CHAPTER 8

DRAINAGE SYSTEM

8.1 Existing Drainage System

The Project Area is generally flat and low-lying, in a tributary of the Prai and Juru rivers, with the area of 11,600 ha of the entire Project Area. The Prai river flows through northern part of the area from east to west. It is very flat "tidal river", which is influenced by the ocean tides up to the point of about 20 km (12 mile) from the river mouth. Ground elevations of the tributary area range from RL+0.1 meters (0.33 ft) to RL+3.8 meters (12.5 ft).

The Juru river has similar characteristic to the Prai river. The river flows through the southern part of the Project Area from east and west with meandering course.

The tributary area consists of steep portion with the ground elevation of RL+5.0 to +230 meters (+16.4 to +750 ft) and flat portion with elevation of RL 0.0 to +2.9 meters (0 to +9.5 ft).

On the other hand, the sea water level is RL+1.68 meters (+5.5 ft) as the highest record and RL+1.10 meters (+3.6 ft) as the average high water level of the spring tide.

In consequence of low-lying and flat situations mentioned above, considerable parts of the Project Area are swampy areas and major parts of the area are subjected to back up of the sea water, which makes it necessary for the existing outlet drains to be provided with tidal gates. Reclamation of lands and/or pumping up of storm water runoff become necessary in the case of development in low-lying areas, as can be seen in the Prai industrial and Seberang Jaya development areas. These industrial areas have been developed on reclaimed land and provided with drainage system, comprising pumping stations and open channels with low velocity due to flatness of tributary areas.

The existing drainage facilities consist of open channels, either lined or unlined, discharging into rivers, major drains and/or the ocean. They are basically natural watercourses with piecemeal improvement in developed areas. Main drains are heavily silted and overloaded. On the part of flat areas, these drains disperse into ponding areas which are drained out to rivers and the sea. Road side drains are of "U" or "V" shape with semicircular invert, and are generally maintained well. Details of the individual systems are described in Sections 2.1 and 2.2, Part IV, "Drainage Master Plan" of this volume. In general, it is considered that the existing storm drainage systems is sufficient to meet with the present drainage requirements where desilting and better maintenance are carried out. However, in the areas where repetitious floodings have been experienced, immediate remedial programme has to be carried out.

8.2 Flooding in the Project Area

As shown in Figure II-10, flood experienced areas are spreading along the Butterworth and the Juru river. Flooding in Butterworth is due mainly to back up of existing major drains, derived from the reduced capacity by heavy silt and high water levels of the Prai river.

Areas liable to flooding in the tributary areas of the Juru river are primarily those of undeveloped swamps or palm and rubber plantation fields, and only the southern fringe of Bukit Mertajam town is inhabited sparsely. However, since this area will be developed for housing development in the foreseeable future, improvement of drainage system will be needed.

Although after the desilting and rehabilitation works of existing drainage systems are carried out, the capacities of the drains become sufficient only to cater present runoff, and no meaning is expected to meet the future urbanization, undergoing rapidly at present, of the Project Area.

Following photographs show the flooding and inundation situations in Butterworth area.

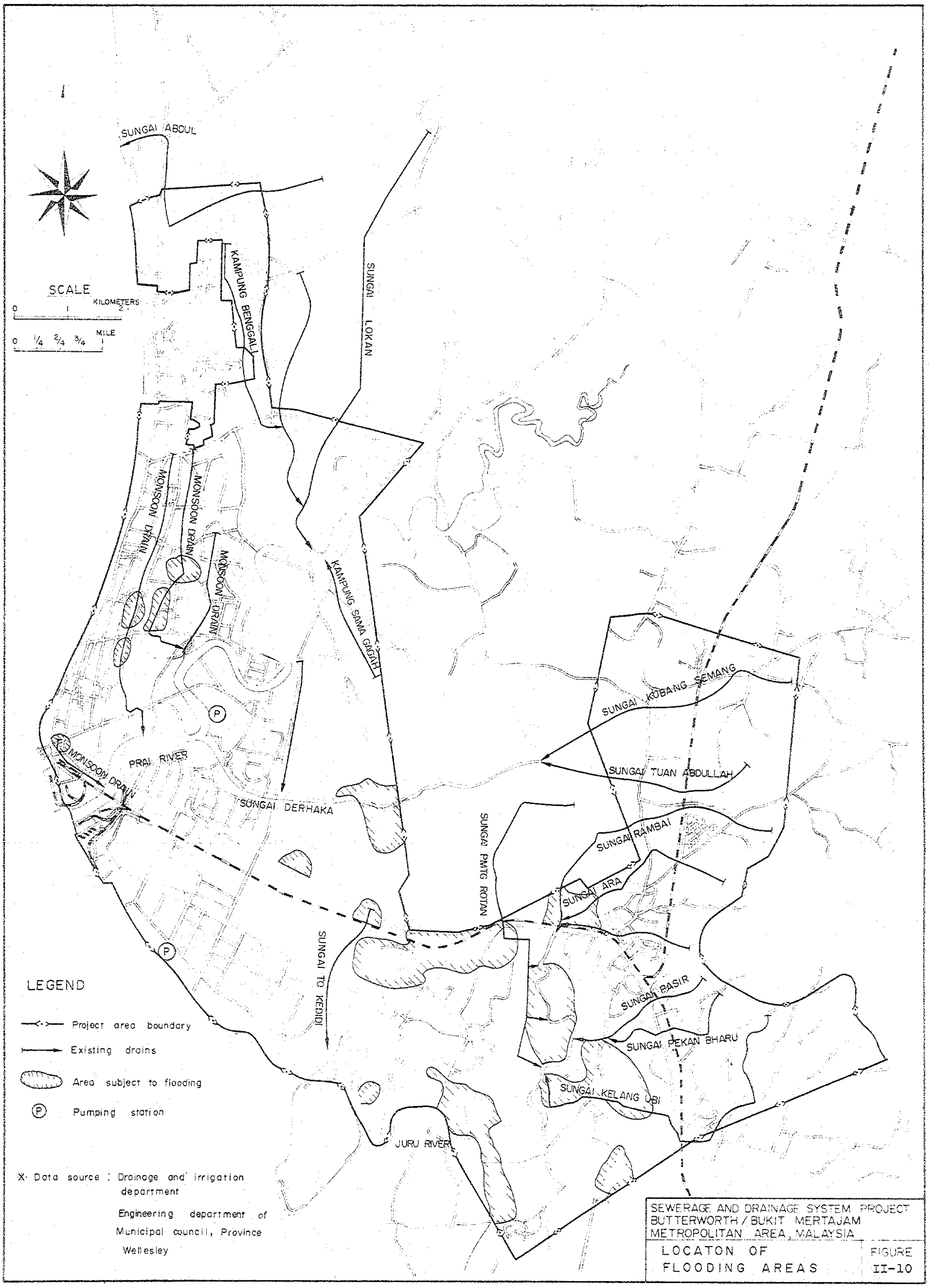
PHOTO II-6 Inundation in Butterworth town area

PHOTO II-7 Inundation in Butterworth kampong area

PHOTO II-8 Flooding in Butterworth area

PHOTO II-9 Flooding in Butterworth area

FIGURE II-10


SUNGAI ABDUL
KAMPUNG BENGGALI
SUNGAI LOKAN
SCALE
KILOMETERS
0 1 2
MILE
0 1/4 2/4 3/4 1
MONSOON DRAIN
MONSOON DRAIN
MONSOON DRAIN
MONSOON DRAIN
KAMPUNG SAMA GAGAH
PRAI RIVER
SUNGAI DERHAKA
SUNGAI KUBANG SEMANG
SUNGAI TUAN ABDULLAH
SUNGAI PMTG ROTAN
SUNGAI RAMBAI
SUNGAI ARA
SUNGAI TO KEDIDI
SUNGAI PASIR
SUNGAI PEKAN BHARU
SUNGAI KELANG UBI
JURU RIVER
LEGEND
Project area boundary
Existing drains
Area subject to flooding
Pumping station
X· Data source : Drainage and irrigation department
Engineering department of Municipal council, Province Wellesley
SEWERAGE AND DRAINAGE SYSTEM PROJECT
BUTTERWORTH / BUKIT MERTAJAM
METROPOLITAN AREA, MALAYSIA
LOCATON OF FLOODING AREAS
FIGURE II-10

CHAPTER 9

EFFECTS OF PRESENT WASTE DISPOSAL SYSTEM

9.1 Environmental Effects

9.1.1 Living Environment

The wastewater produced within the Project Area, including domestic sewage, industrial wastewater, and commercial wastewater, are mostly discharged to the existing drains and other available waterways directly, while night soil is mostly discharged to open-ditches through septic tanks or disposed of by means of bucket system. These are producing septicity in the waterways and causing water pollution in the rivers and drains of the Area.

Because the ground surface slope in the Area (especially in Butterworth area) is generally flat and flow velocities in the existing drains are low, wastewater tends to stagnate and decompose, causing odours and visible nuisance as well as hazards to public health. One of the major causes of water pollution is the uncontrolled wastewater disposal to the waterways.

9.1.2 Water Pollution

Project Area has two major rivers, the Prai and Juru, with many branches within their tributaries, collecting the runoff and discharging it to the sea. These rivers, utilized for irrigation and navigation, are the recipients of much of the sanitary wastes from the population and industrial wastes, as well as other pollution contained in surface runoff.

These river and drain systems comprise a complicated network of water courses, with the gates which have been operated for controlling water level against tidal influence. In both of the two rivers, flow and water surface elevation are affected by the tides, and the tidal compartment of the Prai river extends beyond the boundary of the Project Area.

At present, most of domestic and industrial wastewaters are discharged directly to drains and other available waterways finally reaching the river systems. The pollutant loads discharged to the waterways are transported eventually to the sea, but all the pollutants do not necessarily reach the sea. Some portion of them either settle on the bottom of water courses or decompose biologically on their way to the sea. The flow velocity of these waterways excluding two main rivers is generally at around 0.5 m/sec or less, which intensifies stagnation and biological decomposition. The effects of pollution are most pronounced in the town and industrial areas.

As described in Appendix D, "Water Pollution Studies", the pollution survey conducted by the Survey Team confirms that the rivers in urban areas are generally polluted mostly by the direct discharge of wastewater. Water qualities at the river mouth of the two rivers range between 3.6 mg/l and 6.9 mg/l, in terms of DO concentrations.

Since all of the main intakes for water supply for the Penang State are located outside of the Project Area, pollution in the Project Area as described above does not affect the intake water.

Penang State, including Province Wellesley, has some of the most important recreational resorts in Malaysia, and therefore to keep public environment clean has significant meaning in addition to the improvement of living environment of the residents.

PART III

SEWERAGE MASTER PLAN

CHAPTER 1

PREVIOUS STUDIES

Reports and studies relevant to this project are available on several aspects of Butterworth/Bukit Mertajam Metropolitan Area and its surroundings. The important recent reports and studies are discussed herewith.

1.1 Penang Master Plan Report

This Master Plan was prepared for the Penang Master Plan Committee by Robert Nathan Associates Inc. in March, 1970. The purpose of this study was to establish a long-term programme for urban development of the Penang State. Emphasis was given on resource base study, socio-econimic programme, and physical planning, and programm was outlined extending over the period of 1971 to 1985.

Since data used for analysis of population were those available in the year 1969, the population projections estimated in the "Population and Housing Census of Malaysia, 1970", was not used in this Master Plan. Some over estimation of State population is found compared with the actual development of land use and population growth in recent years.

In the plan, three basic strategies are established for acceleration of economic growth, including development of manufacturing, tourism, and fisheries, but agricultural development is considered not to be the element to stimulate employment opportunities. Among the three basic strategies, manufacturing is expected to contribute the greatest portion of employment opportunities.

The physical plan for development of industrial estates are also established in the outline of this Plan. Most of the planned industrial estates are in the Butterworth and Bukit Mertajam Metropolitan Area. One of the purposes of physical planning is to establish a comprehensive framework to facilitate detailed planning for the different (physical) sectors of the overall plan.

Sewerage schemes for Butterworth and Bukit Mertajam areas, as one of the short-term physical plans, are included in the Plan.

1.2 Water Supply Project Report

A report was prepared for the Penang State Government by Binnie & Partners, Ltd., Malaysia, in 1967, to present a long-range programme for the water supply system of the Penang State up to the year 2000. The main features of the plan are summarized below:

(a) The population to be served by the water supply system will be between 944,600 (upper growth limit) and 683,900 (lower growth limit) in the year 2000.

(b) The estimated average water requirement in 2000 is 277,000 cu m/day (61 IG/day).

(c) In terms of per capita water consumption, 230 l/day (50 IG/day) for direct consumers is assumed for the year 2000.

(d) Average industrail water use is estimated at 126,000 cu m/day (28 IG/day) for the year 2000.

These data are useful for estimating the future wastewater productions in the sewerage master planning.

1.3 WHO Assignment Report

The report, prepared by the World Health Organization (WHO) in 1973, based on the Penang Master Plan referred above, includes brief recommendations of future sewerage system at Butterworth and Bukit Mertajam Metropolitan Area.

It recommends that each sewerage zone be treated by independent stabilization pond and that the main sewers be laid with minimum gradient to the sewage pond. It also points out that due to the high tide level and consequently high ground water level, the sewage has to be pumped up to the ponds by means of a lift station. This is made with assumption that a minimum flow of the Prai river will be of 536,000 cu m per day (118 MIGD) which functions as the main recipient of the effluent from the sewage ponds, after the construction of the Prai barrage.

Due to the poor ground condition, it also recommends that rubber-ring joint reinforced concrete pipes and/or asbestos cement pipes of high quality be used, and treatment facilities with oxidation pond/s for each area without preceding settlement as a satisfactory treatment method.

1.4 Others

Listed below are the references of the other main studies used in establishing the sewerage and drainage master plan:

(1) Third Malaysia Plan, by Government of Malaysia

(2) Kuala Lumpur Sewerage Master Plan, by D. Balfour & Sons of U.K.

(3) Ipoh Sewerage Feasibility Study, by Ennex of New Zealand

CHAPTER 2

PHYSICAL PLANNING AND LAND USE

2.1 Background Information

Town and Country Planning Department (TCP) of the Penang State formulated a 15-year plan to develop establish the development programme for the State taking the socio-economic and physical needs of the population into account, the plan called for the improvement of the general physical condition of the Penang State, including its proper land use.

The land use plan for Butterworth/Bukit Mertajam area, prepared by TCP, divides the whole metropolitan area into four different zones, namely, social and commercial, residential, industrial and others, taking into consideration of the type of future development of the area. Since the plan was prepared, conditions of the area have changed substantially, and also the sewerage master plan is to be planned for the year 2000, it is necessary to adjust the land use pattern in order to indicate the appropriate future status of the Project Area.

Industrial estates have been developed in Prai and Seberang Jaya, and in Mak Mandin development is now under by Penang Development Corporation (PDC). New housing areas and social and administrative areas such as sites for court house and hospital complexes at Seberang Jaya are also under consideration by PDC. In addition to Seberang Jaya, new housing schemes have recently been considered by private developers throughout the Project Area. These schemes are carried out under the control of MPSP, and some of them are already under way or under consideration.

2.2 Land Use Adopted for Sewerage Master Plan

On the basis of the studies mentioned above, future land use up to the year 2000 has been established by the following manners:

(a) Identify the non-habitable areas, such as major rivers (Prai and Juru), cemeteries, swamps and hills of which ground elevations at more than 60 m (200 ft) above mean sea level, in which any development will not be possible.

(b) Identify the industrial areas, i.e. Prai, Seberang Jaya, and Mak Mandin, according to PDC's plan. No other industrial development is considered before the year 2000.

(c) Identify the residential, social and commercial areas in Seberang Jaya according to the development plan of PDC.

(d) Identify the residential areas according to the new housing schemes by the private developers submitted for approval of MPSP.

(e) Remainder of the above mentioned areas are considered to be residential areas.

According to the plan envisaged by the Government, the whole Project Area should be essentially urbanized and no rural and agricultural areas should remain by the target year. Entire Project Area is currently classified into six categories, i.e. industrial, social and commercial, residential, rural, agricultural and others (non-habitable). This is planned to be developed into four categories in the target year of 2000 converting the present rural and agricultural areas to urbanized areas due to the reduced swamp area owing to the land development programmes.

Taking the above conditions into account, the land use plan for the year 2000 is developed and agreed with the Government, as shown in Table III-1 and Figure III-1.

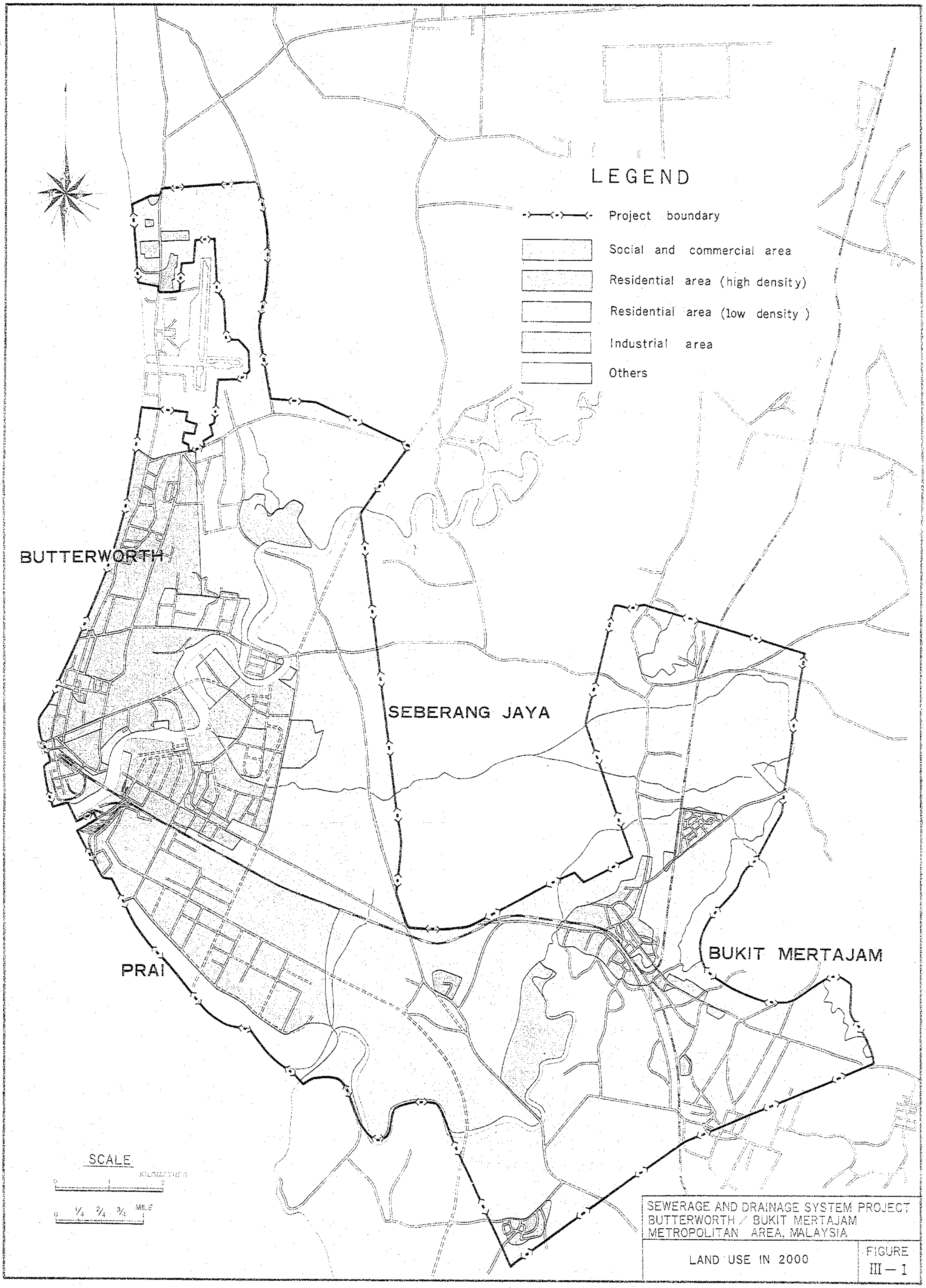
TABLE III-1 Land Use in the Year 2000

		(ha)
a)	industrial	1,289
b)	social and commercial	168
c)	residential	9,397
d)	others	746
	Total	11,600

As regards the residential area, it is considered appropriate for planning purpose to further delineate areas into high density of built-up urban area of averagely 160 persons/ha, average new housing area of 120 persons/ha and low density area of 52 persons/ha.

For master planning purposes, the residential area is further classified into two categories, namely high population density built-up urban area and area to be partly developed for housing.

FIGURE III−1


LEGEND
Project boundary
Social and commercial area
Residential area (high density)
Residential area (low density)
Industrial area
Others
BUTTERWORTH
SEBERANG JAYA
BUKIT MERTAJAM
PRAI
SCALE
KILOMETRES
0 1/4 2/4 3/4 MILE
SEWERAGE AND DRAINAGE SYSTEM PROJECT
BUTTERWORTH / BUKIT MERTAJAM
METROPOLITAN AREA, MALAYSIA
LAND USE IN 2000
FIGURE
III−1

2.3 Sewerage Districts and Zones

Initially, two alternative sewerage systems are considered, one is for a comprehensive sewerage system covering the whole Project Area and the other for multiple sewerage systems. Selection of the system depends upon the characteristics of the Area with due consideration on economical impact.

The physical characteristics of the Project Area are, (1) populated urban areas are limited, (2) huge rural areas still remain at present to be developed in the future, and (3) mostly flat ground surface.

If comprehensive sewerage system is planned in a huge flat ground surface, large sized deep main sewers are required to convey sewage from individual house all the way to the treatment plant, causing high initial investment in addition to the difficulties in implementing construction programme particularly in the built-up areas. Consequently, immediate implementation of the sewage system construction will be delayed with added difficulties in obtaining sufficient funds for small sewers such as laterals, and branches.

Under the circumstance, it is considered practical, as WHO Assignment Report recommends, that the Project Area be properly divided into districts and zones to be dealt with separately, rather than planning area-wide system to cover whole Project Area. The advantages considered would be:

(a) It is possible to design sewer facilities according to the characteristics of each of such districts and zones.

(b) Implementation of construction plan will be flexible to adjust according to the degree of requirement and availability of financial resources.

(c) Long conveyance can be avoided, which will avoid inconvenience in construction and enable earier maintenance and better control of sulfide build-up.

(d) Rural areas, in which urbanization plan is yet to be developed, will remain flexible for future implementation.

The Project Area has, as indicated earlier, total of 11,600 ha altogether, but, excluding watercourses, swamps and other non-habitable areas, total area for sewerage planning purpose is 10,854 ha. For the convenience of planning, an attempt is made to divide the total area into four districts, namely, Butterworth, Seberang Jaya, Prai and Bukit Mertajam in accordance with the geographical conditions. They are further divided for implementation purpose into zones with due consideration of the followings.

(i) Population density by area

(ii) Existence of rivers, railways, and roads

(iii) Land use situation

(iv) Administrative boundaries (Mukim)

(v) Condition of built-up area

(vi) Topography

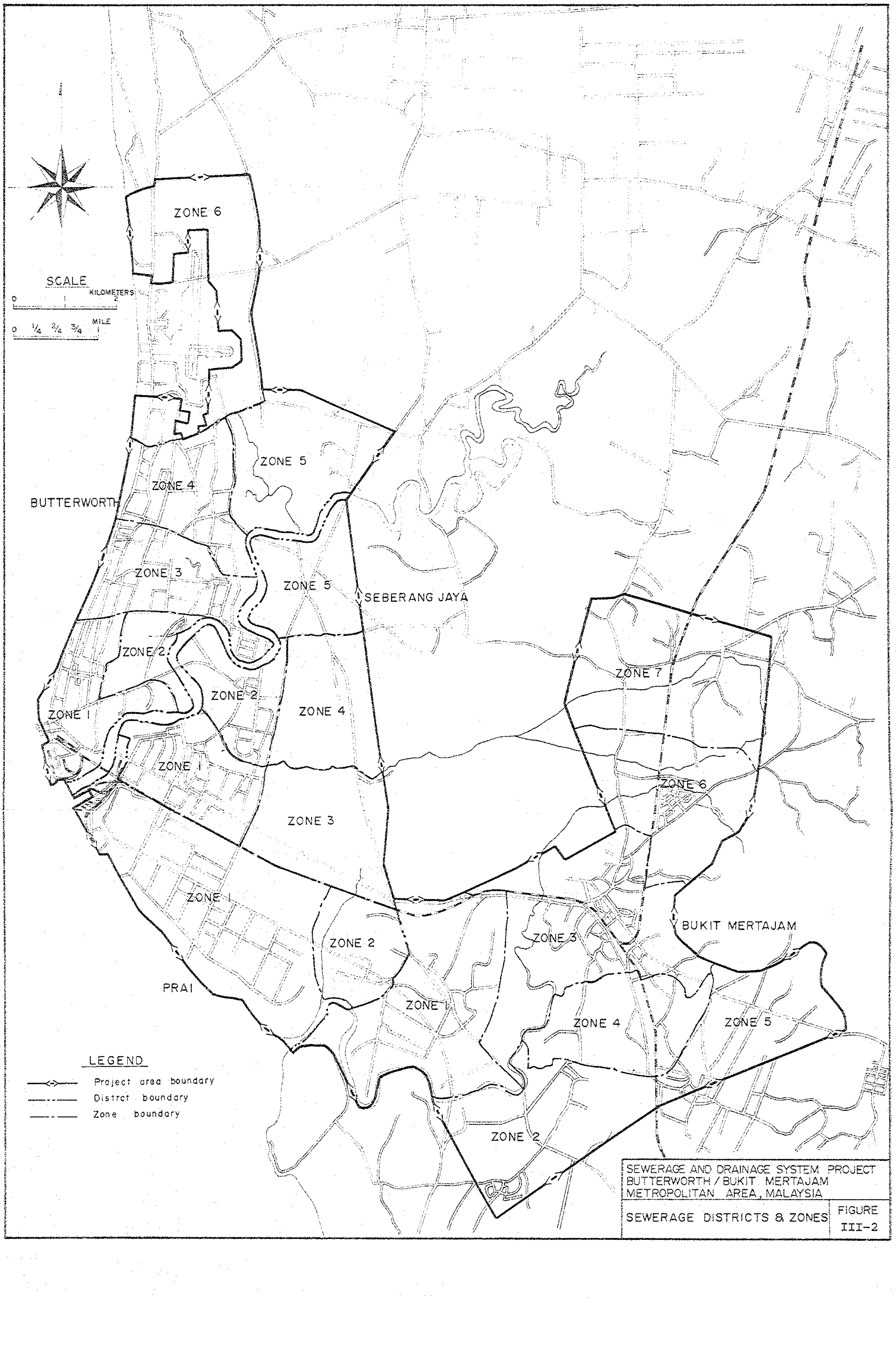
Several alternative delineations are considered, but with due note of the advantages for smaller delineation as stated earlier, the following is considered to serve the purpose.

TABLE III-2 Sewerage Districts and Zones

	Name of District	Name of Zone	Area (ha)	Covered by Sewerage (ha)
1.	Butterworth	Zone - 1	390	367
2.	"	" - 2	200	182
3.	"	" - 3	490	457
4.	"	" - 4	450	444
5.	"	" - 5	570	551
6.	"	" - 6	670	670
7.	Seberang Jaya	Zone - 1	480	438
8.	"	" - 2	360	305
9.	"	" - 3	510	510
10.	"	" - 4	430	430
11.	"	" - 5	420	368
12.	Prai	Zone - 1	1,230	1,063
13.	"	" - 2	280	268
14.	Bukit Mertajam	Zone - 1	940	892
15.	"	" - 2	730	715
16.	"	" - 3	980	927
17.	"	" - 4	470	467
18.	"	" - 5	490	459
19.	"	" - 6	660	573
20.	"	" - 7	850	768
	Total		11,600	10,854

NOTE: The area covered by sewerage of 10,854 ha (26,820 acres) is derived from excluding nonhabitable areas such as mountains, rivers, swamps and cemeteries from the entire Project Area of 11,600 ha (28,660 acres).

FIGURE III-2



SEWERAGE AND DRAINAGE SYSTEM PROJECT
BUTTERWORTH / BUKIT MERTAJAM
METROPOLITAN AREA, MALAYSIA

SEWERAGE DISTRICTS & ZONES

FIGURE III-2

CHAPTER 3

POPULATION PROJECTIONS

3.1 Introduction

Population estimates for the Project Area in 1970 and 1976 are already described earlier in PART II Background, Chapter 4 Population and Land Use. On the basis of the National Census in 27 mukims, which covers partially or totally included in the Project Area, 1970 population for Project Area is estimated to be 172,230, based on which 1976 population for the Area is estimated to be 238,000 by using the annual growth rate of 5.5 percent, as used in Penang Master Plan, as the most reliable data for the population growth up to the present. They are used as a reasonable basis to determine future water requirements and sewage quantities. These projections are discussed in Appendix B, "Population and Land Use Distribution."

3.2 Population of the Project Area

On the basis of the population estimates for the years 1970 and 1976, population of the Project Area up to the year 2000 are estimated as shown in Table III-3. Population estimated for 1985 is that projected in the Penang Master Plan. Annual growth rate from 1970 to 1985 is assumed at uniform annual rate of 5.5 percent in the Project Area, while that of Penang State is 2.2 percent. On the basis of the estimated population for the year 1995, the annual growth rate from 1985 to 1995 is assumed at uniform of 3.5 percent, and in this master plan, the same average growth rate of 3.5 percent is adopted to estimate the population up to the year 2000. (Ref. Appendix B, "Population and Land Use Distribution")

TABLE III-3 Future Population of the Project Area

Year	Population	Average Annual Growth Rate (percent)
1970	172,230	
		5.5
1976	238,000	
		5.5
1980	294,400	
		5.5
1985	385,000	
		3.5
1990	458,000	
		3.5
1995	545 000	
		3.5
2000	648,000	

3.3 Population Distribution by District

The Project Area is proposed to be divided into four sewerage districts, each having a different trend in population growth rate, according to its land use characteristics. Since data on future population growth by districts and zones are not available, the future population by district is assumed under this project on the basis of future land use pattern and estimated population density.

The bases in estimating future population densities by land use are as follows:

(a) Social and commercial area (Public building) .... 0, 120, or 160 persons/ha

(b) " (Commercial) .... 120 persons/ha

(c) Residential area (Built-up urban area) .... 160 "

(d) " (New housing) .... 120 "

(e) " (Others) .... 52 "

(f) Industrial area .... 0 "

(g) Others (Non-habitable area) .... 0 "

Table III-4 Land Use and Population of Zone in 1976

District	Zone No.	Area (ha)								Population Density (persons/ha)				Population		
		Total	Social Commer-cial	Residen-tial	Indust-rial	Rural	Agri-cul-trual	Others	Total	Social Commer-cial	Residen-tial (high)	Residen-tial (low)	Total	Social Commer-tial	Residen-tial	Rural
Butterworth	1	390	16* 47	190	67*			70*	97.2	0 160	160		37,900	0 7,500	30,400	
	2	200		33				167*	17.9		108.6		3,600		3,600	
	3	490	2	176	107*	119		86*	57.7	120	120	57.9	28,200	200	21,100	900
	4	450		21		411		18*	58.5		120	57.9	26,300		2,500	23,800
	5	570				231	75*	264*	6.9			17.1	4,000			4,000
	6	670		18		316	336*		13.3		120	21.3	8,900		2,200	6,700
Sub-Total		2,770	16* 49	438	174*	1,077	411*	605*					108,900	7,700	59,800	41,400
Seberang Jaya	1	480		157	2*	48	159*	114*	28.5		80	22.9	13,600		12,500	1,100
	2	360			29*	3	229*	99*	0.2			23.0	100			100
	3	510				155	300*	55*	5.9			19.3	3,000			3,000
	4	430				143	264*	23*	17.5			52.6	7,500			7,500
	5	420				138	115*	167*	10.4			31.7	4,400			4,400
Sub-Total		2,200	-	157	31*	487	1,067*	458*					28,600	-	12,500	16,100
Prai	1	1,230			639*	94	93*	404*	1.5			19.8	1,900			1,900
	2	280				106	138*	36*	7.1			18.6	2,000			2,000
Sub-Total		1,510	-	-	639*	200	231*	440*					3,900			3,900
Bukit Mertajam	1	940		16		299	450*	175*	8.0		80	21.0	7,600		1,300	6,300
	2	730		38		144	509*	39*	8.7		80	23.2	6,400		3,000	3,400
	3	980	20	209		376	87*	288*	46.5	120	119.2	48.5	45,500	2,400	24,900	18,200
	4	470		9		193	248*	20*	12.9		80	27.8	6,100		700	5,400
	5	490				235	224*	31*	14.8			30.9	7,300			7,300
	6	660		46		208	319*	87*	21.0		120	40.0	13,800		5,500	8,300
	7	850				265	503*	82*	11.7			37.5	9,900			9,900
Sub-Total		5,120	20	318	-	1,720	2,340*	722*					96,600	2,400	35,400	58,800
Total		11,600	16* 69	913	844*	3,484	4,049*	2,225*		0 147.2	118.1	34.4	238,000	10,100	107,700	120,200

Note: * is not inhabited area, e.g. government office zone, water courses, cemeteries, mountainous areas, parks, industrial areas, agricultural areas.

Table III-5 Land Use and Population of Zone in 2000

District	Zone No.	Area (ha)						Population Density (Persons/ha)				Population			
		Tctal	Social Commer-cial	Residen-tial (high)	Residen-tial (low)	Indus-trial	Others	Total	Social Commer-cial	Residen-tial (high)	Residen-tial (low)	Total	Social Commer-cial	Residen-tial (high)	Residen-tial (low)
Butterworth	1	390	16* 47	237		67*	23*	116.5	0 160	160		45,400	0 7,500	37,900	
	2	200		182			18*	109.2		120		21,800		21,800	
	3	490	2	275	73	107*	33*	75.6	120	120	52.0	37,100	300	33,000	3,800
	4	450		212	232		6*	83.4		120	52.0	37,600		25,500	12,100
	5	570		74	477		19*	59.1		120	52.0	33,700		8,900	24,800
	6	670		36	634			55.7		120	52.0	37,300		4,300	33,000
Sub-Total		2,770	16* 49	1,016	1,416	174*	99*					212,900	7,800	131,400	73,700
Seberang Jaya	1	480		354	82	2*	42*	97.4		120	52.0	46,700		42,500	4,200
	2	360	18* 35	154	48	50*	55*	69.9	0 120	120	52.0	25,200	4,200	18,500	2,500
	3	510			510			52.0			52.0	26,500			26,500
	4	430	30*		400			0 48.4			52.0	20,800			20,800
	5	420			368		52*	45.6			52.0	19,200			19,200
Sub-Total		2,200	48* 35	508	1,408	52*	149*					138,400	4,200	61,000	73,200
Prai	1	1,230				1,063*	167*	0							
	2	280			268		12*	49.8			52.0	13,900			13,900
Sub-Total		1,510	-	-	268	1,063*	179*					13,900	-	-	13,900
Bukit Mertajam	1	940		16	876		48*	50.5		120	52.0	47,500		1,900	45,600
	2	730		38	677		15*	54.5		120	52.0	39,800		4,600	35,200
	3	980	20	355	552		53*	75.2	120	120	52.0	73,700	2,400	42,600	28,700
	4	470		9	458		3*	53.0		120	52.0	24,900		1,100	23,800
	5	490			459		31*	48.8			52.0	23,900			23,900
	6	660		46	527		87*	49.9		120	52.0	33,000		5,500	27,500
	7	850			768		82*	47.0			52.0	40,000			40,000
Sub-Total		5,120	20	464	4,317	-	319*					282,800	2,400	55,700	224,700
Total		11,600	64* 104	1,988	7,409	1,289*	746*					648,000	14,400	248,000	385,600

Note: * is not inhabited area, e.g. government office zones, water courses, cemeteries, mountainous areas, industrial

Using the estimated population densities by land use and the land use pattern for the year 1976, the population of each sewerage district and zone is estimated and then the year 2000 is projected, which are shown in Tables III-4 and III-5. The population in 1985, 1990 and 1995 are then estimated as shown in Table III-6. (Ref. Appendix B, "Population and Land Use Distribution")

TABLE III-6 Population Distribution of Sewerage District

District	Year				
	1976	1985	1990	1995	2000
Butterworth	108,900	146,200	164,700	186,800	212,900
Seberang Jaya	28,600	68,000	87,500	110,800	138,400
Prai	3,900	7,500	9,300	11,400	13,900
Bukit Mertajam	96,600	163,300	196,500	236,000	282,800
Total	238,000	385,000	458,000	545,000	648,000

CHAPTER 4

BASIC ENGINEERING CONSIDERATION

4.1 Introduction

Every wastewater control system, from the crude cesspool to the most sophisticated wastewater collection and treatment system, has one or both of two purposes; first to remove the waste materials from the place of origin to the place of disposal, and second, to achieve the disposal, usually into a waterway, without undesirable effects on the receiving water values. This needs to be done as economically and as rapidly as possible to cope with the increase of the waste load of a growing community. Technical soundness and financial feasibility should be kept in mind for realistic and bankable plan for the Project, and economical approach should particularly be stressed to minimize financial burden of the authorities concerned in the way of initial investment, operational cost and recoveries thereof.

Taking these factors into account, possible feasible alternatives for the sewerage system for the Project Area have been considered and analyzed from both the technical and economical view points. Analysis made are described briefly in the following sections.

The basic approach for the master planning is (1) to establish overall sanitary system required by delineating sewerage districts and zones needed to serve the Project Area, (2) to develop a plan for orderly implementation of provision of a separate system sanitary sewers, with priority attention to areas having the most critical sanitation conditions, with due consideration of the existing local storm drains for use with proper improvement programme wherever advantageous, and (3) to develop a plan for facilities for treatment and disposal in each zone which will provide adequate protection to the waterways in the Project Area, including the coastal marine water of Penang Channel with emphasis on protection of the recreational beach areas.

4.2 Collecting System

To determine the most suitable sewerage system for the Project Area various relevant factors are taken into consideration, which include:

(a) Basic consideration for the sewerage system in the Project Area is the existence of natural watercourses and the established flood control system constructed by DID. Hence, there is little point in building another system of closed conduits to take care of storm water runoff together with wastewater, as the existing river and drainage system serving for flood control will serve adequately for handling storm water runoff, if they are properly improved. This situation excludes the concept of combined sewer facilities for the Project Area.

(b) A survey of the existing conditions of water pollution in the Area shows that the rivers and drains are mainly polluted by sanitary wastes, especially during the dry season when the rivers and drains are in fact serving essentially as the main sewers of the Area, and that only the establishment of a separate sewerage system to keep sanitary wastes out of the rivers and drains will be sufficient to change the present gross pollution situation and set the basis for progressive clean-up of the Area.

(c) Because combined sewers are normally deeper than storm channels, excavation costs will be greater. Further, pumping up from greater depths would be needed, which requires increasing pumping station and power costs usually exceeding those for separate storm and sanitary sewer systems added together.

(d) Because traffic conditions in the Project Area are often critical, excessive distruption of traffic and other normal social activities during construction of deep and large sewers for the combined system will generally be greater than the separate sewer system.

(e) It is recognized that sanitary collecting sewers can hardly be provided simultaneously for all of the Area. For practical purpose, the plan has to be developed on priority basis for implementation in accordance with the degree of urgency. Thus, the areas currently served by septic tanks reasonably well even to the foreseeable future may safely be deferred their construction, and even in case of areas to be provided with sanitary sewers, advantage may be taken of the existing local storm drainage systems in kampong areas, to serve temporarily for transporting dry weather sullage flows to the main sanitary sewers. Similarly, in the areas where currently house sewers discharge the wastes into the existing local storm drains which in turn flow to the rivers and drains, these drains can in some cases serve to convey the dry weather sullage waste flows to the sanitary sewers by providing overflow structures to prevent overtaxing of the sanitary sewers and treatment facilities during the time of storm weather.

4.3 Treatment and Disposal System

As discussed in Appendix D, "Water Pollution Studies", water in the drains and rivers in the urbanized areas have already become polluted by domestic and industrial wastes. If no steps were taken to alleviate waste loads discharged to drains and rivers, these areas are anticipated to be further contaminated and degraded in the immediate future.

It is therefore necessary to consider the extent and method of treatment within a sanitary sewerage programme and location of the collected and suitably treated waste water to be disposed of.

4.3.1 Need of treatment

Taking into account of the locality for final disposal, treatment level/disposal method should be considered to safeguard the beneficial values of the receiving area.

Generally, there are three alternatives to be considered for final disposal, as described in the following:

(1) Nontreatment - Discharge into a river or shallow waters near the beach

Along the Butterworth beach, there are many sewer outfalls including domestic wastewater and septic tank effluents. As mentioned in Appendix D, "Water Pollution Studies", the areas near sewer outfall points are contaminated by coliforms. This also is recognized by the pollution control studies conducted by the Ministry of Health.(*1)

The water from the rivers of the Prai and the Juru are also polluted by coliforms. This may be due to faecal pollution of human wastes from the effluents of septic tanks which may sometimes be mal-functioning for elimination of coliform bacteria.

(*1) "Pollution Control Study of the Batu Fringgi/Telok Behang Coastal Areas", Ministry of Health (1972).

Although coliform contamination is found in river and coastal waters, the organic contamination is not significant in coastal and river waters at the present stage. This appears to indicate that the direct discharge of domestic wastewater, except human excreta, into river or coastal waters is not sufficiently destructive for the water quality conservation under the present conditions, due mainly to the unconcentrated discharge of human excreta to the waterways. If significant volume of wastewater were concentrated in the future to a limited receiving water such as the Juru river, this would undoubtedly bring about noticeable pollution in the water.

(2) Non-treatment - Ocean outfall

Non treatment - Ocean outfall system is economical if the following conditions are met:

(a) suitable outfall points are available.

(b) safeguard measures for beneficial use of the receiving water can be established,

(c) construction and maintenance of long piping system for sewage collection are feasible.

Outfall points: For outfall points, the open ocean with strong oceanic currents is the best to protect the coastal sea water from sewage contamination. If ocean outfall is adopted for this sewerage system, the possible water body for sewage outfall will be the Penang Channel. The Penang Channel is narrow with minimum width of about 2 km (3.2 miles) with strong tidal current, roughly estimated at 26 to 100 cm/sec (0.85 to 3.28 ft/sec) in daily maximum. Therefore, capacity of flushing out of sewage by the tidal currents may be sufficient to assimilate the organic pollutants (BOD or PV) from the Project Area.

Safeguard measures: The port of Penang is one of the important ports in Malaysia, and the port area extends over the whole Penang Channel. The area in front of the Project Area is the most important for anchoring of vessels, for which submarine facilities should be avoided for safety of navigation and for safeguard of facilities themselves.

Water pollution control is also necessary because the beaches along or neighbouring the Channel are used for bathing or other water contact sports. The outfall should therefore be long enough to avoid carry back of the sewage pollutants (floating matters and coliforms). However construction of long outfall sewers will be difficult because of narrowness of the Channel and high velocity of the tidal current.

The experience at George Town sewage disposal system suggests that coliform contamination would not be avoided by ocean outfall without treatment.

Long piping system: It is necessary to construct and maintain long piping system to convey the sewage collected from the Area to the outfall site.

Since the Project Area is generally flat, except portion of Bukit Mertajam district, the long piping system would required deep sewers and many lift stations. It is natural that the long sewer system would require high initial investment for construction and also greater maintenance cost in the succeeding years.

(3) Secondary Treatment - Short outfall into river or shallow water near the beach

According to the field surveys, it is evident that the properly treated effluent by means of secondary treatment process can be safely discharged into river or shallow water near the beach, preferably with location near a river or coastal area.

(4) Conclusions

For the reasons mentioned previously, it is concluded that construction of secondary treatment be recommended for final disposal in order to control the water pollution in the Project Area.

4.3.2 Comparison of Alternative Treatment Methods

On the basis of the above conclusions, three possible alternatives are studied in detail (Ref. Appendix G, "Sewerage System Consideration"), namely (1) stabilization pond process, (2) aerated lagoon process, and (3) oxidation ditch process, to select the most appropriate disposal system for the Project Area. The studies include the local conditions such as possibility of land acquisition, availability of skilled labours, capacity of receiving water bodies and construction cost of the facilities. These alternative considerations are described below.

(1) Stabilization Pond Process

Treatment by stabilization pond works by natural conditions involving the action of algae and bacteria under the influence of sunlight (photo-syntheses) and temperature. In order to facilitate easy repairs, maintenance and flexibility in operation, stabilization pond is provided with at least more than two ponds in parallel, depending upon the magnitude of the flow and the topography of the site, and then considered flow patterns are of two series arrangement which is called facultative and maturation ponds.

(2) Aerated Lagoon Process

Aerated lagoon process consists of aerated lagoon and maturation pond. This is the activated sludge units operated without sludge returns. Commonly, floating aerators are used to supply the necessary oxygen and mixing power.

The effluent from aerated lagoon is to be treated further in a maturation pond which will achieve high degree of bacteriological purification and suspended solid removal. Both the aerated lagoon and maturation pond are provided with at least two or more ponds in parallel for easy repairs and maintenance and also flexibility in operation.

(3) Oxidation Ditch Process

Oxidation ditch is essentially a modification of the activated sludge process. This method of aerobic stabilization circulates wastewater in a closed circuit ditch aerated by mechanical aerators. After circulation in the ditch, the mixed liquor is led to the sedimentation tank and solids are removed, then supernatant water is discharged to receiving water bodies after disinfected.

The sludge produced in sedimentation tank should be withdrawn into drying bed. Oxidation ditch process consists of oxidation ditch, sedimentation tank, and drying bed.

In these three treatment systems mentioned above, the treated water is designed to flow by gravity into the receiving water boby, with the expected BOD removal of more than 75 percent if the systems are properly designed and efficiently operated.

To compare the alternatives, each type of treatment is designed for the flow rate of 5,000 to 200,000 cu m daily, then the cost, accruing to alternatives, are estimated using cost functions developed. (Ref. Appendix G, "Sewerage System Consideration")

Table III-7 shows the results of comparison of cost and land space required. The cost of each selected alternative is estimated in terms of total annual cost with respect to construction, operation and maintenance, and depreciated capital cost at 1976 levels taking into account of the life of the facilities provided.

The results of cost analysis indicate that the stabilization pond process would be the most suitable treatment and disposal system for the Project Area.

(4) Recommended System

On the basis of preceding discussions and from an examination of the study results, it is evident that stabilization pond system has a substantial benefit compared with other alternatives considered. Advantages and disadvantages to be derived from stabilization pond system are as follows:

(a) This process is the most economical sewerage disposal system, in terms of construction, operation and maintenance costs, even it may require more land space than other process.

(b) Sufficient land in the Project Area seems to be available, which enables stagewise expansion as the population increase. If the required land area is not available in the final stage, stabilization pond may then be modified to other treatment method such as aerated lagoon or oxidation ditch for the reduction of land requirement.

(c) This method can meet the future modification of design conditions simply by adjusting surface area.

(d) A minimum mechanical and electrical equipment are necessary, which contribute to the economical financing because the major portion of the construction costs can be borne locally.

(e) The maintenance and operation costs are mainly for labour, which will provide opportunity for employment and easiness of maintenance and operation.

(f) Ponds may occasionally emit odours so that ponds should be located as far from existing or future residential or commercial development as is practical or reasonable.

Although stabilization pond system has both advantages and disadvantages as discussed above, it can be concluded that the advantage may overcome the disadvantages and that the system will reasonably be adopted to the sewage disposal system in the Area. Construction of the system may be divided into stages, initial and final stage. The initial stage will be to construct some portion of the system, then to monitor performance to determine the extent of requirements either for extending the system and/or installing the other treatment processes such as aerated lagoons, activated sludge process, etc., which may possibly be required in the future when the situation of the Area changes.

TABLE III-7 Comparison on Alternative Treatment/Disposal Systems

1) Cost comparison on the basis of total annual cost

(M$1,000)

Alternatives	Flow Rate (cu m/day)				
	5,000	10,000	50,000	100,000	200,000
Alt. I Stabilization pond Process	66.8	122.7	571.0	1,131.4	2,252.0
Alt. II Aerated Lagoon Process	150.2	288.8	1,389.3	2,761.2	5,511.4
Alt. III Oxidation Ditch Process	220.1	419.9	1,916.3	3,644.9	7,254.7

2) Land Area required

(ha)

Alternatives	Flow Rate (cu m/day)				
	5,000	10,000	50,000	100,000	200,000
Alt. I Stabilization Pond Process	6.0	11.2	52.4	98.7	197.3
Alt. II Aerated Lagoon Process	2.3	4.3	20.2	38.0	76.1
Alt. III Oxidation Ditch Process	0.6	1.1	4.9	9.2	18.5

4.4 Industrial Wastewater Treatment

4.4.1 Consideration on Joint Treatment of Domestic and Industrial Wastes

Municipal sewage involves both domestic sewage and industrial wastewater. Combined domestic and industrial waste treatment may be the most desirable arrangement, but it always accompanies with certain problems which have to be carefully considered.

As industrial wastes sometime include objectionable matters, such as oils, grease, flammable solvents, excessive acidity or alkalinity and poisonous substances, it is necessary to give due consideration for protection of a conduit system from corrosion, clogging, explosion, and other damages, and for adequate maintenance of each treatment process.

Since most sewage treatment plants use some form of biological treatment, it is essential for satisfactory operation that extremes in industrial waste characteristics be avoided and the waste mixture be (1) as homogeneous in composition and uniform in flow rate as possible and free from shock loads, (2) not highly loaded with floatable and suspended matters, (3) free of excessive acidity or alkalinity, (4) free of undecomposable materials and toxic metals, (5) not too high in BOD materials, such as carbohydrates, sugar, starch and cellulose and (6) low in oil and grease content.

However, in case that industrial wastes are comparatively little compared to domestic wastewater, process of pretreatment may not necessarily be required because the minor objection of industrial wastes could be eliminated by overwhelming domestic wastewater in treatment plant.

In case of dominant industrial wastes, however, careful consideration on the characteristics of the wastes is required, and adequate measures of the following will be required by implementing either one or all of them according to the degree of the actual needs.

(a) To lengthen the detention time of the wastes on treatment process.

(b) To modify or supplement adequate facilities such as oil skimmer, aerators, final sedimentation tank, sludge return system, etc.

(c) To regulate the effluent quality and quantity of individual factories, which will include, by enacting laws on industrial effluent regulation, (i) control of the amount and concentration of potentially objectionable matters of high BOD and/or SS from the factories and, (ii) removal of harmful wastes such as toxic metals and/or undecomposable matters before discharging into municipal sewers.

4.4.2 Industrial Wastes Treatment of the Project Area

There are two distribution forms of factories within the Project Area, one is those scattered within the area and the other concentrated in group as industrial estates. The results of the industrial wastes survey conducted at the selected representative factories (Ref. Appendix F, "Wastewater Characteristics") are summarized as follows:

(1) Average daily flows from sewerage zones

TABLE III-8 Industrial Wastes Flow from Sewerage Zones

Name of District	No. of Zones	Industrial Wastes* (A)	Domestic Sewage* (B)	Ratio (A):(B)
Butterworth	1	1,600	10,450	1 : 6.5
	3	8,560**	8,520	1 : 1
Seberang Jaya	1	160	10,750	1 : 67
	2	4,000**	5,790	1 : 1.5
Prai	1	85,040**	- ***	-

* unit; cu m/day
Projection in the year 2000

** Industrial Estates including domestic wastes producing in industries

*** Domestic waste is included in Industrial Wastes

(2) The estimated industrial wastewater qualities are:

BOD .... 150 mg/l

SS .... 150 mg/l

(3) Characteristics of the wastes

With assumption that the present industrial wastes produced from food and textile industries will continue with little changes of quality and quantity, and these wastes could be treated by biological process. A few factories in the industrial estates are currently producing objectionable effluent containing heavy metals and/or much floatables. These types of industries may increase in the future and certain consideration may become necessary.

On the basis of the above information, most of the industrial wastes in the Area are assumed to be treated with domestic sewage, and the joint treatment system is feasible. The joint treatment system using stabilization pond is recommended, because of its capability for treatment of both domestic wastes and industrial wastes and also easy maintenance and cheaper cost.

However, careful further observation is required as to the increase of volume and change of characteristics of industrial wastes, particularly those from the industrial estates to take necessary steps to modify the methods of conveyance and treatment in accordance with the measures mentioned in Section 4.4.1 wherever required.

CHAPTER 5

DESIGN BASIS

5.1 Wastewater Volume and Strength

5.1.1 Domestic Sewage

On the basis of the data and discussions in Appendix F, "Wastewater Characteristic", the future domestic sewage flow rates and strengthes are estimated as follows:

TABLE III - 9 Estimated Sewage Volume and Strength

Year	Flow	BOD	SS
1976	170 l/day/cap	37 g/day/cap	37 g/day/cap
1980	182	38	38
1985	194	40	40
1990	206	42	42
1995	218	44	44
2000	230	46	46

Based on the data above, it is estimated that both the average BOD and SS of the sanitary sewage in the year 2000 will be in the range of about 200 mg/l.

For sewer design purposes, the estimated domestic sewage flow rate for the year 2000 is used to project domestic sewage volumes. The capacity for each of the sewer lines is calculated by the projected 2000 year population included in its tributary areas, based on their land use and population density distribution.

5.1.2 Industrial Wastes

On the basis of the data and discussions in Appendix F, the wastewater production in industrial zones is estimated at 80 cu m/day/ha, which will be distributed over the total 1,289 ha of industrial zones to be developed by the year 2000.

As described in Appendix F, wastewater characteristics of different industry groups are estimated. For the master planning purposes, it is assumed that in general the future industrial wastewater will not substantially be different from that of domestic sewage and that the average strength of industrial wastewater to be discharged to public sewers will be 150 mg/l of BOD and SS in the year 2000.

5.1.3 Extraneous Water

For separate sewers, an infiltration allowance is considered. As discussed in Appendix F, 18 cu m/day/km of sewer pipe is considered to be a fair estimate for the extraneous flows to sewers, including groundwater infiltration and surface water inflow from public sewers, house connections, and manhole covers, etc.

5.1.4 Overall Volume

The overall sewage volumes of different stages have been calculated, by adding together the domestic sewage and industrial wastewater, and multiplying by a peaking factor, depending upon the scale of tributary area, and adding the extraneous flow allowance.

5.2 Design of Sewers

For determing sewer capacities, the Manning equation is used for pipes and conduits, flowing full or partially full, with 'n' values of 0.013. For stone masonry, an 'n' value of 0.025 is used. Some important elements to be considered in designing sewer capacity are reviewed in Appendix E, "Design Data".

A minimum size of 225 mm (9 in.) is adopted for sanitary sewers, but for house connection pipes 150 mm may be used.

All sanitary sewers are designed to maintain a mean flow velocity, when flowing full or half-full, of not less than 60 cm/sec (2 ft/sec) for VCP, based on the Manning equation using an 'n' value of 0.013. For RCP or any cement-bonded pipe materials, for an 'n' value of 0.013, a minimum velocity of 75 cm/sec (2.5 ft/sec) is used.

Minimum sewer slopes for different pipe sizes are adopted so that the velocity of flow will be not less than 75 cm/sec (2.5 ft/sec) for cement-bonded pipes, and 60 cm/sec (2 ft/sec) for VCP. The recommended minimum slopes for sanitary sewers are presented in Appendix E, "Design Data".

All sewers are designed not to exceed a velocity of flow of 3 m/sec (10 ft/sec), to protect against sewer erosion. When the ground slope is steep and a velocity may come up to more than 3 m/sec (10 ft/sec), special provision is to be made to protect against displacement by erosion and shock.

For sanitary sewer pipe design, full capacity of the design peak flow rate is provided. When a smaller sewer is connected to a large sewer, the crown of both sewers are to be placed at the same elevation.

Earth covering of sewer pipes is not to be less than one meter (3.3 ft) unless special protection measures against the expected load are provided.

CHAPTER 6

PROPOSED SEWERAGE SYSTEM

6.1 Population of Individual Sewerage District

Area and present population of each sewerage district are described as follows. (Ref. Appendix G, "Sewerage System Consideration")

TABLE III - 10 Butterworth Sewerage District

Zone	Area (ha)	Persons	Persons/ha
Zone - 1	367	37,900	103
Zone - 2	182	3,600	20
Zone - 3	457	28,200	62
Zone - 4	444	26,300	59
Zone - 5	551	4,000	7
Zone - 6	670	8,900	13
Total	2,671	108,900	41 (AV.)

TABLE III - 11 Seberang Jaya Sewerage District

Zone	Area (ha)	Persons	Persons/ha
Zone - 1	438	13,600	31
Zone - 2	305	100	0.2
Zone - 3	510	3,000	6
Zone - 4	430	7,500	11
Zone - 5	368	4,400	12
Total	2,051	28,600	14 (AV.)

TABLE III - 12 Prai Sewerage District

Zone	Area (ha)	Persons	Persons/ha
Zone - 1	1,063	1,900	2
Zone - 2	268	2,000	7
Total	1,331	3,900	3 (AV.)

TABLE III - 13 Bukit Mertajam Sewerage District

Zone	Area (ha)	Persons	Persons/ha
Zone - 1	892	7,600	8
Zone - 2	715	6,400	9
Zone - 3	927	45,500	49
Zone - 4	467	6,100	13
Zone - 5	459	7,300	16
Zone - 6	573	13,800	24
Zone - 7	768	9,900	13
Total	4,801	96,600	20 (AV.)

6.2 Design of Sewerage Facilities

6.2.1 Design of Public Sewer

Recommended sewerage system plan is shown in Figure III-4. This plan is based on data obtained from field surveys conducted under this project and available topographic and other maps. For the areas where the exact locations of the road network are not available, routing of sewers is determined on the basis of the available state plan or other development programmes.

In deciding the capacities of public sewers, the area to be served by each sewer is calculated on the basis of available maps in the scale of 1/7500, 1/10000 and 1/25000. Flows are calculated on the basis of the projected population densities for the year 2000, plus industrial wastes contributions and extraneous flows including groundwater infiltration.

Housing and industrial estate development programmes are currently underway by MPSP and PDC in certain parts of the Project Area, but, for most of these areas the road network plans are still at the preliminary planning stage and another few years will be needed to establish the final plans. Routing of public sewers for these areas, therefore, are planned on the basis of the presently available data, and may be subject to minor changes at the later stage when the final plan is made. Because the relative timing for implementation of some of these development plans and for construction of sewers are still to be decided, coordinated with urban planning including road facilities. Detailed surveys of lines, levels, and grades will be necessary before final design and construction.

All sewers are designed to give mean velocities when flowing full or half-full of not less than 60 cm/sec (2 ft/sec) for VCP, based on the Manning formula using an 'n' value of 0.013, but for RCP or any cement-bonded pipe materials, the minimum design velocity of flow of 75 cm/sec (2.5 ft/sec) is specified, in order to prevent hydrogen sulfide generation and accumulation. Because of the combination of relatively high BOD and temperature anticipated for the sewage to be produced in the Project Area, it is expected that sulfide control will need serious consideration.

Sufficient earth covering is to be left between the top of the sewer and the roadway surface to protect the sewers from traffic loads and to avoid undue interference with other underground facilities, with a minimum earth covering of one meter, except for specific situations where shallower depth is feasible.

6.2.2 Mahhole

Manholes are not indicated on the plans and profiles of the sewers but will be provided at each change in direction, in grade, and in sewer diameter, generally with the following maximum spacings:

TABLE III - 14 Maximum Manhole Spacing

Sewer Diameter (mm)	Maximum Manhole Spacing (m)
300 or less	50
600 or less	80
1,000 or less	100
1,500 or less	150
1,650 or more	200

Except for very shallow sewers, all manholes are planned to have adequate dimensions for entry and for operation of cleaning equipment. The internal size of manholes is 120 cm or more, and they are also designed for future extension of the sewers.

6.2.3 Type and Materials of Sewer

Pipes currently available in Malaysia are limited in sizes and materials. Asbestos-cement, centrifugally-cast reinforced concrete, vitrified clay pipes, and pitch fibre pipes, conforming to internationally accepted standard, are being manufactured (or imported) in Malaysia. The main and submain sewers from 375 mm (15 in.) in diameter are designed on the basis of centrifugally-cast reinforced concrete pipes, but smaller sewers, smaller than 375 mm (15 in.) in diameters, are on the basis of vitrified clay pipes. Where sulfide corrosion is anticipated, the coating or lining centrifugally-cast reinforced concrete pipes may be used.

Because of the resistance to corrosion from acids, alkalies, and virtually all corrosive substances, as well as resistance to erosion and scour, vitrified clay pipes are recommended for smaller sizes up to 300 mm (12 in.) in diameter.

6.2.4 House Connection

Households within areas provided with separate sewer service will be connected with public sewers to discharge their domestic sewage to the sewerage system. These pipes are designed to be not less than 150 mm in diameter, preferably with a slope of more than 2 percent. Materials, joints, and workmanship should be equal to those of the public sewers to minimize infiltration and root penetration. Although layout and profile for these pipes are not prepared for master planning purposes, an average house connection pipe length for individual household is estimated at 15 meters.

6.2.5 Sewer Joint

The sewer joints specified for the Project Area are of rubber ring type for concrete pipes and of the factory applied flexible type for clay pipes.

6.2.6 Pumping Station

Some of general items to be considered in the design of pumping stations are as follows:

(a) Type

Sewage pumping stations are to be principally of the dry-well type, except for small intermediate stations where a dry-well is difficult to provide or where the wet-well type will give satisfactory service.

(b) Design Flow

The design of stations is based on the peak flow of the sewage unless special conditions justify the use of a lower rate. All piping and conduits are also designed to carry the expected peak flow, with some allowances for abnormal sewage increases. Enough storage capacity is to be provided in wells, especially where automatic controls and variable speed drives are not furnished, to balance pumping rates within flow rates.

(c) Structure

Wet and dry wells, including their structures, should be separated. Provision is also to be considered in design to facilitate removing pumps and motors. Suitable and safe means of access are to be provided for dry wells and wet-wells, containing either bar screens or mechanical equipment requiring inspection or maintenance.

(d) Pumps

At least two pumps should be provided for station required. The number of pump is to be determined on the basis of flow quantities and variations. Where possible, pumps should have the same capacity and design, with interchangeable parts. Each should be capable of handling flows in excess of the expected maximum flow. Where three or more units are provided, they should be of such capacity that with one unit out of service, the remaining units will have capacity to handle maximum flows.

In addition to the capacities of pumps, careful consideration is to be given to the selection of a pump having the proper head rating, considering the fluctuations of the water surface of the wet-well and the discharge elevation. Due to restricted diameters, small capacity pumps should always be of the non-clog type.

6.2.7 Sewage Treatment Plant

As already discussed in Chapter 4, "Basic Engineering Consideration", it is considered that stabilization pond process is the most suitable treatment plant to be provided for the Project Area. Some of general items considered in the design of sewage treatment plant are described below:

(a) Design Flow

Capacity of treatment process units shall be determined based on the daily average rate of sewage flow. All piping, conduits and other hydraulic units should be designed to carry the expected peak flow.

(b) Quality of Influent

For design of the treatment process units, the expected sewage quality of the influent shall be estimated in terms of BOD and SS based on evaluation of all types of waste to receive from the contributing areas, including commercial, residential and industrial. Estimated BOD and SS of domestic and industrial wastewater are approximately 200 mg/l and 150 mg/l respectively.

(c) Quality of Effluent

Treatment plant effluents may be discharged into a drain, river and/or directly to the sea. The required degree of treatment shall be based on the capacity of the receiving water to assimilate the wastes.

The condition of the receiving water, rate of flow, existing or potential use of water (fishing, bathing, etc.), and seasonal variations are factors to be considered. Expected BOD of effluent will be less than 50 mg/l.

(d) Construction

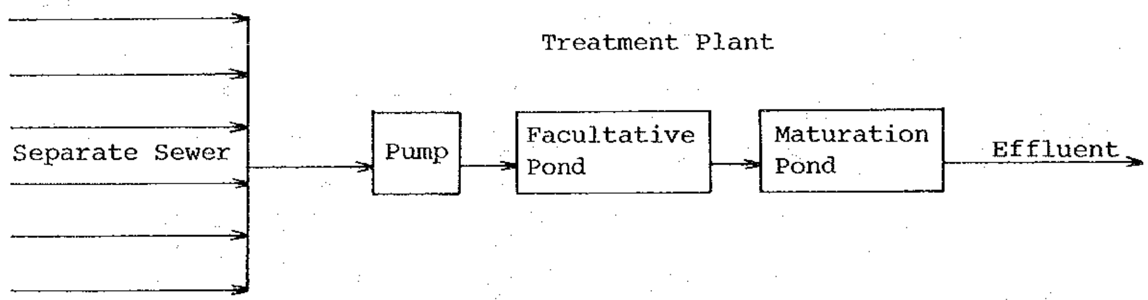
The pond shall be separated into two parts, facultative and maturation ponds, because of their different functions. Each pond shall consist of at least two units depending upon the flow rates, and be constructed in parallel to substitute each other in case of repairing or cleaning.

Ponds will be constructed by excavation and embankment. The embankment of ponds shall be sloped at one horizontal to three vertical and be constructed by impervious material as far as possible and compacted sufficiently to form a stable structure. The pond bottom should be made as flat as possible. The soil formation for the bottom should be relatively impervious to avoid percolation and ground water pollution as far as possible, using either blanket of clayer soil or any other locally available material such as vinyl sheets.

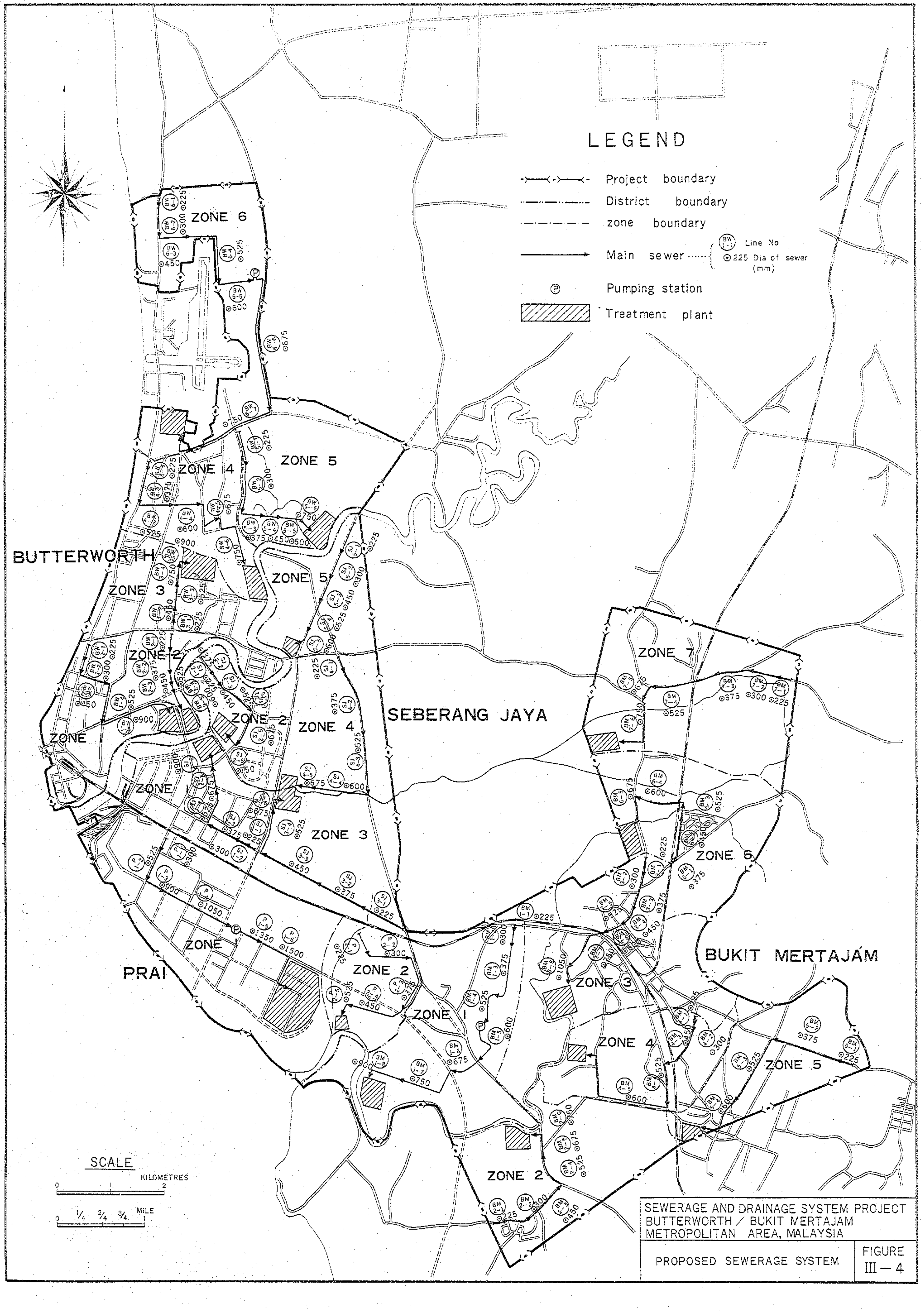
6.3 Recommended Sewerage System

The recommended sewerage system of physical facilities, developed after considering numerous alternatives, comprises pipes sewers flowing by gravity generally following the ground surface slopes in the Area leading the collected sewage to the treatment plants provided at the terminal of each sewerage zone. The recommended sewerage system encompasses; (a) a system of sanitary trunk mains, submains, branch and lateral sewers, and house connections, (b) pumping stations, and (c) sewage treatment plants. The plan of the recommended system is shown in Figure III-4 and the flow diagram of the system is illustrated below:

FIGURE III - 3 Flow diagram of proposed sewerage system



The sewerage programme covers the entire sewerage implementation area of 10,854 ha with an estimated population of 648,000 in the year 2000. The proposed sewerage facilities are listed by sewerage zone in Table III-15.



SEWERAGE AND DRAINAGE SYSTEM PROJECT
BUTTERWORTH / BUKIT MERTAJAM
METROPOLITAN AREA, MALAYSIA

PROPOSED SEWERAGE SYSTEM

FIGURE III-4

TABLE III-15 Proposed Sewerage Facilities

Name of Sewerage Zone	Public Sewer		House Connection		Pumping Station		Treatment Plant		
	Dia. (mm)	Length (m)	Dia. (mm)	Length (m)	Peak flow (cu m/s)	Req'd land Area (sq m)	Process	Average flow (cu m/day)	Req'd land area (ha)
Butterworth, zone-1	225 ∿ 900	92,200	150	110,800			S.P.	15,800	17.6
" 2	" ∿ 600	54,600	"	65,500			"	7,200	8.4
" 3	" ∿ 900	116,800	"	125,700			"	21,500	23.6
" 4	" ∿ 750	133,200	"	111,100			"	13,000	14.6
" 5	" ∿ 750	165,300	"	98,200			"	12,500	14.1
" 6	" ∿ 750	201,000	"	108,000	0.18	100	"	14,100	15.8
Seberang Jaya, zone-1	225 ∿ 900	131,000	"	140,000			"	15,800	17.6
" 2	" ∿ 750	82,000	"	88,700			"	12,900	14.5
" 3	" ∿ 675	153,000	"	76,500			"	10,200	11.6
" 4	" ∿ 675	129,000	"	70,800			"	8,400	9.7
" 5	" ∿ 600	110,400	"	55,200			"	7,400	8.6
Prai, zone-1	225 ∿ 1,500	116,900	"	148,800	0.89	1,540	"	90,400	92.0
" 2	" ∿ 525	80,400	"	40,200			"	5,400	6.4
Bukit Mertajam, zone-1	225 ∿ 900	267,600	"	137,200	0.14	90	"	18,100	20.0
" 2	" ∿ 750	214,500	"	115,200			"	15,000	16.8
" 3	" ∿ 1,050	278,100	"	217,800			"	25,900	28.1
" 4	" ∿ 600	140,100	"	71,900			"	9,500	10.9
" 5	" ∿ 600	137,700	"	68,900			"	9,200	10.5
" 6	" ∿ 675	171,900	"	95,600			"	12,400	14.0
" 7	" ∿ 750	230,400	"	115,200			"	15,300	17.1

NOTE: S.P. means stabilization pond

6.4 Staging of Sewerage Construction

6.4.1 Priorities of Sewerage Zones

The schedule of construction of the sewerage system has been determined based on priorities of each zone in the sewerage districts. In establishing such priorities, an arbitrary rating procedure has been applied by assigning reasonable relative weights to six major controlling parameters as follows:

(1)	Population Density	400
(2)	Waste Load Production Aspect	250
(3)	Excreta Disposal System	150
(4)	Flooding	100
(5)	Availability of Water Supply	50
(6)	Incidence of Water-Borne Diseases	50
	Total	1,000 points

Detailed explanation for each of the elements are described in the following:

(1) Major factor is the improvement of environment for the welfare of the maximum population which will be benefited by the system. It is, therefore, particularly important to provide sewerage facilities in high population density area, in order to gain the maximum benefit with the minimum expenditure, thus making the benefit cost ratio higher. Hence, highest point is assigned for the population density.

(2) Second highest point is assigned to the extent of waste load production. The waste load produced from the housing, commercial and industrial areas are generally discharged into drains and rivers without any treatment except septic tanks, it is necessary to identify quantity of the waste load in each of the sewerage zones to determine the urgency of the need of sewerage facilities.

(3) Since there is no sanitary sewerage system in the Project Area, except a few local systems, practically all of the excreta produced in the area is disposed of either septic tank, bucket, pit privy or directly to waterways, causing water pollution at many places in the Area. The existing excreta disposal system is therefore analyzed as to the present excreta disposal and third highest point is given for the rating.

(4) Although the Government has undertaken improvement works for the existing rivers and drains, flooding has occurred frequently and caused substantial damage in the built-up urban areas. Sanitary conditions in these areas have been significantly deteriorated, which can only be improved by the provision of the sewerage system.

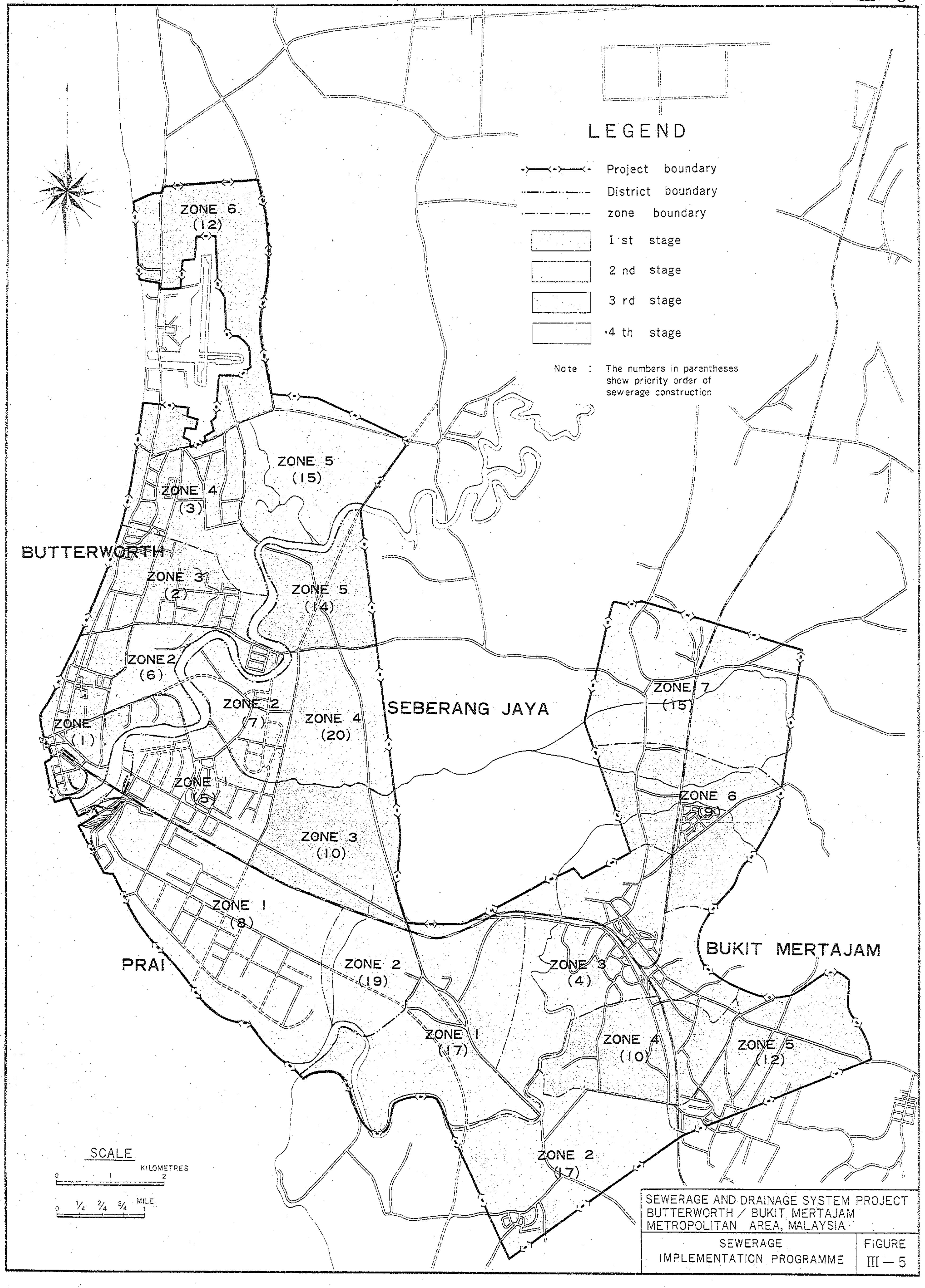
(5) The remaining elements, namely, availability of water supply, and incidence of water-borne diseases, have also effected to sanitation conditions, but these are less critical than the above four elements, and they are given lower points.

The results of the rating system indicate that the zone 1 of Butterworth District has the highest total number of points, representing the combined rating for all the six elements, followed by the zones 3 and 4 of Butterworth, zone 3 of Bukit Mertajam District and so forth as listed below.

TABLE III - 16 Priorities of Sewerage Zones

Priority of Construction	District	Zone	Weighted Points
1	Butterworth	1	865
2	"	3	675
3	"	4	565
4	Bukit Mertajam	3	535
5	Seberang Jaya	1	387
6	Butterworth	2	315
7	Seberang Jaya	2	290
8	Prai	1	265
9	Bukit Mertajam	6	205
10	Seberang Jaya	3	188
10	"	4	188
12	Butterworth	6	186
12	Bukit Mertajam	5	186
14	Seberang Jaya	5	185
15	Butterworth	5	182
15	Bukit Mertajam	7	182
17	"	1	181
17	"	2	181
19	Prai	2	180
20	Seberang Jaya	4	130

The implementation of sewerage construction is proposed to be staged in accordance with the priority determined in this study. However, the zones in which housing and industrial development programme is established, will be nominated in the first implementation programme by the request of government policy. Detailes of the study are described in Appendix H, "Staging of Sewerage Construction" and the priority of each sewerage district and zone is illustrated in Figure III-5.



SEWERAGE AND DRAINAGE SYSTEM PROJECT
BUTTERWORTH / BUKIT MERTAJAM
METROPOLITAN AREA, MALAYSIA

SEWERAGE IMPLEMENTATION PROGRAMME	FIGURE III－5

6.4.2 Staging of Programme

As the first step for determining the staging of sewerage construction, the possible alternatives on construction components and duration of time are considered for each stage.(Ref. Appendix G, "Sewerage System Consideration", and Appendix H, "Staging of Sewerage Construction") From these studies, the most feasible alternative sewerage construction programme is identified with due consideration on the components of the programme.

It is appropriate to divide the entire sewerage programme into four consentive stages up to the year 2000 on the basis of the priorities of zones determined, magnitude of investment and size of the component works.

(1) First Stage Programme (1981 to 1985)

It is proposed that the four highest priorities of zones, zones 1, 3 and 4 of Butterworth, and zone 3 of Bukit Mertajam, be taken up in the first stage programme. The component of works will include (a) public sewers (main, branch and lateral sewers) of 620 km, (b) house connections, and (c) four sewage treatment plants. Implementation of this stage is recommenced to start in 1981, ending by 1985. When this stage is completed, 193,700 persons within a total area of 2,195 hectares will be served by the system in the year 1985.

Areas and population to be served in this stage are as follows:

TABLE III - 17 Proposed First Stage Area

Name of Zone	Area Served (ha)	Population (persons in 2000)
Butterworth, Zone-1	367	45,500
" "	457	37,000
" " -4	444	37,500
Bukit Mertajam, Zone-3	927	73,700
Total	2,195	193,700

(2) Second Stage Programme (1986 to 1990)

With the completion of the sewage collection and disposal systems scheduled for the proposed first stage, it is proposed to set the years between 1986 to 1990 as the second stage programme based on the current projection of development. The sewerage system to be constructed during this stage includes public sewers (main, branch and lateral sewers) of 385 km, house connections, and treatment plant for zone 2 of Butterworth and zones 1 and 2 of Seberang Jaya, and zone 1 of Prai (with a pumping station). When this tage is completed, additional 93,800 persons within a total area of 1,988 hectares will be served by the system. Areas and population to be served in this stage are as follows:

TABLE III - 18 Proposed Second Stage Area

Name of Zone	Area Served (ha)	Population (persons in 2000)
Butterworth, Zone-2	182	21,800
Seberang Jaya, Zone-1	438	46,800
" " -2	305	25,200
Prai, Zone-1	1,063	
Total	1,988	93,800

(3) Third Stage Programme (1991 to 1995)

The sewerage system components to be constructed during this stage include public sewers (main, branch and lateral sewers) of 910 km, house connections and treatment plant, for zone 6 (with a pumping station) of Butterworth, zones 3 and 5 of Seberang Jaya, and zones 4, 5 and 6 of Bukit Mertajam. When this stage is completed, additional 164,700 persons within a total area of 3,047 hectares will be served by the system.

TABLE III - 19 Proposed Third Stage Area

Name of Zone	Area Served (ha)	Population (persons in 2000)
Butterworth Zone-6	670	37,300
Seberang Jaya, Zone-3	510	26,500
" " -5	368	19,200
Bukit Mertajam, Zone-4	467	24,900
" " -5	459	23,900
" " -6	573	32,900
Total	3,047	164,700

(4) Fourth Stage Programme (1996 to 2000)

By the year 2000, work can be completed on the entire sewerage implementation area, covering a total area of 10,854 hectares with a total served population of 648,000. This stage includes construction of sewers, pumping station, and treatment plants in the remaining portions of the entire Project Area, covering totally 3,624 hectares. Areas to be served by the system in this period are:

TABLE III - 20 Proposed Fourth Stage Area

Name of Zone	Area Served (ha)	Population (persons in 2000)
Butterworth, Zone-5	551	33,700
Beberang Jaya, Zone-4	430	20,800
Prai, Zone-2	268	14,000
Bukit Mertajam, Zone-1	892	47,500
" -2	715	39,800
" -7	768	40,000
Total	3,624	195,800

CHAPTER 7

CONSTRUCTION AND MAINTENANCE COSTS

7.1 Construction Costs

7.1.1 Public Sewers

(a) Main Sewers

All construction costs for the recommended main sewer are estimated on the basis of the procedures described in Appendix G, "Sewerage System Consideration". Construction costs for each size of sewer pipe are derived from unit construction costs which correspond to the designed sewer depth. All costs are expressed at 1976 price levels.

(b) Branch and Lateral Sewers

For estimating construction costs of branch and lateral sewers, the total lengths of these sewers by size are obtained, using per unit area sewer lengths of the different sewer size developed from the selected new housing schemes that are representative for the averaged condition in the Area. Then, the construction costs for all the sewer sizes are estimated, multiplying the lengths by the unit costs.

7.1.2 House Connections

For cost estimation of house connections it is assumed that each household has a total of 15 meters pipe, and then the total length of these pipes are calculated taking into account of the population served and the average size of family in each of the sewerage districts under considerations.

The average construction cost for house connection is estimated at 30 M$ per meter.

7.1.3 Pumping Stations

Three pumping stations are to be provided at Butterworth (zone-6) in the third stage, at Prai (zone-1) in the second stage, and at Bukit Mertajam (zone-1) in the fourth stage, to lift the sewage and convey it to the treatment plants.

All construction costs for these stations are estimated on the basis of the unit costs developed for buildings and equipment, assuming that most of equipment including pumps, controlling devices, electric facilities, screening and grit removal facilities, gates and piping materials will be imported, but materials for building and civil works will be available in Malaysia.

7.1.4 Sewage Treatment Plants

All construction costs for treatment plants are derived on the basis of the unit cost developed each for civil works and equipment, assuming that most of equipment, including pumps, flow measuring devices, electric facilities, aerators, and others will be imported, but materials for civil works will be available in Malaysia.

7.1.5 Construction Costs by Stage

The estimated construction costs for the sewerage system by stage are summarized in Tables III-21 to III-28.

Table III-21 Summary of Sewerage Construction Costs for First Stage Programme with 1985 Completion (Government Contribution)

(In thousand of M$ at 1976 Price Level)

Description	Local Currency	Foreign Currency	Total Cost	Remarks
a. Public Sewers (main)	25,980	6,500	32,480	
b. Pumping Stations	-	-	-	
c. Treatment Plants	7,890	1,970	9,860	
d. Land Acquisition	5,590	-	5,590	
(A) Sub-Total	39,460	8,470	47,930	
(B) Contingency	7,890	1,690	9,580	(A) x 0.20
(C) Engineering Fee				
Design	1,720	1,150	2,870	(A+B) x 0.05
Supervision	1,720	1,150	2,870	(A+B) x 0.05
Total	50,790	12,460	63,250	

Note: Twenty percent of construction cost and 40 percent of engineering fee are estimated as foreign currency.

TABLE III-22 Summary of Sewerage Construction Costs for First Stage Programme with 1985 Completion (Private Contribution)

(In thousand of M$ at 1976 Price Level)

Description	Local Currency	Foreign Currency	Total Cost	Remarks
a. Branch & Lateral Sewers	47,530	11,880	59,410	
b. House Connections	13,560	3,390	16,950	
(A) Sub-Total	61,090	15,270	76,360	
(B) Contingency	12,220	3,050	15,270	(A) x 0.20
(C) Engineering Fee				
Design	4,580	-	4,580	(A+B) x 0.05
Supervision	4,580	-	4,580	(A+B) x 0.05
Total	82,470	18,320	100,790	

Note: Twenty percent of construction cost is estimated as foreign currency, and no foreign currency is estimated for engineering fee.

TABLE III-23 Summary of Sewerage Construction Costs for Second Stage Programme with 1990 Completion (Government Contribution)

(In thousand of M$ at 1976 Price Level)

Description	Local Currency	Foreign Currency	Total Cost	Remarks
a. Public Sewers (main)	27,610	6,900	34,510	
b. Pumping Stations	3,800	950	4,750	
c. Treatment Plants	17,180	4,290	21,470	
d. Land Acquisition	27,800	-	27,800	
(A) Sub-Total	76,390	12,140	88,530	
(B) Contingency	15,270	2,430	17,700	(A) x 0.20
(C) Engineering Fee				
Design	3,190	2,120	5,310	(A+B) x 0.05
Supervision	3,190	2,120	5,310	(A+B) x 0.05
Total	98,040	18,810	116,850	

Note: Twenty percent of construction cost and 40 percent of engineering fee are estimated as foreign currency.

TABLE III-24 Summary of Sewerage Construction Costs for Second Stage Programme with 1990 Completion (Private Contribution)

(In thousand of M$ at 1976 Price Level)

Description	Local Currency	Foreign Currency	Total Cost	Remarks
a. Branch & Lateral Sewers	20,540	5,130	25,670	
b. House Connections	10,630	2,660	13,290	
(A) Sub-Total	31,170	7,790	38,960	
(B) Contingency	6,230	1,560	7,790	(A) x 0.20
(C) Engineering Fee				
Design	2,330	-	2,330	(A+B) x 0.05
Supervision	2,330	-	2,330	(A+B) x 0.05
Total	42,060	9,350	51,410	

Note: Twenty percent of construction cost is estimated as foreign currency, and no foreign currency is estimated for engineering fee.

TABLE III-25 Summary of Sewerage Construction Costs for Third Stage Programme with 1995 Completion (Government Contribution)

(In thousand of M$ at 1976 Price Level)

Description	Local Currency	Foreign Currency	Total Cost	Remarks
a. Public Sewers (main)	37,600	9,400	47,000	
b. Pumping Stations	180	50	230	
c. Treatment Plants	6,880	1,720	8,600	
d. Land Acquisition	8,810	-	8,810	
(A) Sub-Total	53,470	11,170	64,640	
(B) Contingency	10,690	2,230	12,920	(A) x 0.20
(C) Engineering Fee				
Design	2,320	1,550	3,870	(A+B) x 0.05
Supervision	2,320	1,550	3,870	(A+B) x 0.05
Total	68,800	16,500	85,300	

Note: Twenty percent of construction cost and 40 percent of engineering fee are estimated as foreign currency.

TABLE III-26 Summary of Sewerage Construction Costs for Third Stage Programme with 1995 Completion (Private Contribution)

(In thousand of M$ at 1976 Price Level)

Description	Local Currency	Foreign Currency	Total Cost	Remarks
a. Branch & Lateral Sewers	71,660	17,920	89,580	
b. House Connections	11,440	2,860	14,300	
(A) Sub-Total	83,100	20,780	103,880	
(B) Contingency	16,620	4,150	20,770	(A) x 0.20
(C) Engineering Fee				
Design	6,230	-	6,230	(A+B) x 0.05
Supervision	6,230	-	6,230	(A+B) x 0.05
Total	112,180	24,930	137,110	

Note: Twenty percent of construction cost is estimated as foreign currency, and no foreign currency is estimated for engineering fee.

TABLE III-27 Summary of Sewerage Construction Costs for Fourth Stage Programme with 2000 Completion (Government Contribution)

(In thousand of M$ at 1976 Price Level)

Description	Local Currency	Foreign Currency	Total Cost	Remarks
a. Public Sewers (main)	41,520	10,380	51,900	
b. Pumping Stations	160	40	200	
c. Treatment Plants	8,020	2,000	10,020	
d. Land Acquisition	3,200	-	3,200	
(A) Sub-Total	52,900	12,420	65,320	
(B) Contengency	10,580	2,480	13,060	(A) x 0.20
(C) Engineering Fee				
Design	2,350	1,560	3,910	(A+B) x 0.05
Supervision	2,350	1,560	3,910	(A+B) x 0.05
Total	68,180	18,020	86,200	

Note: Twenty percent of construction cost and 40 percent of engineering fee are estimated as foreign currency.

TABLE III-28 Summary of Sewerage Construction Costs for Fourth Stage Programme with 2000 Completion (Private Contribution)

(In thousand of M$ at 1976 Price Level)

Description	Local Currency	Foreign Currency	Total Cost	Remarks
a. Branch & Lateral Sewers	85,230	21,310	106,540	
b. House Connections	13,850	3,460	17,310	
(A) Sub-Total	99,080	24,770	123,850	
(B) Contingency	19,820	4,950	24,770	(A) x 0.20
(C) Engineering Fee				
Design	7,430	-	7,430	(A+B) x 0.05
Supervision	7,430	-	7,430	(A+B) x 0.05
Total	133,760	29,720	163,480	

Note: Twenty percent of construction cost is estimated as foreign currency, and no foreign currency is estimated for engineering fee.

7.2 Maintenance Costs

7.2.1 Sewers

Maintenance costs for sewer pipes are derived from data obtained both in Malaysia and Japan, assuming that all sewers will be cleaned at least every four years by use of thrusting rods and/or bucket machines. (For detail, see Appendix G, "Sewerage System Consideration")

7.2.2 Pumping Stations

Operation and maintenance costs for pumping stations are derived from the current labour and material costs in Penang State, including power, fuel, water for cooling and sealing, lubrication, grit and screening removals, and minor repair of equipment. Needs for the operation and maintenance are estimated on the basis of daily average flow rates. These are also discussed in detail in Appendix G, "Sewerage System Consideration".

7.2.3 Treatment Plants

Operation and maintenance costs for treatment plants are derived from the current labour and material costs in Penang State, including power, water for cooling and sealing, lubrication, and minor repair of equipment. Estimated operation and maintenance costs for treatment plants are given in detail in Appendix G, "Sewerage System Consideration".

7.2.4 Operation and Maintenance Costs by Stage

Estimated sewerage operation and maintenance costs by stage are shown in Table III-29.

TABLE III-29 Sewerage Operation and Maintenance Costs for Incremental Stage

(In thousand of M$ per annum at 1976 Price Level)

Description	Stage	1st Stage	2nd Stage	3rd Stage	4th Stage
Public Portion*	a. Main Sewers	330	350	470	560
	b. Branch & Lateral Sewers	720	310	1,080	1,300
	c. Pumping Stations	-	110	30	20
	d. Treatment Plants	250	310	260	270
	Total	1,300	1,080	1,840	2,150
Private Portion	House Connections	400	310	340	410
	Total	400	310	340	410

Note: * Operation and maintenance cost for branch and lateral sewers are included in public portion.

CHAPTER 8

BENEFITS

8.1 Anticipated Benefits

Significant benefits to public health of the community can be derived from installation of an adequate sewerage system in the sewerage implementation area. The benefits to be derived from the construction and operation of the recommended sewerage system can be grouped into several categories, namely (1) health benefits, (2) environmental benefits, (3) economic benefits, and (4) general benefits.

All anticipated benefits have been evaluated for the sewerage project on the basis of either quantifiable or nonquantifiable benefits.

8.2 Recognition and Measurement of Benefits

Associated benefits through a more pleasant community environment, greater potential for tourism, opportunity for more intensive land use, and opportunities to facilitate housing and industrial construction, together with a cause of other less tangible benefits have been identified.

Major benefits resulting from the improvement of health conditions, environmental aspect, and from increases in land values, are quantified as follows.

8.2.1 Health and Sanitation Benefits

The major benefit from the proposed sewerage system will be the sanitation improvement resulting from removal of human excreta and other wastes from the community.

Anticipated benefit resulting from the sewerage system can be measured if the cause and effect relationship of the sewerage system to incidence of the water-borne diseases and to the levels of mortality and morbidity of the populations served by the system, are determined, and if reduction of pertinent diseases are estimated on the basis of reasonable assumptions.

A statistical data prepared by MHD indicates that the number of gastro-entritic disease cases in the Project Area is 81 per year by an average occurred from the year 1970 to 1975. Also, a survey on the cost for treatment of the diseases under the present Project in 1976 indicates that expenses for treating water-borne diseases, including amounts spent for medical care, cost about M$27 per person per day for an average of two weeks hospitalization. To estimate the benefit to be derived from the sewerage system, it is assumed that approximately 50 percent of these is attributable to unsatisfactory excreta disposal, and if this can be eliminated by the sewerage system, then this represents a quantifiable cost of about M$15,000 per year (81/2 x 27M$ x 14 days).

The main elements of indirect cost can also be calculated assuming the average wage lost and the number of man-days lost due to disability. The wage lost is estimated to be about M$1,500 per year on an average at 1976 price levels, assuming from the data collected that the average income of labour participation group is M$250 per person per month. This is on the basis of assumption that the incidence and age distribution of diseases to be affected for assumption of wage loss will be limited to the labour force, which is approximately 47 percent of the total population, excluding unemployment factor. (Ref. Appendix A,"Economy")

In addition, other benefits, although mostly unquantifiable, are expected, including (1) reduction of discomfort and distress, (2) improvements in environmental aesthetics from elimination of the present sewage odours emanating from drains and sludge accumulation, (3) reduction of groundwater contamination resulting from improved measures for handling sanitary wastes.

8.2.2 Water Pollution Control Benefits

From the extensive investigation to the drains and rivers under the present project (Ref. Appendix D), most of drains in urbanized area of the Project Area have been polluted and are expected to become much more polluted in the future. Also rivers will be polluted from the drain flows. Currently, these drain and river waters are used for the purpose of irrigation, fishing, etc.

The reduction of waste loads or improvement of water quality in the drains and rivers is therefore the major benefit to be derived from the sewerage system. Waste loads in sewered areas will be reduced considerably through the treatment plant and will improve the river water qualities which will make the river water available as new water resources for various purposes.

8.2.3 Values Added to Land

Investment in sewerage facilities will have the effect of raising the intrinsic values of the parcels of land served by the system. These additional land values constitute a major economic benefit of the project in that, by improving the sanitary and aesthetic quality of the community, they not only contribute to the quality of life of the residents, but also as additional source of taxation for the revenue in favour of government authorities. The value of such benefit is measured by the additional price observed in the areas where similar projects have been carried out, that buyers are willing to pay for properties on which such physical improvements have been made.

On the basis of the data obtained at project site during 1976, the present land value in sewerage implementation areas is rated to an average of M$8 per sq meter by the categories of land use employed (i.e. social and commercial area of 85 ha, residentail area of 913 ha, industrial area of 85 ha, residential area of 913 ha, industrial area of 844 ha, rural area (kampong) of 3,484 ha, and agricultural and non-habitable area of 6,274 ha). It was also obtained that, prior to any development programme the cost were M$1.5 per sq meter for agricultural and non-habitable areas such as mountain, M$3.0 per sq meter for areas slightly inhabited or rural areas, and M$54 and M$22 per sq meter for built-up urban area and developed industrial area respectively. Hence, before improvement by development programme, land value of the whole area is estimated to be M$928 million at 1976 price level.

After the Project Area is improved by development programme based on the land use envisaged by the year 2000 (Ref. Appendix B), the land value would be increased to an average of M$15 per sq meter. Then, land value for the whole area is estimated to increase to M$1,740 million.

For evaluation of the benefit derived from the increase in land values, it is assumed that 20 percent of land value increased is attributed by the construction of sewerage system, then quantifiable cost is estimated to be approximately M$162 million at 1976 price level [(1740-928) x 0.2)].

8.2.4 Other Economic Benefits

In the Project Area, there are many development programmes including housing and industrial development. Although the exact construction schedules for these programmes are not yet firmly decided, if it is implemented during the same period as overall project of sewerage provision, the cost for constructing septic tank will be avoided. Table III-30 shows a comparison of septic tank and sewage treatment plant as recommended in the Master Plan, including cost of construction, maintenance and operation. It is clear from the table that the cost of septic tank is higher than that of sewerage, and further the septic tank is only to receive human excreta (W.C.) and do nothing to resolve the problems of contaminated sullage on industrial wastes water. Thus, the provision of the sewerage system, consisting of sanitary sewer and treatment plant, would be of benefit to the individual expenditure in comparison with other sanitary system such as septic tank.

TABLE III-30 Cost Comparison of Alternative Sewage Treatment Plant

Alternatives	Construction Costs (M$ per Capita)	Maintenance/Operation Cost (M$ per year per Capita)
*Septic Tank (with filtration)	166	8.5
Recommended Sewage Treatment Plant	53.8	0.8

Note: * Data obtained from MPSP. Septic tanks receive human excreta only. No cost for sewer is included in this comparison.

8.3 Benefit Justification

On the basis of the results of evaluations of benefits by the proposed sewerage system for the Project Area, both tangible and intangible, it is concluded that the Project is definitely justifiable. If no sewerage system were provided in the areas, sanitary conditions, which are already deplorable in many areas of the city, will become progressively worse. Moreover, if this Project is not undertaken at this time, the cost for implementation at later times will become increasingly higher. Thus the accumulated total cost could become so high that Project could become almost unmanageable. The Project therefore is indeed timely now.

PART IV

DRAINAGE MASTER PLAN

CHAPTER 1

AREA COVERED BY DRAINAGE PROGRAMME

1.1 Classification of Area

The Project Area concerned for consideration of the drainage systems proposed under this Project is identical to that for the sewerage system covering the area of 11,600 hectares inclusive of river surface, and nonhabitable mountainous portions higher than RL + 60 meters (+200 ft).

However, for planning drainage capacity, it is necessary to consider the catchment areas, into which stormwater inflows from outside of the Project Area due to topographical condition. The total area of these contributing areas is estimated to be 4,290 hectares (10,600 acres). But in drainage master plan no facilities will be planned in these areas.

Thus, the area concerned to drainage system planning is estimated as summarized below:

The Project Area	11,600 ha	(28,660 acres)
Contributing Area	4,290 "	(10,600 ")
Total	15,890 "	(39,260 ")

On the other hand, two development areas, Prai and Seberang Jaya, are not considered for drainage master planning purposes, because these two areas have already been served by existing drainage system. Since they form independent drainage areas, they can be excluded from the drainage master planning.

Further, nonhabitable areas, including river surface and mountain zone, are to be excluded from the planning and cost estimation. They are:

Prai and Seberang Jaya	980 ha	(2,422 acres)
Nonhabitable area	746 "	(1,843 ")
Total	1,726 "	(4,265 ")

Finally, the area to be taken by drainage system under this Project is; 15,890 - (4,290 + 1,726) = 9,874 ha (24,398 acres).

1.2 Drainage Basins

Considering existing waterways, natural and artificial, and general feature of land use, the proposed concept of drainage basins in the Assignment Report of WHO is considered to be reasonable, and therefore the Project Area is divided into six drainage basins as proposed in the Report, as shown in Figure IV-1. Table IV-1 shows the areas of individual drainage basin, with contributing areas (areas inflowing from outside of the Area) and nonhabitable areas.

TABLE IV-1 Area in Individual Drainage Basin

Name of Drainage Basin	Area to be served by Drainage System	Area excluded from the Project	Sub-Total	Area contributing from outside of the Project Area	Total
B-I	980	93	1,073	55	1,128
B-II	3,591	202	3,793	1,669	5,462
B-III	2,632	1,332	3,964	993	4,957
B-IV	1,576	80	1,656	42	1,698
B-V	551	19	570	1,063	1,633
B-VI	544	0	544	468	1,012
Total	9,874	1,726	11,600	4,290	15,890

1.3 Design Master Plan and Preventative Master Plan

In accordance with the Terms of Reference for drainage master plan, the area covered by drainage programme is classified into two types, one for Design Master Plan area and Preventative Master Plan area. These are defined as follows:

(a) Design Master Plan (DMP)

This plan covers the built-up areas. Its objective is to prepare comprehensive long-range plan for the solution of existing drainage problems in the built-up areas.

(b) Preventative Master Plan (PMP)

The objective of this plan is to prepare drainage strategies to prevent drainage problems from occuring with future urban development of the land.

Figures IV-2 and 3 show the main drains. The main drains studied under DMP are RAM. 5, 6, ARA. 1 - 3, TAN., PAY. 1, 2, BUK. 1, 2, PAS 1 - 3, PEK. 1 - 3, BKC and BKD(*1) in Basin II and all main drains in Basin IV.

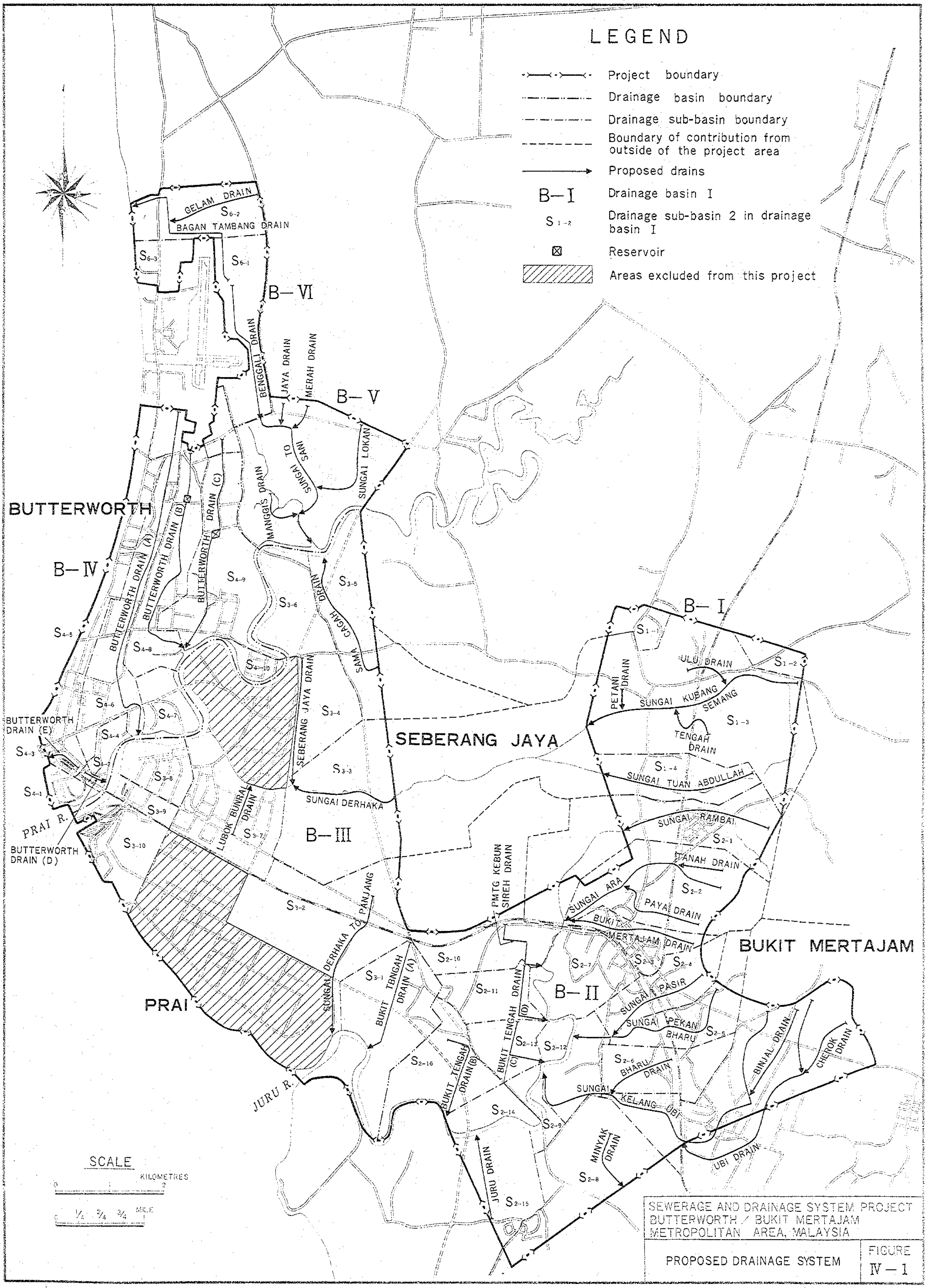
All remaining main drains are discussed under PMP, because they are located in the undeveloped areas or the vicinity of urbanized areas, in which the land spaces necessary for future drainage strategy are still available and the requirement for improvement of drainage situation is not imminent.

(*1) These abbreviations are tabulated in Table IV-2.

TABLE IV-2 Abbreviation of Name of Drains

Basin	Name of Drain	Abbreviation
I	Sungai Kubang Semang	KUB
	Ulu Drain	ULU
	Tengah Drain	TEN
	Petani Drain	PET
	Sungai Tuan Abdullah	TUA
II	Sungai Rambai	RAM
	Sungai Ara	ARA
	Tanah Drain	TAN
	Paya Drain	PAY
	Bukit Mertajam Drain	BUK
	Sungai Pasir	PAS
	Sungai Pekan Bharu	PEK
	Sungai Kelang Ubi	KEL
	Binjal Drain	BIN
	Ubi Drain	UBI
	Cherok Drain	CHE
	Bharu Drain	BHA
	Minyak Drain	MIN
	Pmtg Kebun Siren Drain	PMT
	Bukit Tengah Drain (B)	BKB
	Bukit Tengah Drain (C)	BKC
	Bukit Tengah Drain (D)	BKD
	Juru Drain	JUR
III	Bukit Tengah Drain (A)	BKA
	Sungai Derhaka To Panjang	DEJ
	Sungai Derhaka	DER
	Seberang Jaya Drain	SEB
	Lubok Bunral Drain	LUB
	Sama Cagah Drain	SAM
IV	Butterworth Drain (A)	BWA
	" (B)	BWB
	" (C)	BWC
	" (D)	BWD
	" (E)	BWE
V	Sungai To Sani	SAN
	Jaya Drain	JAY
	Merah Drain	MER
	Sungai Lokan	LOK
	Manggis Drain	MAN
VI	Benggali Drain	BEN
	Bagan Tambang Drain	BAG
	Gelam Drain	GEL

FIGURE Ⅳ−1



LEGEND
Project boundary
Drainage basin boundary
Drainage sub-basin boundary
Boundary of contribution from outside of the project area
Proposed drains
B−I Drainage basin I
S 1-2 Drainage sub-basin 2 in drainage basin I
Reservoir
Areas excluded from this project
BUTTERWORTH
SEBERANG JAYA
BUKIT MERTAJAM
PRAI
B−I
B−II
B−III
B−IV
B−V
B−VI
GELAM DRAIN
BAGAN TAMBANG DRAIN
BENGGALI DRAIN
JAYA DRAIN
MERAH DRAIN
SUNGAI TO SANI
SUNGAI LOKAN
MANGGIS DRAIN
BUTTERWORTH DRAIN (A)
BUTTERWORTH DRAIN (B)
BUTTERWORTH DRAIN (C)
BUTTERWORTH DRAIN (D)
BUTTERWORTH DRAIN (E)
SAMA CAGAH DRAIN
SEBERANG JAYA DRAIN
SUNGAI DERHAKA
LUBOK BUNRAL DRAIN
SUNGAI DERHAKA TO PANJANG
PRAI R.
JURU R.
ULU DRAIN
PETANI DRAIN
SUNGAI KUBANG SEMANG
TENGAH DRAIN
SUNGAI TUAN ABDULLAH
SUNGAI RAMBAI
TANAH DRAIN
SUNGAI ARA
PAYA DRAIN
BUKIT MERTAJAM DRAIN
PMTG KEBUN SIREH DRAIN
SUNGAI PASIR
SUNGAI PEKAN BHARU
BHARU DRAIN
SUNGAI KELANG UBI
UBI DRAIN
BINJAL DRAIN
CHEROK DRAIN
MINYAK DRAIN
JURU DRAIN
BUKIT TENGAH DRAIN (A)
BUKIT TENGAH DRAIN (B)
BUKIT TENGAH DRAIN (C)
BUKIT TENGAH DRAIN (D)
S1-1 S1-2 S1-3 S1-4
S2-1 S2-2 S2-3 S2-4 S2-5 S2-6 S2-7 S2-8 S2-9 S2-10 S2-11 S2-12 S2-13 S2-14 S2-15 S2-16
S3-1 S3-2 S3-3 S3-4 S3-5 S3-6 S3-7 S3-8 S3-9 S3-10
S4-1 S4-2 S4-3 S4-4 S4-5 S4-6 S4-7 S4-8 S4-9 S4-10
S6-1 S6-2 S6-3
SCALE
KILOMETRES
MILE
SEWERAGE AND DRAINAGE SYSTEM PROJECT
BUTTERWORTH / BUKIT MERTAJAM
METROPOLITAN AREA, MALAYSIA
PROPOSED DRAINAGE SYSTEM
FIGURE Ⅳ−1

CHAPTER 2

BASIC ENGINEERING CONSIDERATION

It is necessary to find technically and economically feasible means for alleviating flooding in the Area. Most of the existing built-up areas are served by concrete-lined road side drains and trapezoidal main drains, either lined or unlined. Many of those main drains are heavily silted and the capacity is reduced, thus causing frequent flooding in many places throughout the area. Predominant topographical features in the Project Area are flatness and low ground elevation, and the rivers and drains are affected by the tide, causing flooding at some parts of the area due to the back-up of the river and/or sea waters.

In view of the present situations mentioned above, it is considered that solutions to the flood problems in the Project Area may include:

(a) Improvement of existing drains and/or provision of new drains for reinforcing collection and conveyance systems of stormwaters.

(b) Storage of stormwaters in assigned area for alleviating flood in downstream areas.

(c) Shutting out the back water by gates or levees, and where necessary, draining off the stormwater runoff to the rivers by means of pumps during the period of high water levels in the rivers.

(d) Raising of ground elevations by land filling.

2.1 Reinforcement of Collection and Conveyance Systems for Stormwaters

In considerable part of the Project Area, the lack of drains is the main cause of flooding, and stormwater runoff can not find its way to rivers and other waterways. The existing drains are in many cases inadequate to accomodate the runoffs from heavy rain storm. The basic work to be implemented urgently to alleviate floods in the Project Area includes therefore improvement of existing inadequate facilities and provision of new drains in the area where flooding occur frequently. This works are required most urgently and should be included in the 1st stage programme of the Master Plan.

2.2 Storage of Stormwaters for Alleviating Flood in Downstream Areas

To store stormwaters is one of the most effective means to reduce the peak stormwater runoff, but it requires generally considerable land spaces. This facility should be considered therefore for the areas presently undeveloped within which enough land space is still available. Even when some development is applied in such undeveloped areas in the future, the concept of storing stormwaters to limit the discharge to downstream and eliminate the major flood damages should also be adopted. Storage of stormwaters would be able to reduce the cost for improvement of drainage system downstream generally requires due to development in upstream areas. In the Project Area, except some built-up urbanized portion, the land is relatively easily available, and the storage of runoff is the preferable measure for the Project Area.

The storage capacity can be calculated on the basis of following guideline which are applied by the DID:

(a) Allowable amount of stormwater runoff from the area under consideration should be that is equivalent to the amount of runoff caused from 2-yr rainfall frequency storm with 0.35 runoff coefficient. The amount of the runoff beyond that amount will have to be stored in retention reservoir with the capacity to cope with the stormwater discharge resulted from 100-yr frequency storm, with runoff coefficient of 0.65.

(b) In areas within which enough land space for reservoir is not available, the storage capacity may have to be adjusted from those mentioned in (a), depending upon the local conditions. However, as much as possible capacity has to be provided utilizing the available land space to the maximum extent.

2.3 Pumped Drainage System

Cutting off back water effect from rivers or the sea by providing levees or gates, and lifting stormwater runoff within closed areas by pumps are the effective counter measures to alleviate the flooding.

One of the major factors which has to be taken for the pump provision is the frequency of pump operation. For lower areas wherein flood occurs frequently due to the back-up water, provision of pumps will be warranted because the pumps will be effectively used, however, for the areas pumps will not be used so often, provision of pump station would not be economically feasible.

Construction of pumping station may require considerable amount of initial investment, including procurement of equipment and their spare parts. Besides, careful operation and maintenance service would also be essential for maintaining proper function of station.

If pumped drainage system is selected, the planning and projection of the power requirements of the pumping stations by the National Electricity Board should be considered too.

In view of these evident disadvantages of pumped drainage system, the provision of pumps for drainage system should be avoided as much as possible.

2.4 Raising of Ground Elevation by Land Filling

Land filling has been most commonly applied for housing development programmes in the Project Area through its history. Although it requires considerable initial costs, once land has been reclaimed, no maintenance works and accruing costs are expected thereafter. If fund is available and wherever the topography warrants, land filling is the most effective measure for alleviating floods, provided necessary consideration will be given to control the discharge rate from the area for preventing adverse effect to downstream areas.

Estimated elevation for the land reclamation is RL +2.30 meters (+7.5 ft) in the tributaries of the Prai and Juru river. (Ref. Appendix J, "Drainage System Consideration")

CHAPTER 3

DESIGN BASIS

3.1 Open Channel vs. Closed Conduit

Existing drains in the Project Area are mostly of open channels, which have considerable advantages over closed conduits, including the easeness of maintenance, elimination of hazardous problems relating to manholes, shallow excavation required, and the fact that road kerbs and gullys are not necessary to accept runoff from roads. In addition, the shallow construction requirement would minimize the crossings with sewer pipes in case of the separate system, as recommended for the Project. The major disadvantage, on the other hand, is that residents can easily access to the dispose of refuse into drains resulting in blockages many places. This disadvantage should be dealt with, although it would take time, by an educational campaign for cleanliness of environment to prohibit the disposal of refuse into open channels. Anti-litter campaign is now intensively underway by the Government, and this will help to maintain the existing drains thus making open channels free from clogging.

The advantage of closed conduits is that the conduits conserve spaces for road and other utilities, especially in the highly developed areas closed conduits have an advantage. However, the areas for the proposed drainage are mostly those where the stage of development does not warrant underground closed conduits. Even in case of open channels, spaces for other utilities can be provided by covering them when such are needed.

On the basis of the reasons above, basically, open channel will be used in the Project Area.

3.2 Survey Datum

The reference data used in this Report is Malaysian Survey Ordinance Datum, of which the zero point is mean sea level (1912 determination).

The ground elevation used in this Report is expressed as reduced level (RL) which has the same zero point with survey ordinance datum. The sea level as a design basis of this Project is determined on the basis of records during 1952 - 1967. The applied figures, described below, are also quoted in the "Project Report on Drainage and Reclamation of Sungai Prai Basin". The above report has various relations with the drainage plan in the Project Area, and it is considered that the use of the same design sea level will be preferable. The applied sea level used in the present document is shown below:

HHWL (highest recorded level)	SOD +1.68 m (+5.5 ft)
MHWL (spring tide)	" +1.10 m (+3.6 ft)
Mean sea level	" +0.15 m (+0.5 ft)
KLW (spring tide)	" -0.79 m (-2.6 ft)

SOD: Survey Ordinance Datum which is the hight above mean sea level at Port Swettenham in 1912.

It is expressed as,
mean sea level (in 1912) ..... SOD + 0.00

3.3 Stormwater Quantities

As the basis of the engineering design of drainage facilities, stormwater quantities have to be estimated as accurate as possible, for which many formulae and methods have been developed. The purpose of this section is to describe the various factors, required for this Project as a basis of design, which are developed in association with matters included in DID's Planning and Design Procedure No. 1 "Urban Drainage Design Standards and Procedures for Peninsular Malaysia". (hereinafter referred to as the Malaysian Standards)

(1) Runoff Formulae

The "Rational Formula" is widely used as current practice for computing quantities of stormwater runoff. Although, it is normal to apply the "Rational Method" in which no storage effects inside ditches are weighted, the Malaysian Standards mentioned above recommended the use of the "Rational Method" with a storage coefficient as described follow.

$$Q = \frac{1}{360} \; CsCIA \; .... \quad (IV\text{-}1)$$

where Q : the peak discharge, cu m/sec

I : the average intensity of rainfall, mm

A : the catchment area, ha

C : a runoff coefficient

Cs: a storage coefficient which is expressed as;

$$Cs = \frac{2tc}{2tc + td}$$

tc: the time of concentration

td: the time of flow in the drain

The application of a runoff formula modified by a storage coefficient is preferable in the Project Area which is totally flat and low-lying.

The relationship between Cs, tc and td in Malaysian Standard is derived on the basis of the theory acceptable internationally, and the result of its practical application on four drainage basins in Kuala Lumpur (KL) coincide with those obtained by the more elaborate routing procedure by way of computer calculation. The derivation of Cs as a function of tc and td is explained in "Flood Estimation for Urban Areas in Peninsular Malaysia", Hydrological Procedure No. 16, published by Ministry of Agriculture and Rural Development Malaysia. With the background above, "Rational Method" with storage coefficient Cs, i.e., Q = 1/360 CsCIA is adopted for this Project.

(2) Rainfall Formula

The rainfall intensity-duration-frequency curves which have been developed on the basis of rainfall data in George Town and included in the Malaysian Standards are applied for this Project.

The curves are expressed in the following equations.

Two-year frequency $$I_2 = \frac{6,270}{t + 32}$$

Five-year frequency $$I_5 = \frac{8,070}{t + 30}$$

Hundred-year frequency $$I_{100} = \frac{13,940}{t + 33}$$

(3) Rainfall Frequencies for Design

Basically, storm drains could be designed to carry the runoff from the maximum stormwater expected for a given location. However, when construction cost of the required sewers and other facilities are considered, the determination of a rainfall frequency becomes necessary. The standards as for rainfall freqnencies as a basis for the design of urban drainage systems are two years for residential areas and five years for commercial and industrial areas. These figures are acceptable for the size of municipalities like those in the Project Area and for the sake of design practices. For this Project, therefore, the same rainfall frequencies as that of the national standards is applied, except for major drains flowing through varied land-use areas, the five years is considered more adequate as design rainfall frequencies. The design rainfall frequencies are summarized as follows:

Residential area	2 years
Commercial area	5 years
Industrial area	5 years
Main drains	5 years

(4) Runoff Coefficient

Runoff coefficients to be used for drainage design are determined, taking into account the various types of surface of the Project Area. The recommended coefficients for the area by types of future land use are as follows: (Detailes refer to Appendix I, "Stormwater Quantity")

TABLE IV-3 Runoff Coefficient by Type of Land Use

Land Use		Runoff Coefficient
Residential area	Densely inhabitted	0.65
	Sparsely inhabited	0.35
Commercial area		0.85
Industrial area		0.50
Mountainous area		0.50

(5) Time of Concentration

The concept of the time of concentration is used for the estimation of peak discharge rate derived from rainfall duration relationship curve for the given frequency. The time of concentration consists of the inlet time plus the time of flow in the sewer from the most remote inlet to the point under consideration.

Time of flow in the sewer is estimated depending upon the hydraulic properties of the individual conduit. Inlet time is estimated on the basis of situation in the area considered. In Appendix I, "Stormwater Quantity", the estimation of inlet time is described in detail.

3.4 Hydraulic Design of Open Channels

(1) Manning Formula

For the hydraulic design of open channels, Manning Formula is applied and expressed as follows:

$$V = \frac{1}{n} R^{2/3} \cdot I^{1/2}$$

V : velocity, m/sec

n : roughness coefficient

R : hydraulic radius, m

I : gradient

The value of "n" is defined as follows:

cast-in-place concrete channel	n = 0.015
pre-cast concrete channel	n = 0.013
wet masonry channel	n = 0.025
earth channel	n = 0.030

(2) Type of Cross Section

As a result of cost comparison, it becomes clear that the earth channel is the cheapest, which means to suggest that earth drains should be used as much as possible in the proposed drainage system.

However, earth drains are specified with trapezoidal cross section which result in requirements for land space larger than the case of rectangular type. So, in the case of sufficient surface spaces are not available for drains, stone masonry channels or rectangular concrete channels should be used. In case of smaller roadside drains, pre-cast "U" shape channels are to be used taking advantage of the shorter construction time required.

3.5 Design of Reservoirs

The capacity of reservoirs is calculated by following processes:

- develop inflow hydrograph
- develop cumulative inflow curve
- develop cumulative outflow curve
- read the maximum volume required

In usual case, the capacity of reservoir is selected among those resulted from two types of inflow hydrograph, one is for the situation of tc > te and another of tc < te (Ref. Appendix J). Thus, maximum capacity required would be found.

where, tc : time of concentration

te : rainfall duration time