting point by each industry (B) are calculated by multiplying by the numbers of factories (A) and the total weighting point (C) for each service area calculated,
- Using the average weight point by one factory (F), the toxic factory ratio for all factories (G), the industrial wastewater ratio to total sewage (H), etc., the toxicity points (I) of each service areas is calculated. Then, (H) are converted into the toxicity indices at present (J) ranging from 0 to 10.
- Finally, the total toxicity indices (L) are induced by (J) multiplied by the potential growth indices in industrial sectors (K) derived from future perspective rating from 0 to 10, and the risk ranking is determined.

As the results of the risk evaluation of heavy metal intrusion, the following risk ranking, which indicates the Khlong Toey East service area at the highest risk, has been identified:

1st:	Khlong Toey East,	2nd:	Nong Khaem,
3rd:	Ratburana,	4th:	Khlong Toey West,
5th:	Huay Kwuang,	6th:	Ratanakosin,
7th:	Thonburi South,	8th:	Si Phraya,
9th:	Yannawa,	10th:	Thonburi Central,
11th:	Bung Kum,	12th:	Wang Thong Lang,
13th:	Thonburi North,	14th:	Bang Sue,
15th:	Din Daeng,	16th:	Chatuchak.

The risk rankings resulting from the risk evaluation have been employed in the expedient stratification of generated sludge to make the decision of final disposal destinations, as described in the subsection 7.2.5. It is the matter of course that the actual extent of heavy metal intrusion should be determined by actual monitoring results.