SECTION 4 SANITATION CONDITIONS AND WATER POLLUTION CONTROL MEASURES AT PRESENT AND IN THE FUTURE

4.2 Existing Public Sewage Works, Industrial Wastewater Treatment Works and Urban Drainage

4.2.1 Treatment Status of Existing Sewage Treatment Works and Evaluation Criteria by Treatment Method

In the existing sewage treatment works, the following three treatment systems are currently being used:

- WSP (wastewater stabilization pond)
- TF (trickling filter)
- BNR (biological nutrient removal)

The factors determining which system is used at a given treatment works include the scale and size of the treatment works, the nature of the receiving water body, etc. It is possible to break down each of the above treatment systems into separate treatment processes which may be selected and combined according to the required treatment purpose.

For organic matter removal, two primary treatment processes are available: AP (aerobic pond) and PST (primary sedimentation tank). Three secondary treatment processes are available: WSP (facultative pond), TF, and BNR. The possible combinations of these primary and secondary treatment processes yield the following six options: AP+WSP, AP+TF, AP+BNR, PST+WSP, PST+TF, and PST+BNR. AP+BNR and PST+WSP are not currently being employed. The combinations that are currently employed are as follows:

(1) AP + WSP
(2) AP + TF
(3) PST + TF
(4) PST + BNR.

For nutrient removal, two processes are employed: Irrigation and BNR. To achieve both organic matter and nutrient removal, the following four combinations of treatment processes are available:

(1) AP + WSP + Irrigation
(2) AP + TF + Irrigation

(3) PST + TF + Irrigation

(4) PST+BNR

The combination employed at a given treatment works depends on the conditions at that plant.

The combinations of treatment processes given above will presumably be employed in the future as the appropriate treatment processes for the Study Area. To establish the stable treatment efficiency for each treatment process with regard to organic matter (BOD and COD) and nutrients (T-N and P-P), operational status of the existing treatment works shall be examined.

1. Treatment Capability of Existing Sewage Treatment Works

Table 4.2.1 summarises the principal features of the existing STWs, such as treatment capacity, dimensions, present conditions, and existing extension plans for Harare, Chitungwiza, Norton and Ruwa.

Table 4.2.2 shows the quality of the raw and treated wastewater of the existing respective sewage treatment works. The present operating conditions and treatment capabilities of the respective STWs are as follows :

(1) Crowborough STW

1) Influent wastewater flow rate and quality

The average inflow was 55,311 m^3/day during the period from May 1995 to April 1996, which slightly exceed the treatment capacity of the STW, 54,000 m^3/day. The inflow is characterized by a very high concentration of BOD: 619 and 792 mg/l on average flow and 75 % non-exceedance probability flow (NEPF) respectively. Such a high concentration is deemed to be attributed to the industrial wastewater.

Table 4.2.1 The List of Existing Sewage treatment Works

Urban Authority	Sewage Treatment Works	Treatment method	Design Capacity m3/d	Present Influent Flow m3/d	Note (Construction Time)
Harare City	Crowborough	TF	36,000	39,325	Unit 1 1957
					Unit 2 1970's
		BNR	18,000	15,986	Unit 3 1980's
		BNR	*1 (25,000)	-	Unit 4 1996 to
			(79,000)		Total in the future
			54,000	55,311	
	Firle	TF	36,000	104,636	Unit 1 1960
					Unit 2 1970's
		BNR	36,000	12,403	Unit 3 1979 to 1981
				15,252	Unit 4 1986 to 1996
		BNR	(72,000)	-	Unit 5(I) 1994 to 1996
					Unit 5(II) 1995 to 1997
			(144,000)		Total in the future
			72,000	132,291	
	Marlborough	WSP	2,000	2,000	
	Donnybrook				
	Block 1	WSP	-	400	
	Block 2	WSP	-	1,350	
	Block 3	WSP	-	1,396	
	Block 4	WSP	-	2,351	
		Total	*2 5,500	5,497	
	Hatcliffe	AL	1,300	2,500	
Chitungwiza Municipality	Zengeza	TF	21,750	36,405	Under repair
Norton Town	Norton	TF	3,400	2,700	Unit 1 1953
					Unit 2 1975
					Under repair
Ruwa Local Board	Ruwa	WSP	5,300	2,865	1993
Total			(262,250)		
			165,250	239,569	

Note: Present influent flow is estimated based on the Average Dry Weather Flow (ADWF)

*1; The latest on-going plan for BNR of Crowborough is 60,000 m^3/day

*2; Design capacity (5,500 m^3/day) of Donnybrook (refer to Section 4.2, Chapter 2, Supporting Report)

TF; Trickling Filter
BNR; Biological Nutrient Removal
WSP; Wastewater Stabilitation Pond
AL; Aerated Lagoon

Table 4.2.2 Influent Flow Rate, Influent and Effluent Quality in STWs

STW			Influent Flow Rate	Influent					Effluent					Note
				BOD	COD	SS	TN	P-P	BOD	COD	SS	T-N	P-P	
			m^3/d	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
Crowborough	Unit 1	Avg.	39,325	619.0	1,355.0	650.0	55.0	6.7	128.0	282.0	102.0	38.1	5.0	TF
	Unit 2	75%		792.0	1,726.0	840.0	66.0	7.8	157.0	341.0	118.0	47.0	5.7	e
	Unit 3	Avg.	15,986	ditto	ditto	ditto	ditto	ditto	21.7	92.5	30.7	9.3	1.4	BNR
		75%		ditto	ditto	ditto	ditto	ditto	30.1	104.5	44.0	16.8	1.5	e
Firle	Unit 1	Avg.	104,636	483.0	1,026.0	509.0	64.1	8.0	153.0	268.0	98.0	38.7	4.5	TF
	Unit 2	75%		641.0	1,225.0	710.0	78.0	9.0	209.0	338.0	134.0	48.0	5.5	e
	Unit 3	Avg.	12,403	461.0	997.0	583.0	62.4	8.9	23.6	107.6	24.8	13.7	2.8	BNR
		75%		640.0	1,225.0	740.0	77.0	11.0	27.4	106.2	31.0	19.2	3.2	e
	Unit 4	Avg.	15,252	496.0	975.0	572.0	62.2	8.1	17.3	94.7	29.1	13.0	2.2	BNR
		75%		661.0	1,161.0	730.0	75.0	10.6	25.0	108.3	35.0	20.8	2.6	e
Marlborough		Avg.	a 2,000	331.0	-	-	58.1	6.3	74.3	-	-	36.4	4.0	WSP
		75%		460.0	-	-	73.0	7.3	120.7	-	-	42.0	4.8	f
Donnybrook	Block 1	Avg.	400	855.0	-	-	194.9	16.8	93.4	-	-	106.4	11.7	WSP
		75%		1,061.0	-	-	230.0	20.0	141.3	-	-	110.0	13.5	f
	Block 2	Avg.	1,350	777.0	-	-	218.8	13.3	104.6	-	-	99.6	11.0	WSP
		75%		1,130.0	-	-	268.0	17.8	160.2	-	-	108.0	12.0	f
	Block 3	Avg.	1,396	846.0	-	-	188.4	15.5	127.1	-	-	93.7	9.6	WSP
		75%		1,062.0	-	-	270.0	18.0	195.3	-	-	86.0	11.7	f
	Block 4	Avg.	2,351	776.0	-	-	186.2	14.6	124.1	-	-	77.8	9.1	WSP
		75%		1,002.0	-	-	210.0	17.0	186.3	-	-	92.0	10.5	f
Zengeza		Avg.	b 36,405	974.0	-	-	d 52.2	-	141.0	-	-	58.3	-	TF
		75%		1,160.0	-	-	d 57.0	-	180.0	-	-	67.8	-	e
Norton		Avg.	2,700	660.0	1,496.0	-	83.3	7.6	520.0	1,192.0	-	65.8	7.6	TF
		75%												g
Ruwa		Avg.	c 2,865	657.0	-	-	44.7	10.2	133.6	-	-	2.8	2.4	WSP
		75%		580.0	-	-	31.0	8.4	185.0	-	-	3.1	3.2	h
Hatcliffe		Avg.		705.0	1,725.0	791.0	253.4	16.9	268.7	527.0	-	110.4	7.6	AL
		75%		810.0	1,793.0	844.0	220.0	21.2	351.0	576.0	-	92.0	8.2	f

a. Influent Flow is estimated value.
b. Average value in 1994
c. Average value in March 1996.
d. Kjeldahl Nitrogen is not measured, almost of them are ammonia.
e. Data from May 1995 to April 1996. (once a week)
f. Data from May 1994 to April 1996. (once a month)
g. Data measured on 7 June 1995.
h. Data from October 1994 to September 1995. (once a month)

TF: Trickling Filter Process
BNR: Biological Nutrient Reduction Process
WSP: Wastewater Stabilization Pond Process
AL: Aerated Lagoon

Figure 4.2.1 and 4.2.2 and Table 4.2.3 and 4.2.4 present the schematic flow diagram and features of the Crowborough STW.

2) Treatment status

In order to judge the treatment status of the respective treatment components, the "Treatment Capability Evaluation Criteria" (hereinafter referred to as "the Evaluation Criteria") on the basis of the "Wastewater Treatment Engineering, Disposal and Reuse, MetCalf and Eddy INC., Third Edition" and the "Sanitation Manual Design Procedure No. 5 in Zimbabwe" are prepared by the Study Team. In the light of the Evaluation Criteria, the treatment status of this STW is evaluated as follows :

a. Trickling filter (TF, Units 1 and 2)

BOD removal

	Primary Sedimentation Tank	Trickling Filter + Sedimentation Tank
Hydraulic loading rate, average flow :	26.2 m^3/m^2/day	4.82 m^3/m^2/day
BOD loading rate on TF	-	0.52 kg/ m^3/day
BOD removal ratio, average flow:	49.1 %	59.4 %
75 % NEPF	49.9 %	60.5 %

COD removal

COD removal ratio, average flow:	79.2 %
75 % NEPF	80.2 %

T-N and P-P removal

T-N removal ratio, average flow:	30.7 %
75 % NEPF	28.8 %
75 % NEPF	26.9 %

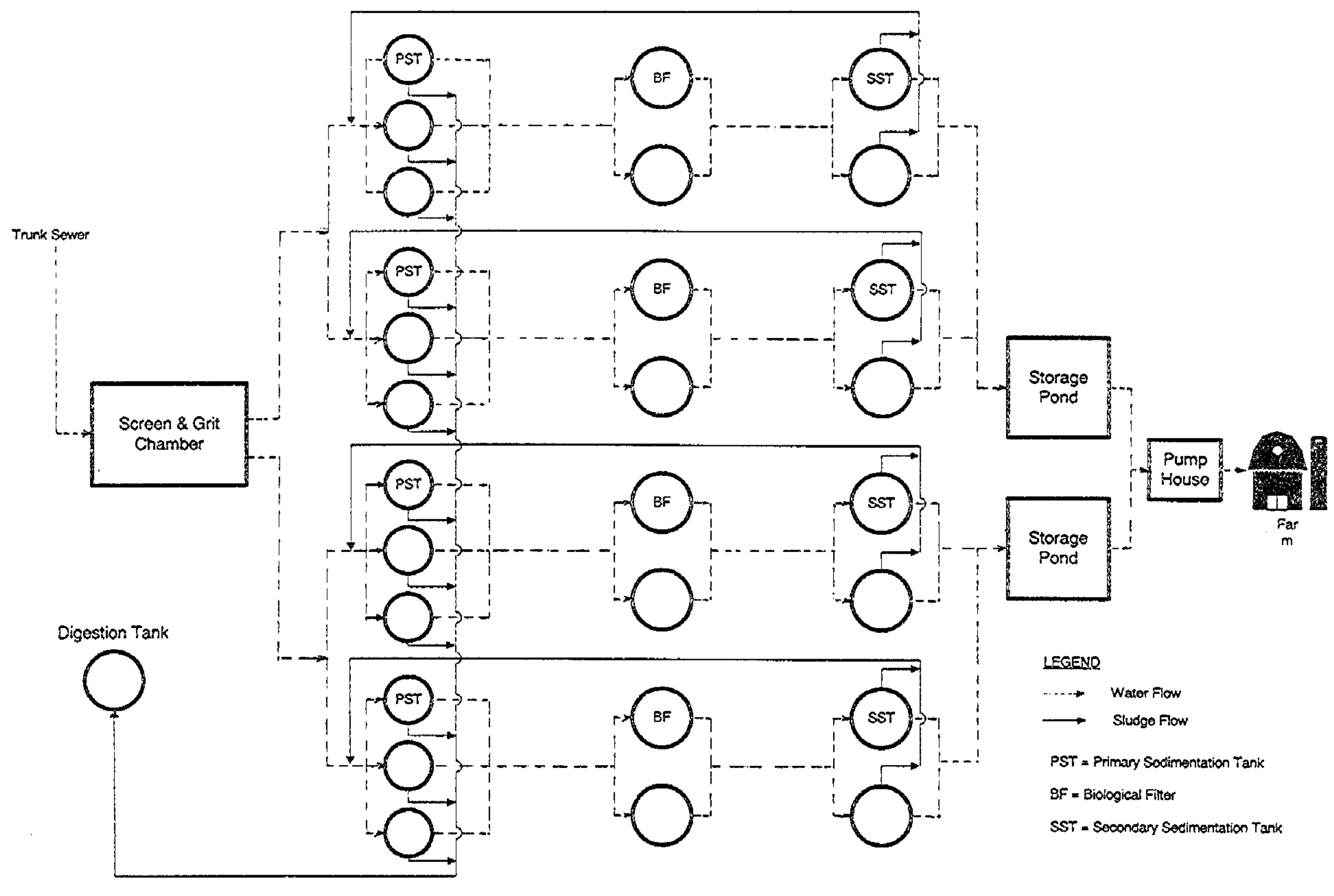

Figure 4.2.1 Existing Crowborough STW (No. 1 & 2 Units) Flow Diagram (Design Capacity: 18,000 x 2 = 36,000 m^3/day)

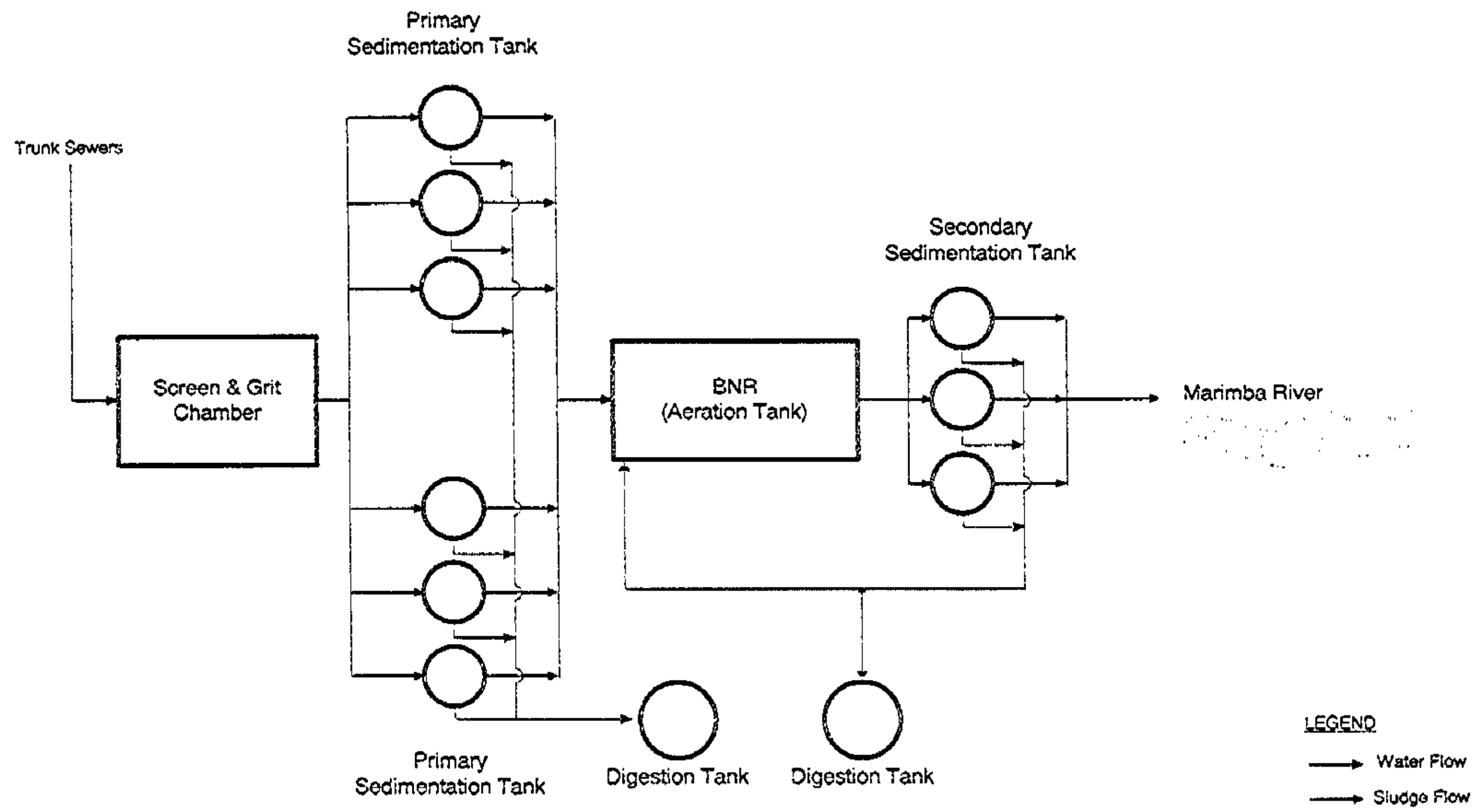

Figure 4.2.2 Existing Crowborough STW (No. 3 Unit) Flow Diagram (Design Capacity: 18,000 m^3/day)

Table 4.2.3 Crowborough STW Treatment Performance (Present)

Design Treatment Capacity	Unit 1,2 (TF)	36,000 m3/d
	Unit 3 (BNR)	18,000 m3/d
	Total	54,000 m2/d

Current Flow	Unit 1,2 (TF)	39,325 m3/d
	Unit 3 (BNR)	15,986 m3/d
	Total	55,311 m3/d

Current Influent BOD	Unit 1,2 (TF)	619 mg/L (Avg.)	792 mg/L (75%)
	Unit 3 (BNR)	619 mg/L (Avg.)	792 mg/L (75%)
Current Influent BOD Load	Unit 1,2 (TF)	24,342 kg/d (Avg.)	31,145 kg/d (75%)
	Unit 3 (BNR)	9,895 kg/d (Avg.)	12,661 kg/d (75%)
	Total	34,237 kg/d (Avg.)	43,806 kg/d (75%)
Current Effluent BOD	Unit 1,2 (TF)	128 mg/L (Avg.)	157 mg/L (75%)
	Unit 3 (BNR)	21.7 mg/L (Avg.)	30.1 mg/L (75%)
Current Effluent BOD Load	Unit 1,2 (TF)	5,034 kg/d (Avg.)	6,174 kg/d (75%)
	Unit 3 (BNR)	347 kg/d (Avg.)	481 kg/d (75%)
		5,381 kg/d (Avg.)	6,655 kg/d (75%)

Current Influent COD	Unit 1,2 (TF)	1,355mg/L	(Avg.)	1,726 mg/L	(75%)
Current Influent COD	Unit 3 (BNR)	1,355mg/L	(Avg.)	1,726 mg/L	(75%)
Current Influent COD Load	Unit 1, 2 (TF)	53,285kg/d	(Avg.)	67,875 kg/d	(75%)
Current Influent COD Load	Unit 3 (BNR)	21,661 kg/d	(Avg.)	27,592 kg/d	(75%)
	Total	74,946 kg/d	(Avg.)	95,467 kg/d	(75%)
Current Influent T-N	Unit 1, 2 (TF)	55.0 mg/L	(Avg.)	66.0 mg/d	(75%)
Current Influent T-N	Unit 3 (BNR)	55.0 mg/L	(Avg.)	66.0 mg/d	(75%)
Current Influent T-N Load	Unit 1, 2 (TF)	2,163 kg/d	(Avg.)	2,595 kg/d	(75%)
Current Influent T-N Load	Unit 3 (BNR)	879 kg/d	(Avg.)	1,055 kg/d	(75%)
	Total	3,042 kg/d	(Avg.)	3,650 kg/d	(75%)
Current Influent P-P	Unit 1, 2 (TF)	6.7 -mg/d	(Avg.)	7.8 mg/L	(75%)
Current Influent P-P	Unit 3 (BNR)	6.7 mg/d	(Avg.)	7.8 mg/L	(75%)
Current Influent P-P Load	Unit 1, 2 (TF)	263 kg/d	(Avg.)	307 kg/d	(75%)
Current Influent P-P Load	Unit 3 (BNR)	107 kg/d	(Avg.)	125 kg/d	(75%)
	Total	370 kg/d	(Avg.)	332 kg/d	(75%)

Current Effluent COD	Unit 1, 2 (TF)	282mg/L	(Avg.)	341mg/L	(75%)
Current Effluent COD	Unit 3 (BNR)	92.5mg/L	(Avg.)	104.5mg/L	(75%)
Current Effluent COD Load	Unit 1, 2 (TF)	11,090kg/d	(Avg.)	13,410kg/d	(75%)
Current Effluent COD Load	Unit 3 (BNR)	1,479kg/d	(Avg.)	1,671kg/d	(75%)
	Total	12,569kg/d	(Avg.)	15,081kg/d	(75%)
Current Effluent T-N	Unit1, 2 (TF)	38.1mg/L	(Avg.)	47.0mg/L	(75%)
Current Effluent T-N	Unit 3 (BNR)	9.3mg/L	(Avg.)	10.8mg/L	(75%)
Current Effluent T-N Load	Unit 1, 2 (TF)	1,498kg/d	(Avg.)	1,848kg/d	(75%)
Current Effluent T-N Load	Unit 3 (BNR)	149kg/d	(Avg.)	269kg/d	(75%)
	Total	1,647kg/d	(Avg.)	2,117kg/d	(75%)
Current Effluent P-P	Unit 1, 2 (TF)	5.0mg/L	(Avg.)	5.7mg/L	(75%)
Current Effluent P-P	Unit 3 (BNR)	1.4mg/L	(Avg.)	1.5mg/L	(75%)
Current Effluent P-P Load	Unit 1, 2 (TF)	197kg/d	(Avg.)	224kg/d	(75%)
Current Effluent P-P Load	Unit 3 (BNR)	22kg/d	(Avg.)	24kg/d	(75%)
	Total	219kg/d	(Avg.)	248kg/d	(75%)

Table 4.2.4 Crowborough STW Treatment Performance (Present) (cont'd)

Facilities		Tank Size	Tank Area Tank Volume	Load	Loading	Typical Loading Rate	Expected Effluent Quality
Trickling Filter (TF or, Biofilter)	Inlet Works (IW)	Trunk Sewer 835,875 mm Grit Chamber W1.8m x L6.1m x H7.0m Number 6					
	Primary Sedimentation Tank (PST)	Dortmund Tank Diameter 12.6m Depth 10.8m (1.8m + 9.0) Number 12	A = 125 x 12 = 1,500m2	39,325m3/d	39,325/1,500 = 26.2m3/m2/d		
	Trickling Filter (TF, or Biofilter)	Diameter 36.0m Depth 3.7m (3.6 to 3.75m) Number 8 Recirculation Ratio	A = 1,020 x 8 = 8,160m2 V = 3,760 x 8 = 30,080m3	39,325m3/d From the criteria BOD removal ratio in PST (Actual) 50% 31,145 x (1 -0.50) = 15,573kg/d	39,325/8,160 = 4.82m3/m2/d 15,573/30,080 = 0.52kgm3/d		From the criteria BOD removal ratio in TF 792 x (1 - 0.50) x (1 - 0.60) = 158mg/L (75%) 15,573 x (1 - 0.55) = 7,008kg/d 619 x (1 - 0.55) x (1 - 0.60) = 124mg/L (Avg.) 24,342 x (1 - 0.55) x (1 - 60) = 4,868kg/d
	Secondary Sedimentation Tank (SST, or Human Tank)	Dortmund Tank Diameter 12.6m Depth 10.8m (1.8 + 9.0m) Number 8	A = 125 x 8 = 1,000m2				
	Storage Pond	No. 1 50m x 45m x H 4m No. 2 60m x 45m x H 4m No. 3 190m x 100m x H 4m					
	Pump Station for Irrigation	1,500m3/h x 39m x 260kw x 2 825m3/h x 150kw x 3 (including 1 standby)					
BNR	Primary Sedimentation Tank (PST)	Drtmund Tank Diameter 13.0m Depth 12.6m (2.0 + 10.6m) Number 6	A = 133 x6 = 798m2	15,986m3/d	15,986/798 = 20.0m3/m2/d		
	BNR Reactor Fermentation Anoxic I Airation Anoxic II Reaeration	Width Length Depth Number Aerator 55kw x 3.45kw x 3 37kw x 6.22kw x 2 Total 566kw Agitation 7.5 x 6 = 45kw	A = V = 18,000m3 MLSS = 4,000 to 6,000mg/L STR = 15 to 25 days MLSS (Actual) mg/L	15,986m3/d BOD removal ratio in PST (Actual) = 50% 12,661 x (1 - 0.50) = 6,331kg/d	Retention time 18,000/15,986 x 24 = 27.0 hours 6,331/18,000/5,000 x 10^3 0.070kg/kg/d		BOD removal ratio in BNR (Actual) 93% 792 x (1 - 0.50) x (1 - 0.93) = 28mg/L (75%) 12,661 x (1 - 0.50) x (1 - 0.93) = 443kg/d 619 x (1 - 0.50) x (1 - 0.93) = 22mg /L (Avg.) 9,895 x (1 - 0.50) x (1 - 0.93) = 346kg/d
	Clarifier (Secondary Sedimentation Tank)	Diameter 26.0m Depth 3.5m Number 3	A = 531 x 3 = 1,593m2	15,986m3/d	15,986/1,593 = 10m3/m2/d		
Sludge Treatment	Primary Digester	Diameter 13.5m Depth 6.5m Number 4 Diameter 14.0m Depth 14.5m Number 2					
	Secondary Digester	Diameter 12.6m Depth Number 2					
	Sludge Drying Bed	60m x 110m	A = 0.66ha				

b. BNR (Unit 3)

BOD removal

	Primary Sedimentation Tank	BNR + Clarifier
Hydraulic loading rate, average flow:	26.2 m^3/m^2/day	-
Retention time	-	27.0 hours
BOD loading rate, 75 % NEPF		0.070 kg/kg/day
BOD removal ratio, average flow:	49.1 %	93.1 %
75 % NEPF	49.9 %	92.4 %

COD removal

COD removal ratio, average flow:	93.2 %
75 % NEPF	93.9 %

T-N and P-P removal

T-N removal ratio, average flow:	83.1 %
75 % NEPF	74.5%
P-P removal ratio, average flow:	79.1%
75 % NEPF	80.8%

3) Estimate in reduction of pollutant loads

Pollution reduction by the respective component is as follows :

	Unit	Influent	Effluent	Reduction
BOD Reduction				
Trickling filter	kg/day	24,342	5,034	19,308
BNR (3)	kg/day	9,895	347	9,548
Total	kg/day	34,237	5,381	28,856
COD reduction				
Trickling filter	kg/day	53,285	11,090	42,195
BNR (3)	kg/day	21,661	1,479	20,182
Total	kg/day	74,946	12,569	62,377
T-N reduction				
Trickling filter	kg/day	2,163	1,848	315

BNR (3)	kg/day	879	269	610
Total	kg/day	3,042	2,117	925
P-P reduction				
Trickling filter	kg/day	263	224	39
BNR (3)	kg/day	107	24	83
Total	kg/day	370	248	122

The BNR's effluent flows into the river, which means that the pollutant load is discharged into the public water body. The treated effluent of the trickling filter is used for irrigation, thus the load is not discharged into the public water body, excepting during the wet season.

(2) Firle sewage treatment works

1) Influent wastewater flow rate and quality

The flow measurements during the period from May 1995 through to April 1996 showed an average flow inflow of 132,291 m^3/day, which is almost twice of the present treatment capacity (72,000 m^3/day). At present, an extra facility with a treatment capacity of 72,000 m^3/day is under construction next to the existing plant to cope with the increased sewage. The quality of the influent is better than that of STW: the BOD concentration is 461-496 mg/l for average flow and 640-661 mg/l for 75 % NEPF.

Figure 4.2.3 to 4.2.5 and Table 4.2.5, 4.2.6 and 4.2.7 present the schematic flow diagram and features of the Crowborough STW ,respectively.

2) Treatment status

In light of the Evaluation Criteria, the treatment capability of this STW is evaluated as follows :

a. Trickling filter (TF, Units 1 and 2)

BOD removal

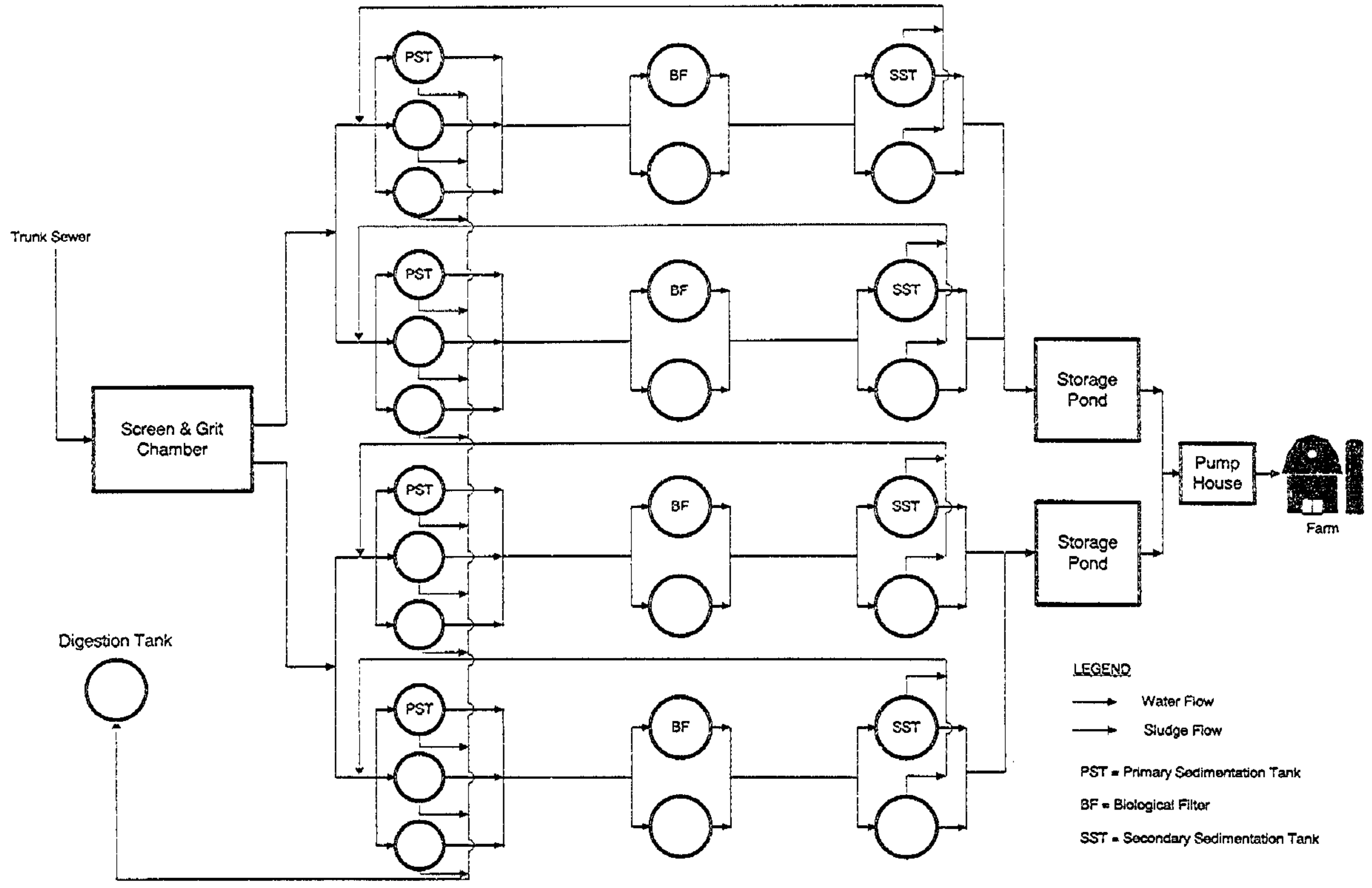

Figure 4.2.3 Existing Firle STW (No. 1 & 2 Units) Flow Diagram (Design Capacity: 18,000 x 2 = 36,000 m^3/day)

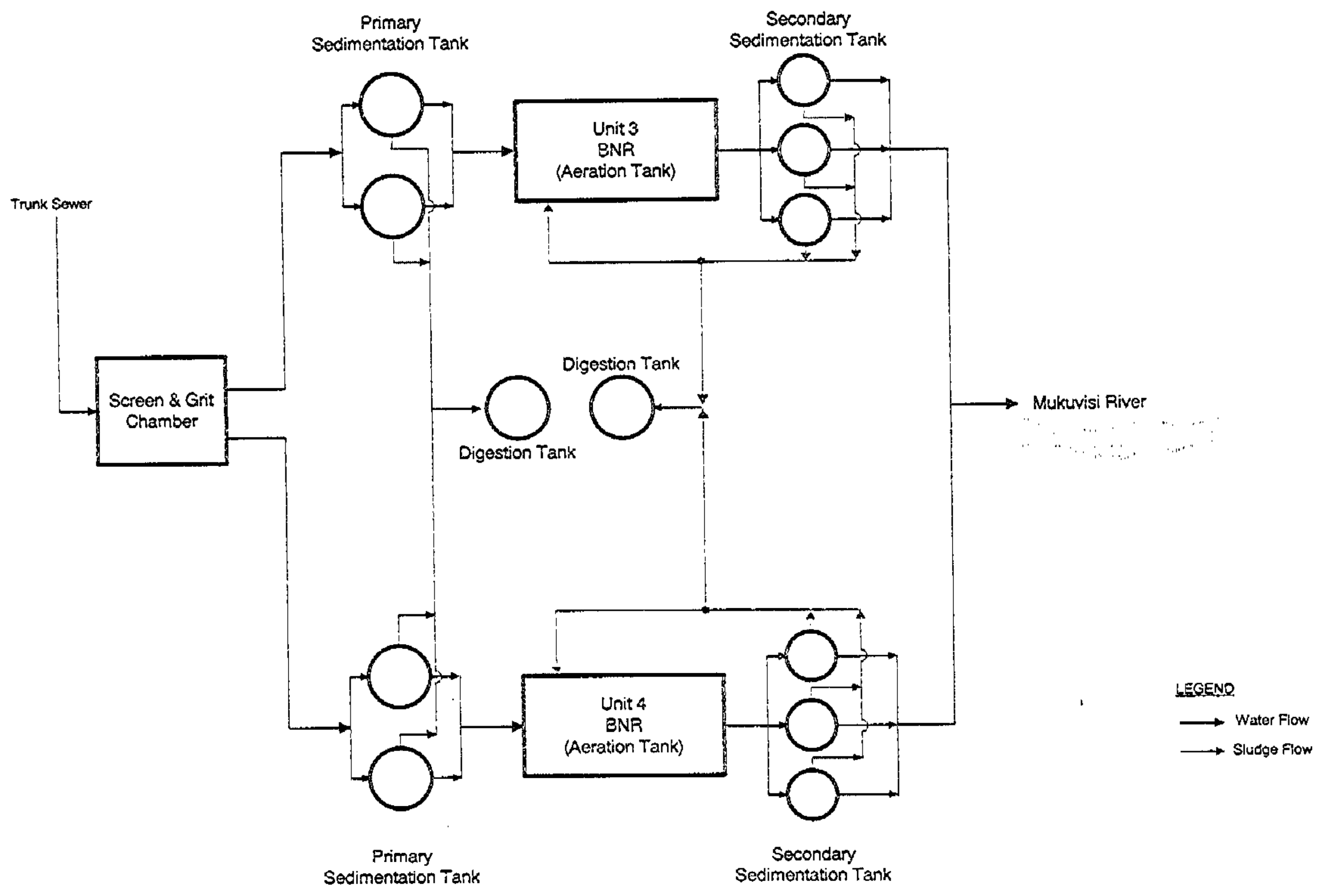

Figure 4.2.4 Existing Firle STW (No. 3 & No. 4 Units) Flow Diagram (Design Capacity: 18,000 m^3/day x 2 = 36,000 m^3/day)

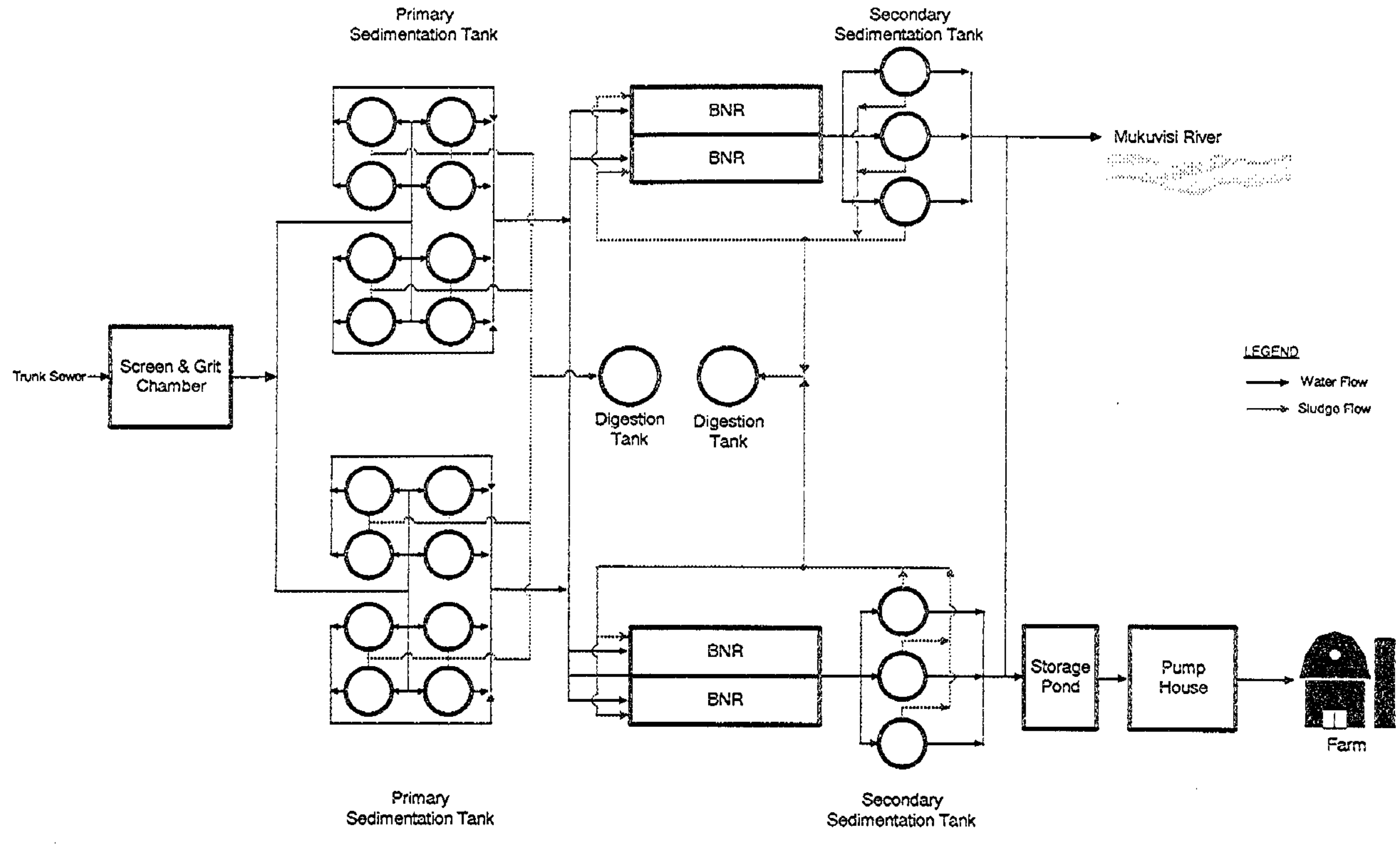

Figure 4.2.5 Firle STW (Unit 5: Under Construction) Flow Diagram (Design Capacity: 36,000 m^3/day x 2 = 72,000 m^3/day)

Table 4.2.5 Firle STW Treament performance (Present)

Design Treatment Capacity	Unit 1, 2	(FT)	36,000m3/d			
	Unit 3	(BNR)	18,000m3/d			
	Unit 4	(BNR)	18,000m3/d			
	Total		72,000m3/d			
Current Flow	Unit 1, 2	(FT)	104,636m3/d			
	Unit 3	(BNR)	12,403m3/d			
	unit 4	(BNR)	15,252m3/d			
	Total		27,655m3/d			
Current Influent BOD	Unit 1, 2		483mg/L	(Avg.)	641mg/L	(75%)
	Unit 3		461mg/L	(Avg.)	640mg/L	(75%)
	Unit 4		496mg/L	(Avg.)	661mg/L	(75%)
Current Influent BOD Load	Unit 1, 2		50,539kg/d	(Avg.)	67,072kg/d	(75%)
	Unit 3		5,718kg/d	(Avg.)	7,938kg/d	(75%)
	Unit 4		7,565kg/d	(Avg.)	10,082kg/d	(75%)
	Total		63,822kg/d	(Avg.)	85,092kg/d	(75%)
Current Influent COD	Unit 1, 2	(FT)	1,026mg/L	(Avg.)	1,225mg/L	(75%)
Current Influent COD	Unit 3	(BNR)	997mg/L	(Avg.)	1,225mg/L	(75%)
Current Influent COD	Unit 4	(BNR)	975mg/L	(Avg.)	1,161mg/L	(75%)
Current Influent COD Load	Unit 1, 2	(FT)	107,357kg/d	(Avg.)	128,179kg/d	(75%)
Current Influent COD Load	Unit 3	(BNR)	12,366kg/d	(Avg.)	15,194kg/d	(75%)
Current Influent COD Load	Unit 4	(BNR)	14,87kg/d	(Avg.)	17,708kg/d	(75%)
	Total		134,594kg/d	(Avg.)	161,081kg/d	(75%)
Current Influent T - N	Unit 1, 2	(FT)	64.1mg/L	(Avg.)	78.0mg/L	(75%)
Current Influent T - N	Unit 3	(BNR)	62.4mg/L	(Avg.)	77.0mg/L	(75%)
Current Influent T - N	Unit 4	(BNR)	62.2mg/L	(Avg.)	75.0mg/L	(75%)
Current Influent T - N Load	Unit 1, 2	(FT)	6,707kg/d	(Avg.)	8,162kg/d	(75%)
Current Inlfuent T - N Load	Unit 3	(BNR)	774kg/d	(Avg.)	955kg/d	(75%)
Current Influent T - N Load	Unit 4	(BNR)	949kg/d	(Avg.)	1,144kg/d	(75%)
	Total		8,430kg/d	(Avg.)	10,261kg/d	(75%)
Current Influent P - P	Unit 1, 2	(FT)	8.0mg/L	(Avg.)	9.0mg/L	(75%)
Current Influent P - P	Unit 3	(BNR)	8.9mg/L	(Avg.)	11.0mg/L	(75%)
Current Influent P - P	Unit 4	(BNR)	8.1mg/L	(Avg.)	10.6mg/L	(75%)
Current Influent P - P Load	Unit 1, 2	(FT)	837kg/d	(Avg.)	942kg/d	(75%)
Current Influent P - P Load	Unit 3	(BNR)	110kg/d	(Avg.)	136kg/d	(75%)
Current Influent P - P Load	Unit 4	(BNR)	124kg/d	(Avg.)	162kg/d	(75%)
	Total		1,071kg/d	(Avg.)	1,240kg/d	(75%)

Current Effluent BOD	Unit 1, 2		153mg/L	(Avg.)	209mg/L	'(75%)
	Unit 3		23.6mg/L	(Avg.)	27.4mg/L	(75%)
	Unit 4		17.3mg/L	(Avg.)	25.0mg/L	(75%)
Current Effluent BOD Load	Unit 1, 2		16,009kg/d	(Avg.)	21,869kg/d	(75%)
	Unit 3		293kg/d	(Avg.)	340kg/d	(75%)
	Unit 4		264kg/d	(Avg.)	381kg/d	(75%)
	Total		16,566kg/d	(Avg.)	22,590kg/d	(75%)
Current Effluent COD	Unit 1, 2	(FT)	268mg/L	(Avg.)	338mg/L	(75%)
Current Effluent COD	Unit 3	(BNR)	108mg/L	(Avg.)	106mg/L	(75%)
Current Effluent COD	Unit 4	(BNR)	95mg/L	(Avg.)	108mg/L	(75%)
Current Effluent COD Load	Unit 1, 2	(FT)	28,042kg/d	(Avg.)	35,367kg/d	(75%)
Current Effluent COD Load	Unit 3	(BNR)	1,340kg/d	(Avg.)	1,315kg/d	(75%)
Current Effluent COD Load	Unit 4	(BNR)	1,449kg/d	(Avg.)	1,647kg/d	(75%)
	Total		30,831kg/d	(Avg.)	38,329kg/d	(75%)
Current Effluent T - N	Unit 1, 2		38.7mg/L	(Avg.)	48.0mg/L	(75%)
Current Effluent T - N	Unit 3		13.7mg/L	(Avg.)	19.2mg/L	(75%)
Current Effluent T - N	Unit 4		13.0mg/L	(Avg.)	20.8mg/L	(75%)
Current Effluent T - N Load	Unit 1, 2		4,049kg/d	(Avg.)	5,023kg/d	(75%)
Current Effluent T - N Load	Unit 3		170kg/g	(Avg.)	238kg/d	(75%)
Current Effluent T - N Load	Unit 4		198kg/d	(Avg.)	317kg/d	(75%)
	Total		4,417kg/d	(Avg.)	5,578kg/d	(75%)
Current Effluent P - P	Unit 1, 2	(FT)	4.5mg/L	(Avg.)	5.5mg/L	(75%)
Current Effluent P - P	Unit 3	(BNR)	2.8mg/L	(Avg.)	3.2mg/L	(75%)
Current Effluent P - P	Unit 4	(BNR)	2.2kg/d	(Avg.)	2.6mg/L	(75%)
Current Effluent P - P Load	Unit 1, 2	(FT)	471kg/d	(Avg.)	575kg/d	(75%)
Current Effluent P - P Load	Unit 3	(BNR)	35kg/d	(Avg.)	40kg/d	(75%)
Current Effluent P - P Load	Unit 4	(BNR)	34kg/d	(Avg.)	40kg/d	(75%)
	Total		540kg/d	(Avg.)	655kg/d	(75%)

Table 4.2.6 Firle S T W Treatment performance (Present)

	Tank	Tank Size	Tank Area Tank Volume	Load	Loading	ypical Loading Rat	Expected Effluent Quality
	Inlet Works (I W)	Trunk Sewer 1,350mm, 675mm Grit Chamber Width 1.8m Length 6.2m Depth Number 6					
	Primary Sendimentatio Tank (PST)	Dortmund Tank Diameter 12.6m Depth 10.8m (1.8 + 9.0) Number 12	A = 125 x 12 = 1,500	104,636m3/d	104,636/1,500 = 69.8m3/m2/d		
Trickling Filter (TF, or Biofilter)	Trickling Filter	Diameter 36.0m Depth 3.7m (3.6 to 3.75) Number 8 Recirculation ratio	A = 1,020 x 8 = 8,160 V = 3,760 x 8 = 30,08	104,636m3/d BOD removal ratio in PST (Actual) 67,072 x (1- 0.50) = 33,536kg/d	104,636/8,160 = 12.8m3/m2/d 33,536/30,080 = 1.11kg/m3/d		BOD removal ratio in TF (Actual) 40% 641 x (1 - 0.50) x (1 - 0.40) = 192mg/L 67,072 x (1 - 0.50) x (1 - 0.40) = 20,122kg/d 483 x (1 - 0.50) x (1 - 0.40) = 145mg/L 50,539 x (1 - 0.50) x (1 - 0.40) = 15,162kg/d
Unit 1 Unit 2	Secondary Sendimenta Tank	Diameter 13.5m Depth Number 8	A = 143 x 8 = 1,144m	104,636m3/d	104,636/1,144 = 91.5m3/m2/d		
	Storage Pond	40m x 50m x H2m x 2 pond 110m x 165m x H2m x 1 pond	A =20,200m2 V = 33,700m3				
	Pump Station	25m3/min x 6 pump (including 1 pump for river water) pumping main 675mm					
	Inlet Works (I W)	Trunk Sewer mm Detritor m x H m Number 2					
	Primary Sedimentation Tank (PST)	Dortmund Tank Diameter m Depth m Number 2 (Unit 3) 2 (Unit 4)	(Unit 3) A = (Unit 4) A =	12,403m3/d 15,252m3/d			
BNR Unit 3 Unit 4	BNR Reactor (Unit 3) Fermentation Basin Primary Anoxic Basin Airation Basin Secondary Anoxic Basi Reairation Basin	Width 35.0m (Bottom), 52.0m (Top) Length 103.0m (Bottom), 120.0m (Top) Depth 4.5m Number 1 Arator 37kw x 11 30kw x 4 22 kw x 2 Total 571kw Agitator 4kw x 2 7.5kw x 4 Total 38kw	A = 6,240m2 V = 22,300m3 MLSS 4,000 to 5,000 SRT 15 to 25 days MLSS (Actual) m	12,403m3/d BOD removal ratio in PST 50% 7,938 x (1 - 0.50) = 3,969kg/d	Retention time 22,300/12,403 x 24 = 43.2 hours 3,969/22,300/5,000 x 10^3 = 0.056kg/kg/d		BOD removal ratio in BNR (Actual) 90% 640 x (1 - 0.50) x (1 - 0.90) = 32mg/L 7,938 x (1 - 0.50) x (1 - 0.90) = 397kg/d 461 x (1 - 0.50) x (1 - 0.90) = 23mg/L 5,718 x (1 - 0.50) x (1 - 0.90) = 286kg/d
	BNR Reactor (Unit 4) Fermentation Airation	Width Length Depth Number 1 Aerator 55kw x 8 = 440kw Agitation 5.9kw x 2 = 11.8kw	A = V = 18,000m3 MLSS 4,000 to 5,000 SRT 15 - 25 days	15,252m3/d BOD removal ratio in PST 50% 10,082 x (1 - 0.50) = 5,041kg/d	Retention time 18,000/15,252 x 24 = 28.3 hours 5,041/18,000/5,000 x 10^3 = 0.036kg/kg/d		BOD removal ratio in BNR (Actual) 93% 661 x (1 - 0.50) x (1 - 0.93) = 23mg/L 10,082 x (1 0.50) x (1 - 0.93) = 353kg/d 496 x (1 - 0.50) x (1 - 0.93) = 17mg/L 7,565 x (1 - 0.50) x (1 - 0.93) = 265kg/d
	Clarifier (Secondary Sedimentat Tank)	Diameter 26.0m Depth 3.5m Number 3 (Unit 3) 3 (Unit 4)	(Unit 3) A = 531 x 3 = 1,593m2 (Unit 4) A = 531 x 3 = 1,593m2	12,403m3/d 15,252m2/d	12,403/1,593 = 7.8m3/m2/d 15,252/1,593 = 9.6m3/m2/d		
	Storage Pond	90m x 185m x H2.0m	A = 16,650m2 V = 28,200m3				
	Pump Station	Pumping main 900mm 25m3/min x 57.5m x 315kw x 1,480rpm x 4 pump					
	Sludge Thickner	Dortmund Tank Diameter 6m Depth 6.7m (1.8 + 4.9) Number					
	Primary Digester	Number 8					
Sludge Treatment	Secondary Digester	Number 2					
	Gas Holder	Number 1					
	Sludge Drying Bed	Number 1					

Table 4.2.7 Firle STW Treatment Performance (2000)

Design Treatment Capacity Unit 5 (BNR) 72,000m3/d

	Tank	Tank Size	Tank Area Tank Volume	Load	Loading	Typical Loading Rate	Expected Effluent Quality
BNR (New)	Inlet Works (IW)	Trunk Sewer 1,350mm Detritor 9.5m x H0.6m Number 2					
	Primary Sedimentation Tank (PST)	Dortmund Tank Diameter 13.0m Depth 13.2m (2.6 + 10.6) Number 8 (Phase I 1994 - 1996) 8 (Phase II 1995 - 1997)	A = 133 x 8 x 2 = 2,128m2				
	BNR Reactor	Width 15.5m (Bottom), 32.5m (Top) Length 77.5m (Bottom), 94.5m (Top Depth 4.5m Number 2 (Phase I) 2 (Phase II) Airator Agitator	A = 3,070 x 2 x = 12,280m2 V = 9,640 x 2 x 2 = 38,560m3	72,000m3/d	Retention Time 38,560/72,000 x 24 = 12.9 hours		
	Clarifier (Secondary Sedimentation Tank)	Diameter 25.8m Depth 3.5m Number 6 (Phase I) 6 (Phase II)	A = 523 x 6 x 2 = 6,276m2	72,000m3/d	72,000/6,276 = 11.5m3/m2/d		
	Storage Pond						
	Pump Station						
Sludge Treatment	Sludge Thickner						
	Primary Digester	Number 11					
	Secondary Digester	Number 3					
	Gass Holder	Number 1					
	Sludge Drying Bed	Number 1					

	Primary Sedimentation Tank	Trickling Filter + Sedimentation Tank
Hydraulic loading rate, average flow	69.8 m^3/m^2/day	12.8 m^3/m^2/day
BOD loading rate on TF	-	1.11 kg/ m^3/day
BOD removal ratio, average flow:	46.8%(Avg.)	40.5 %
75 % NEPF	53.0%(75%)	30.6 %

COD removal

COD removal ratio, average flow:	73.9 %
75 % NEPF	72.4 %

T-N and P-P removal

T-N removal ratio, average flow:	39.6 %
75 % NEPF	38.5 %
P-P removal ratio, average flow:	43.8 %
75 % NEPF	38.9 %

b. BNR (Units 3 and 4)

BOD removal

	Unit 3	Unit 4
Primary Sedimentation Tank		
Hydraulic loading rate, average flow	20.0 m^3/m^2/day	-
Retention time	-	27.0 hours
BOD loading rate, 75 % NEPF		0.070 kg/ m^2/day
BOD removal ratio, average flow	47.3 %	52.0 %
75 % NEPF	51.0 %	54.9 %
BNR + Clarifier		
Retention time	43.2 hours	28.3 hours
BOD loading rate, 75 % NEPF	0.036 kg/day	0.056 kg/day
BOD removal rate, average flow	90.3 %	90.8 %
75 % NEPF	90.8 %	91.6 %

COD removal

	Unit 3	Unit 4
COD removal ratio, average flow	89.2 %	90.3 %
75 % NEPF	91.3 %	90.7 %

T-N and P-P

	Unit 3	Unit 4
T-N removal ratio, average flow	78.0 %	79.1 %
75 % NEPF	75.1 %	72.3 %
P-P removal ratio, average flow	68.5 %	72.8 %
75 % weight	70.9 %	75.5 %

3) Estimate in reduction of pollutant loads

Pollution reduction by the respective component is as follows :

	Unit	Influent	Effluent	Reduction
BOD Reduction				
Trickling filter	kg/day	50,539	16,009	34,530
BNR (3)	kg/day	5,718	293	5,425
BNR (4)	kg/day	7,565	264	7,301
Total	kg/day	63,822	16,566	47,256
COD reduction				
Trickling filter	kg/day	107,357	28,042	79,315
BNR (3)	kg/day	12,366	1,340	11,026
BNR (4)	kg/day	14,871	1,449	13,422
Total	kg/day	134,594	30,831	103,763
T-N reduction				
Trickling filter	kg/day	6,707	4,049	2,658
BNR (3)	kg/day	774	170	604
BNR (4)	kg/day	949	198	751
Total	kg/day	8,430	4,417	4,013
P-P reduction				
Trickling filter	kg/day	837	471	366

BNR (3)	kg/day	110	35	75
BNR (4)	kg/day	124	34	90
Total	kg/day	1,071	540	531

The treated effluent of the BNR flows into the river. In effect, the load is discharged into the public water body. The treated effluent of the TF is used for irrigation, meaning that the load is not discharged into the public water body, excepting the during the wet season.

(3) Marlborough STW

1) Influent wastewater flow rate and quality

The service area of the Marlborough STW mostly covers the low density residential areas. The actual sewage quantity is not exactly known. According to the STW operator, inflow is estimated to be about 2,000 m^3/day. This figure is supposed to be reliable judging from the present potable water consumption of 80 to 100 l/capita/day. The influent flow is almost identical to the treatment capacity of this sewage works, 2,000m^3/day.

The quality of the raw sewage is of medium strength: BOD concentration is 337 mg/l for average flow and 496 mg/l for 75 % NEPF. Table 4.2.8 presents the schematic flow diagram and features of the Marlborough STW.

2) Treatment status

In light of the Evaluation Criteria, the treatment capability of this STW is evaluated as follows :

BOD removal

Retention time	18.0 days (assuming no sludge accumulation)
BOD removal ratio, average flow:	77.6 %
75 % NEPF	73.8 %

The quality of treated effluent from anaerobic and secondary ponds is estimated on the basis of the wastewater stabilisation pond design criteria with no sludge accumulation.

Table 4.2.8 Marlborough STW Treatment Performance (Present)

Design Treatment Capacity		Q = 2,000 m3/d			
Current Flow Rate		Q = 2,000 m3/d			
Current Influent BOD	460 mg/l (75%)	331 mg/l (avg.)	Current Effluent BOD	74.3 mg/l (75%)	120.7 mg/l (avg.)
Current Influent BOD Load	920 kg/d (75%)	662 kg/d (avg.)	Current Effluent BOD load	149 kg/d (75%)	241 kg/d (avg.)

Pond	Pond Size	Pond Area Pond Volume	Load	Loading	Typical Loading Rate
Intake Works IW)					
Primary Pond (PP)	No.1 45m x 45m x H 1.3m	No.1 A = 2,030m2 V = 1,800m3	No.1 2,000m3/d 920 kg/d	2,880 / 2,000 = 1.4 days	1 - 5 days
	No.2 45m x 20m x H 1.3m	No.2 A = 840m2 V = 540m3		920 / 2,880 x 10^3 =329g-BOD/m3/d	>100g BOD/m3/d
	No.3 45m x 20m x H 1.3m	No.3 A = 840m2 V = 540m3			
		Total A = 3,710m2 Total V = 2,880m3			
Secondary pond (SP)	No.1, No.2 150m x 80m x H 1.2m	No.1, No.2 A = 12,000 x 2 = 24,000m2 V = 12,475 x 12 = 24,950m3	In case of removal ratio 30% 920 x (1 - 0.30) = 644 kg/d	33,140 / 2,000 =16.6 days	5 - 45 days
Tertiary Pond (TP)	150m x 55m x H 1.2m x 1	A = 8,250m2 V = 8,190m3 SP + TP Total A = 32,250m2 = 3.23 ha Total V = 33, 140m3		644 / 3.23 = 199 kg/ha/d	135kg/ha/d

COD removal

	Anaerobic Pond	Secondary Pond
Retention time	1.4 days	16.6 days
BOD removal ratio	30 %	80 %
(derived from the Criteria)		

The effluent BOD of Secondary Pond is therefore calculated as follows :

For 75 % NEPF : 460 x (1-0.30) x (1-0.80) = 64 mg/l

For average flow : 331 x (1-0.30) x (1-0.80) = 46 mg/l

The actual monitoring values were 120.7 and 74.3 mg/l for 75 % NEPF and average flow respectively, being approximately two times the calculated values. However, if the sludge is removed, they should be improved to the above calculated values.

COD removal

COD removal is estimated on the basis of the BOD removal. On the assumption that the treated effluent has characteristics similar to raw sewage, the COD/BOD ratio will not be altered. Therefore, the same BOD removal ratio is employed to estimate COD removal.

COD removal ratio, average flow:	77.6 %
75 % NEPF	73.8 %

T-N and P-P removal

T-N removal ratio, average flow:	37.3 %
75 % NEPF	42.5 %
P-P removal ratio, average flow	39.7 %
75 % NEPF	34.2 %

3) Estimate in reduction of pollutant loads

Pollution reduction by the respective component is as follows :

	Unit	Influent	Effluent	Reduction
BOD Reduction	kg/day	662	241	421
COD reduction	kg/day	1,324	482	842
(assumed to be 2 times of BOD)				

T-N reduction	kg/day	116	73	43
P-P reduction	kg/day	13	8	5

Of the treated effluent, it is estimated that almost a half to one third is estimated to be used for irrigation and the rest is discharged into the public water body.

(4) Donnybrook (Block 1-4) STW

1) Influent sewage flow rate and quality

Almost all of the sewerage areas of the four STWs in Donnybrook are high density residential areas. The total inflow into the STWs is 5,497 m^3/day. Table 4.2.9 and 4.2.10 show the sewage inflow by STW. The quality of the influent is highly contaminated: BOD value is as high as 833 - 864 and 1,021 - 1,130 mg/l for average flow and 75 % NEPF, respectively.

Figure 4.2.6 and 4.2.7 and Table 4.2.9 and 4.2.10 present the schematic flow diagram and features of the STWs.

2) Treatment status

In light of the Evaluation Criteria, the treatment status of this STW is evaluated as follows :

<u>BOD removal</u>

Retention time (AS + SP)	33.3 days (assuming no sludge accumulation)
BOD removal ratio, average flow:	84.0 - 89.1 %
75 % NEPF	81.4 - 86.7 %

The quality of the treated effluent is estimated on the basis of the wastewater stabilization pond design criteria and that sludge will accumulate in the wastewater stabilization pond. The estimate is attempted for the integration of the four sewage treatment works.

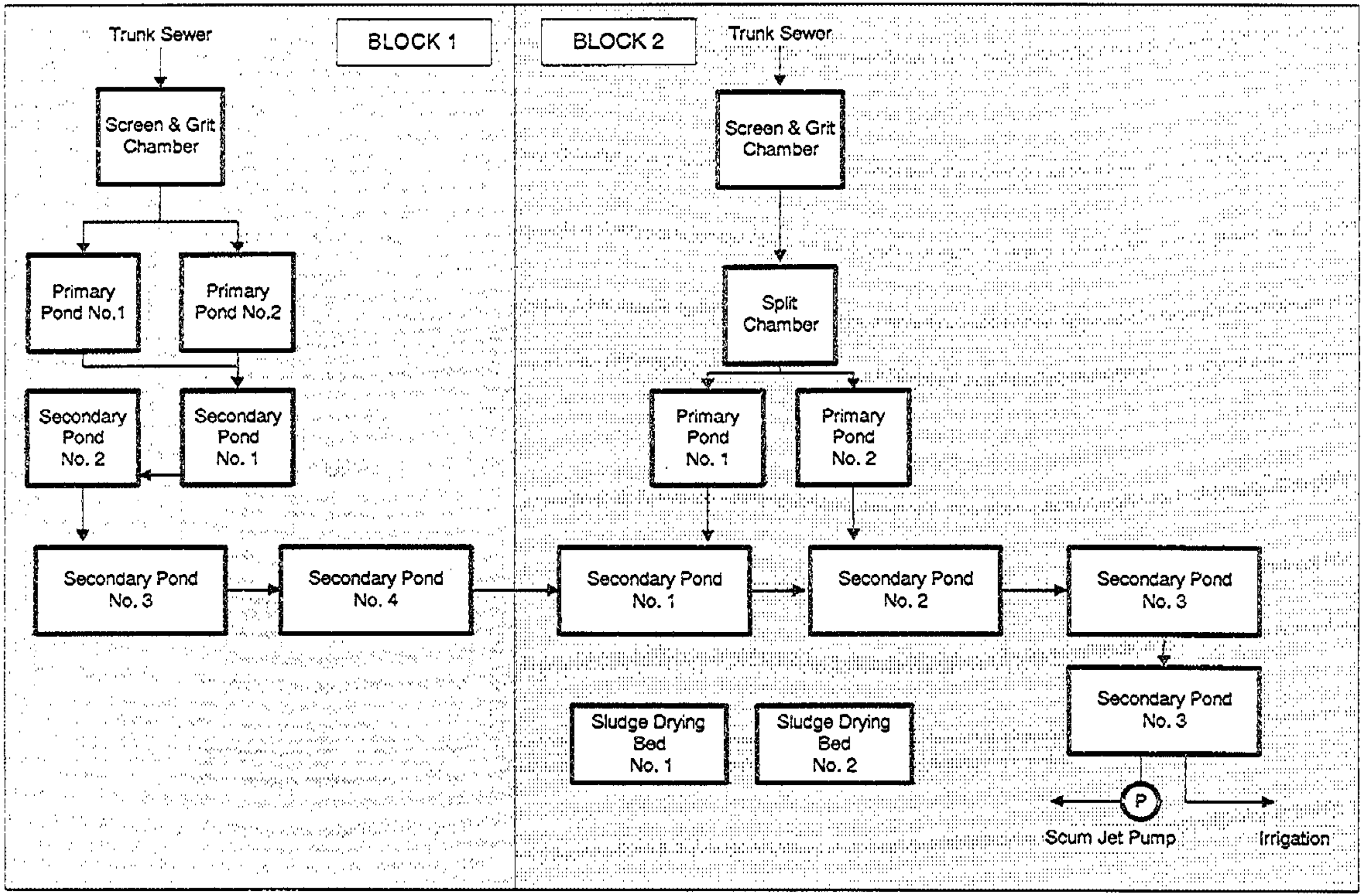

Figure 4.2.6 Existing Donnybrook (Block 1 and 2) Flow Diagram

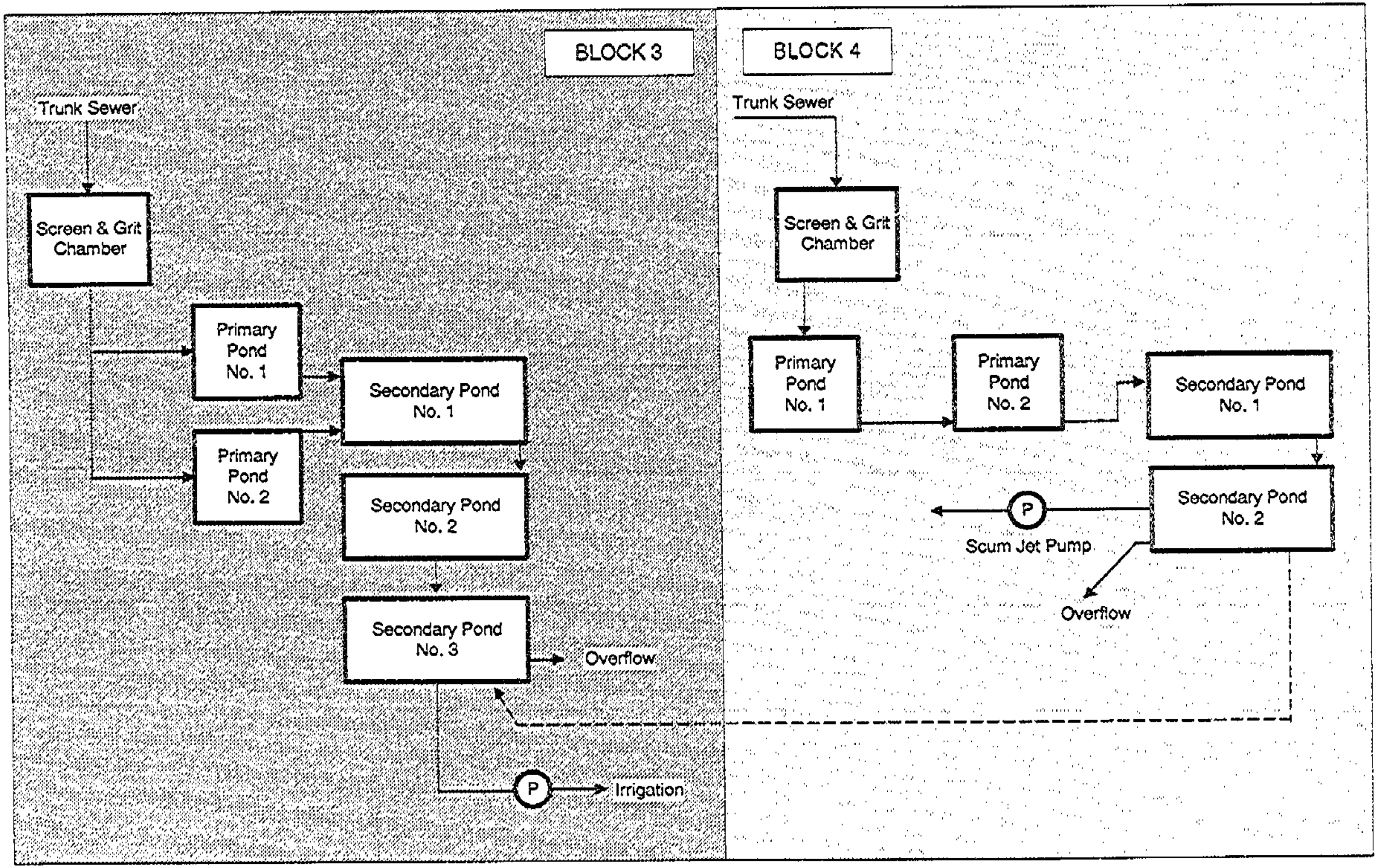

Figure 4.2.7 Existing Donnybrook (Block 3 and 4) Flow Diagram

Table 4.2.9 Donnybrook STW Treatment Performance (Block 1 to 4)

Design Treatment Capacity	Block 1	N/A	Current Flow Rate	Block 1	400 m3/d
	Block 2	N/A		Block 2	1,350 m3/d
	Block 3	N/A		Block 3	1,396 m3/d
	Block 4	N/A		Block 4	2,351 m3/d
	Total	5,500 m3/d		Total	5,497 m3/d
Current influent BOD	Block 1	1,061 mg/L (75%)			856 mg/L (avg.)
	Block 2	1,130 mg/L (75%)			838 mg/L (avg.)
	Block 3	1,062 mg/L (75%)			864 mg/L (avg.)
	Block 4	1,021 mg/L (75%)			833 mg/L (avg.)
Current Influent BOD Load	Block 1	424 kg/d (75%)			342 kg/d (avg.)
	Block 2	1,526 kg/d (75%)			1,131 kg/d (avg.)
	Block 3	1,483 kg/d (75%)			1,206 kg/d (avg.)
	Block 4	2,400 kg/d (75%)			1,958 kg/d (avg.)
	Total	5,833 kg/d			4,637 kg/d
Current Effluent BOD	Block 1	120 mg/L (75%)			95 mg/L (avg.)
	Block 2	160 mg/L (75%)			110 mg/L (avg.)
	Block 3	195 mg/L (75%)			123 mg/L (avg.)
	Block 4	190 mg/L (75%)			136 mg/L (avg.)
Current Effluent BOD Load	Block 1	48 kg/d (75%)			38 kg/d (avg.)
	Block 2	216 kg/d (75%)			149 kg/d (avg.)
	Block 3	272 kg/d (75%)			172 kg/d (avg.)
	Block 4	447 kg/d (75%)			320 kg/d (avg.)
	Total	983 kg/d			679 kg/d

(...cont'd)

Table 4.2.10 Donnybrook STW Treatment Performance (Block 1 to 4) (cont'd)

Pond		Pond Size	Pond Area Pond Volume	Load	Loading	Typical Loading Rate
Block 1	Primary Pond (PP)	No 1 - 2 45m x 60m x H 1 3 m	A = 2,700 x2 = 5,400 m2 V = 3,510 x 2 = 7,020m2	400 m3/d 424 kg/d	7,020 = 17 6 days 424 / 7,020 x 103 =60g BOD/m3/d	
	Secondary Pond (SP)	No 3, No 4 45m x 60m x H 1 3m	A = 2,700 x 2 = 5,400m2 V = 3,510 x 2 = 7,020m3			
		NO 5 45m x145m x Ht 2m	A= 6,520m2 V = 6,250m3	400m3/d	19,070 / 400 = 47 7 days	
		No. 6 45m x 135m x Ht 2m	A = 6,070m2 V = 5,800m3	424 x (1-0 70) = 127kg/d	127 / 1 799 = 71kg/ha/d	
			Total A = 17,990m2 Total V = 19,070m3			
Block 2	Primary Pond (PP)	No 1, No 2 60m x 30m x H3 0m	A = 3,600 x 2 = 7,200m2 V = 3,340 x 2 = 6,680m3	1,350m3/d 1,526kg/d	6,680 / 1,350 = 4 9 days 1,526 / 6,680 x 10^3 = 228g BOD/m3/d	
	Secondary Pond (SP)	No. 1 90m x 50 x Ht 2m	A = 4,500m2 V = 4,250m3	1,350m3/d	68 850 / 1,350 = 51 days	
		No 2 105m x 200m x Ht 2m	A = 21,000 V = 22,600			
		No 3 105m x 240m x Ht 2m	A = 25,200 V = 27,300	1,526kg/d x (1-0 70) = 458kg/d	458 / 6 51 = 70kg/ha/d	
		No 4 60m x 240m x Ht 2m	A = 14,400 V = 14,700			
			Total A = 65,100 Total V = 68,850	1,396m3/d	3,090 / 1,396 = 2 2days	
Block 3	Primary Pond (PP)	No 1 45m x 35m x Ht 3m	A = 1,400m2 V = 1,820m3			
		No 2 30m x 50m x Ht 3m	A = 1,500m2 V = 1,270m3	1,483kg/d	1,483 / 3,090 x 10^3 = 480g BOD/m3/d	
			Total A = 2,900m2 Total V = 3,090m3			
	Secondary Pond (SP)	No. 1 45m x 440m x Ht 2m	A = 19,800m2 V = 19,600m3	1,396m3/d	45,900 / 1,396 = 32 9days	
		No. 2 40m x 400m x Ht 2m	A = 16,000 V = 15,500	1,483 x (1-0 60) = 593kg/d	593 / 4 78 = 124kg/ha/d	
		No 3 30m x 400m x Ht 2m	A = 12,000 V = 10,850			
			Total A = 47,800m2 Total V = 45,900m3			
Block 4	Primary Pond (PP)	No. 1, No. 2 45m x 45m x Ht 3m	A = 3,030 x 2 V = 4,060m2 A = 1,850 x 2 V = 3,700 x 3	2,351m3/d 2,400kg/d	3,700 / 2,351 = 1 6 days 2,400 / 3,700 x 10^3 = 649g BOD/m3/d	1 - 5 days >100gBOD/m3/d
	Secondary Pond (SP)	No. 1 60 x 280 x Ht 2m	A = 16,800m2 V = 17,300m3	2,351m3/d	28,700 / 2,351 = 12 2 days	5 - 45 days
		No. 2 50m x 190m x Ht 2m	A = 9,500m2 V = 11,400m3	2,400 x (1-0 50) = 1,200kg/d	1,200 / 2 63ha = 456kg/ha/d	135kg/ha/d
			Total A = 26,300m2 Total V = 28,700m3			
Total	Primary Pond (PP)		A = 10,060m2 V = 20,490m3	5,497m3/d 5,833kg/d	20,490 / 5,497 = 3 7 days 5,833 / 20,490 x 10^3 = 285g BOD/ha/d	1 - 5 days > 100g BOD/m3/d
	Secondary Pond (SP)		A = 157,190m2 V = 162,520m3	5,497m3/d 5,833 x (1 - 0 65) = 2,042kg/d	162,520 / 5,497 = 29 6 days 2,042 / 15 7 = 130kg/ha/d	5 - 45 days 135kg/ha/d

	Anaerobic Pond	Secondary Pond
Present flow rate	5,497 m^3/day	5,497 m^3/day
Concentration of BOD of influent	1,021 - 1,130 mg/day	357 - 396 mg/l
Influent BOD volume	5,833 kg/day	
BOD removal ratio	65 %	90 %
(referring to Criteria)		
Retention time	3.7 days	29.6 days
BOD of effluent of SP	-	36 - 40 mg/l

Actual monitoring values were 120 - 195 and 95 - 136 mg/l for 75 % NEPF and average flow respectively, which exceeds the calculated values. According to the reconnaissance survey, there is an accumulation of sludge on the bottom of the pond, resulting in shortened the retention times.

An attempt is made to estimate roughly the volume of sludge accumulation on the basis of information given by the operators. It is assumed that 90 % of the SS should be removed by the anaerobic pond.

SS of influent : 600 mg/l

Sludge volume : 600 mg/l x (1 - 0.9) x 5,497 m^3/day = 2,968 kg/day

Assuming that the water content of the sludge at 95 %, volume of sludge is 21,666 m^3/year. According to the operators, the anaerobic pond is periodically de-sludged at intervals of 2 - 4 years. The primary pond has a storage volume of only 20,490 m^3. If desludging is made at intervals of two years, approximately 11,400 m^3/year of sludge ran into the secondary pond. The secondary pond storage volume is 162,520 m^3, which is supposed to be filled up by the sludge from the anaerobic pond within about 14 years.

In fact, the secondary pond shows signs of sludge accumulation to a certain extent as well as slope erosion.

COD removal

COD removal is estimated from BOD removal. On the assumption that the treated effluent has characteristics similar to the raw sewage, the COD/BOD ratio will not be altered. Therefore the same BOD removal ratio is employed to estimate COD removal.

COD removal ratio, average flow:	84.0 - 89.1 %
75 % NEPF	81.4 - 86.7 %

T-N and P-P removal

T-N removal ratio, average flow:	45.6 - 58.2 %
75 % NEPF	52.2 - 68.1 %
P-P removal ratio, average flow:	17.3 - 37.7 %
75 % weight	32.5 - 38.2 %

3) Estimate in reduction of pollutant loads

Pollution reduction by the respective component is as follows :

	Unit	Influent	Effluent	Reduction
BOD Reduction	kg/day			
Block 1	kg/day	342	38	304
Block 2	kg/day	1,131	149	982
Block 3	kg/day	1,206	172	1,034
Block 4	kg/day	1,958	320	1,638
Total	kg/day	4,637	679	3,958
COD reduction	kg/day			
(assumed to be two times of BOD)				
Block 1	kg/day	684	76	608
Block 2	kg/day	2,262	298	1,964
Block 3	kg/day	2,412	344	2,068
Block 4	kg/day	3,916	640	3,276
Total	kg/day	9,274	1,358	7,916
T-N reduction	kg/day			
Block 1	kg/day	78	43	161
Block 2	kg/day	295	134	161

Block 3	kg/day	263	131	132
Block 4	kg/day	438	183	255
Total	kg/day	1,074	491	583
P-P reduction	kg/day			
Block 1	kg/day	7	5	2
Block 2	kg/day	18	15	3
Block 3	kg/day	22	13	9
Block 4	kg/day	34	21	13
Total	kg/day	81	54	27

Of the treated effluent, it is estimated that a half to one-third is estimated to be used for irrigation and the rest is discharged into the public water body.

(5) Zengeza sewage treatment works

1) Influent wastewater flow rate and quality

The sewered service area extends over the residential area and the Tilcol Industrial Area. The ADWF (Average Dry Weather Flow) in 1994 was 36,405 m^3/day and is discharged from the said industrial area. The data in 1995 was incomplete because the flow meter was out of order.

Because of the industrial wastewater, the influent to the STW is highly contaminated: the BOD concentration is as high as 974 mg/l for average flow and 1,160 mg/l for 75 % NEPF. For the purpose of pre-treatment of such highly contaminated wastewater, there are two (2) anaerobic ponds in the Tilcol STW. They are not properly functioning due to a lack of adequate operation and maintenance.

Figure 4.2.8 and 4.2.9 and Table 4.2.11 presents the schematic flow diagram and features of the STW, respectively.

2) Treatment status

In light of the Evaluation Criteria, the treatment status of this STW is evaluated as follows :

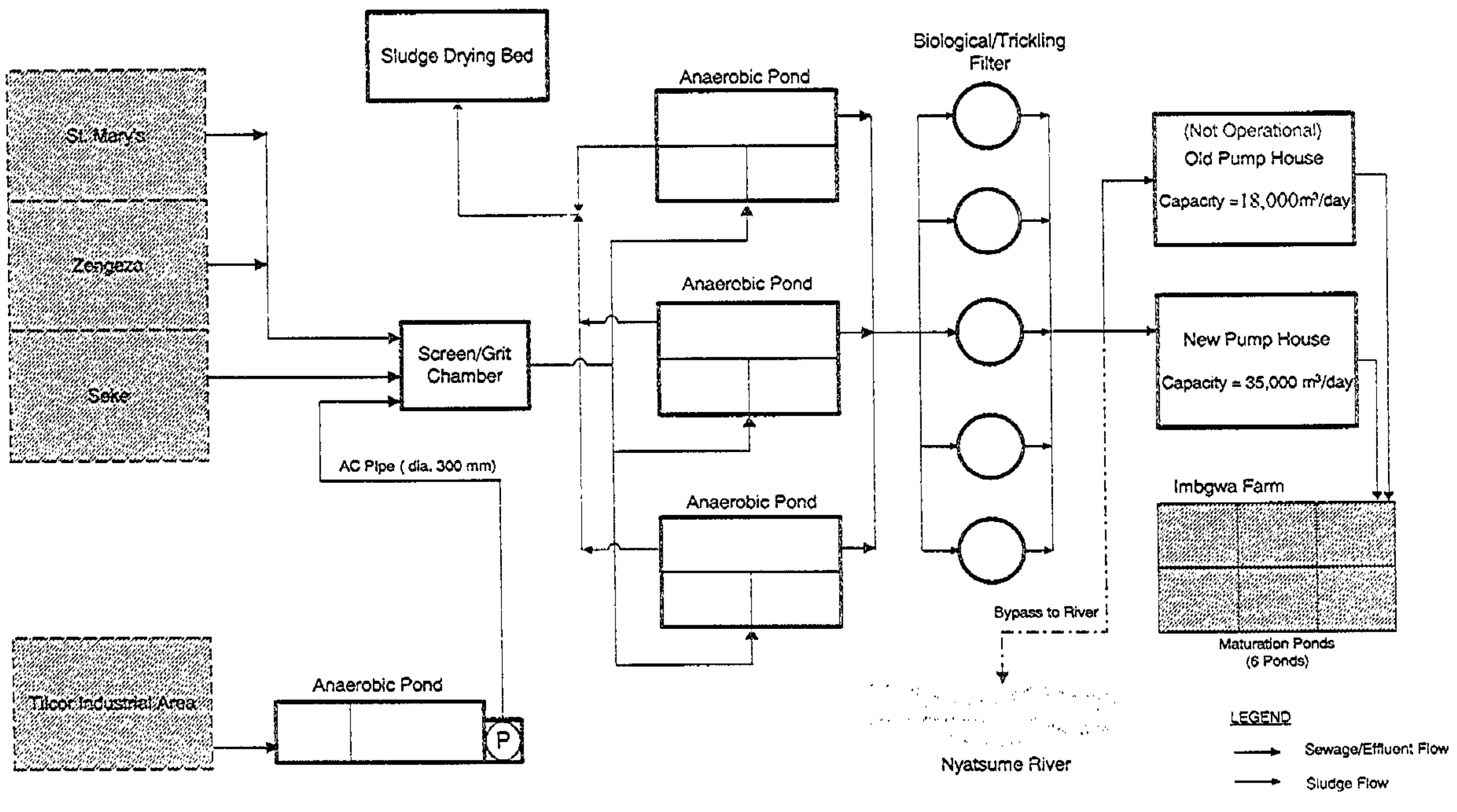

Figure 4.2.8 Flow Diagram of Present Sewage Collection & Treatment of Zengeza System (Design Capacity: 21,750 m³/day)

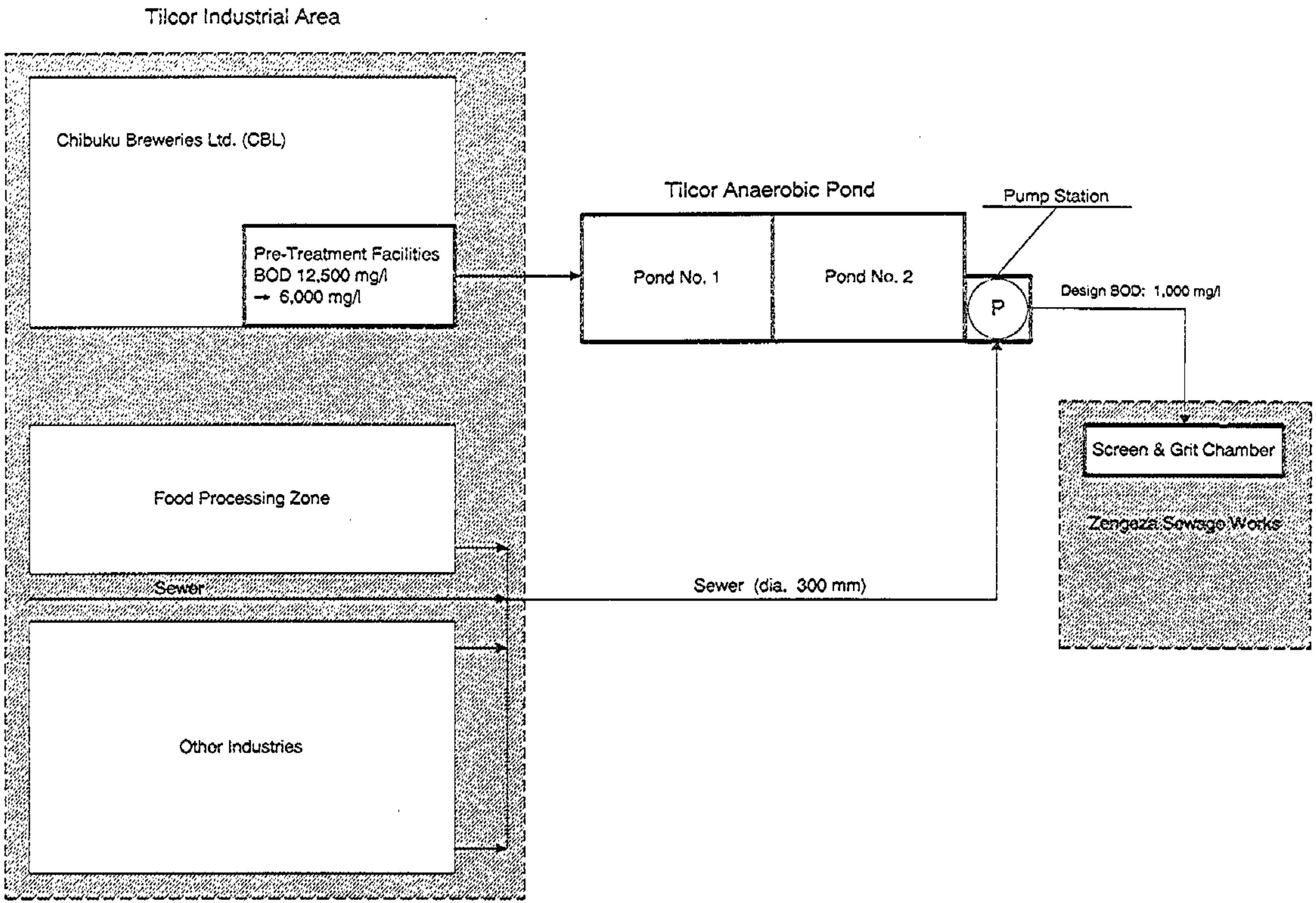

Figure 4.2.9 Present Sewage Collection and Treatment in the Tilcor Industrial Area

Table 4.2.11 Zengeza STW Treatment Performance (Present)

Design Treatment Capacity	20,400 m^3/d				
Current Flow	36,405 m^3/d				
Current Influent BOD	974 mg/L (Avg.)	1,160 mg/L (75%)	Current Effluent BOD	141 mg/L (Avg.)	180 mg/L (75%)
Current influent BOD Load	35,458 kg/d (Avg.)	42,230 kg/d (75%)	Current Effluent BOD Load	5,133 kg/d (Avg.)	6,553 kg/d (75%)

Tank	Tank Size	Tank Area Tank Volume	Load	Loading	Typical Loading Rate	Expected Effluent Quality
Inlet Works (IW)	Trunk Sewer 675, 675, 300 Grit Chamber W 1.8 x L 6.0m x H 7.7m Number 2					
Anaerobic Pond (AP)	3 ponds per unit (total 3 units) Pond Nos. 1 & 2 67.5m x 67.5m x H4.0m Pond No. 3 30.0m x 139.0m x H 3.5m	A = 9,110 x 2 = 18,220m2 V = 13,300 x 2 = 26,600m3 A = 4,170m2 V = 9,700m3 Total A = 22,390m2 x 3 unit = 67,170m2 Total V = 36,300m3 x 3unit = 108,900m3	36,405m3/d 42,230kg/d	108,900/36,405 = 3.0 days 42,230 x 10^3/108,900 = 388g BOD/m3/d	1 - 5 days > 100g BOD/m3/d	
Trickling Filter (TF or Biofilter)	No.1 -No.5 Diameter 38.7 m Depth 3.7 m (3.6 to 3.8) Number 5 Recirculation Pump 625m3/h x 200kw x 2 pumps	A = 1,175 x 5 = 5,875m2 V = 4,350 x 5 = 21,750m3	from the criteria BOD removal ratio in AP 60% 42,230 x (1-0.60) = 16,892kg/d 36,405m3/d	16,892/21,750 = 0.78kg/m3/d 36,405/5,875 = 6.20m3/m2/d		from the criteria BOD removal ration in TF 974 x (1 - 0.60) x (1 - 0.50) = 195mg/L 36,405 x 19 / 10^3 = 7,099 kg/d 1,160 x (1 - 0.60) x (1 -0.50) = 232mg/L 36,405 x 232 / 10^3 = 8,446kg/d
Secondary Sedimentation Tank (SST or Humus Tank)	None					
Drying Bed (DB)	No. 1 96m x 25m x 2 N0. 2 40m x 200m No. 3 95m x 190m	A = 4,500m2 A = 8, 000m2 A = 18,050m2 Total A = 30,550m2				
Pump Station for Irrigation	850m3/h x 44.5m x 150kw x 3 pump (including standby 1)					
Current Influent COD Current Influent COD Load Current Influent T-N Current Influent T-N Load Current Influent P-P Current Influent P-P Load	N/A N/A 52.2mg/L (Avg.) 57.0 mg/L (75%) 1,900kg/d (Avg.) 2,075kg/d (75%) N/A N/A	Current Effluent COD Current Effluent COD Load Current Effluent T-N Current Effluent T-N Load Current Effluent P-P Current Effluent P-P Load	N/A N/A 58.3 mg/L (Avg.) 67.8mg/L (75%) 2,122kg/d (Avg.) 2,468kg/d (75%) N/A N/A			Estimated Effluent Quality COD 195 x 2.0 = 390mg/L 36,405 x 390 x 10^3 = 14,198kg/d

BOD removal

Retention time in Anaerobic Pond:	3.0 day
Hydraulic loading rate in trickling filter:	6.2 m^3/m^2/day
BOD loading rate on tickling filter:	0.78 kg/m^3/day
Total BOD removal ratio, average flow	85.5 %
75 % NEPF	84.5 %

According to the waste stabilisation pond design criteria, the treatment capacity of the existing treatment works was assessed. The theoretical values of BOD of the effluent quality are 195 and 232 mg/l for average flow and 75 % NEPF. This is due to the higher treatment efficiency of the anaerobic pond, being more than 60 %.

COD removal

COD removal is estimated assuming the same removal ratio as that of BOD.

COD removal ratio, average flow:	85.5 %
75 % NEPF	84.5 %

T-N and P-P removal

T-N removal ratio, on average flow:	Nil
P-P removal ratio, on average flow:	Not available

3) Estimate in reduction of pollutant loads

Pollution reduction by the respective component is as follows :

	Unit	Influent	Effluent	Reduction
BOD Reduction	kg/day	35,458	5,133	30,325
COD reduction	kg/day	70,916	10,266	60,650
(assumed to be 2 times of BOD)				
T-N reduction	kg/day	n.a	2,122	n.a
P-P reduction	kg/day	n.a	n.a	n.a

According to the monitoring record, the value of T-N of treated effluent is more than that of the influent quality, probably resulting from over-loaded operation. No data is available for P-P.

(6) Norton STW

1) Influent sewage flow rate and quality

The sewered service area consists of high density residential areas and some factories. About 5 % of the households depends on the septic tanks for the sewage treatment, since they could not be connected to the sewer by gravity owing to topographic constraints. According to the Report on the Feasibility Study for New Sewage Treatment Works, May 1996, the influent flow and its quality are 2,700 m^3/day and the BOD is 660 mg/l, respectively.

Figure 4.2.10 and Table 4.2.12 present the schematic flow diagram and features of the STW respectively.

2) Treatment status

In light of the Evaluation Criteria, the treatment status of this STW is evaluated as follows:

BOD removal

Although the rehabilitation works are on-going, there will be no substantial changes in its treatment capacity even after rehabilitation. In accordance with the trickling filter design criteria, the quality of the treated effluent is attempted to be estimated.

Current flow rate	: 2, 700 m^3/day
Current influent BOD	: 660 mg/l
Current influent BOD volume	: 1,782 kg/day
BOD removal ratio in primary tank	: 50 % (from the Criteria)
Trickling Filter influent BOD	: 660 x (1-0.50) = 330 mg/l
BOD removal ratio in Trickling Filter	: 60 % (from the criteria)
Final Settling Tank effluent BOD	: 330 x (1-0.60) =132 mg/l

The monitoring record shows a BOD value of 520 mg/l; however, this was measured when the sewage works were out of order. When the reconstruction/rehabilitation works will be completed, it is expected that the treated effluent quality will be almost the same as the theoretical value.

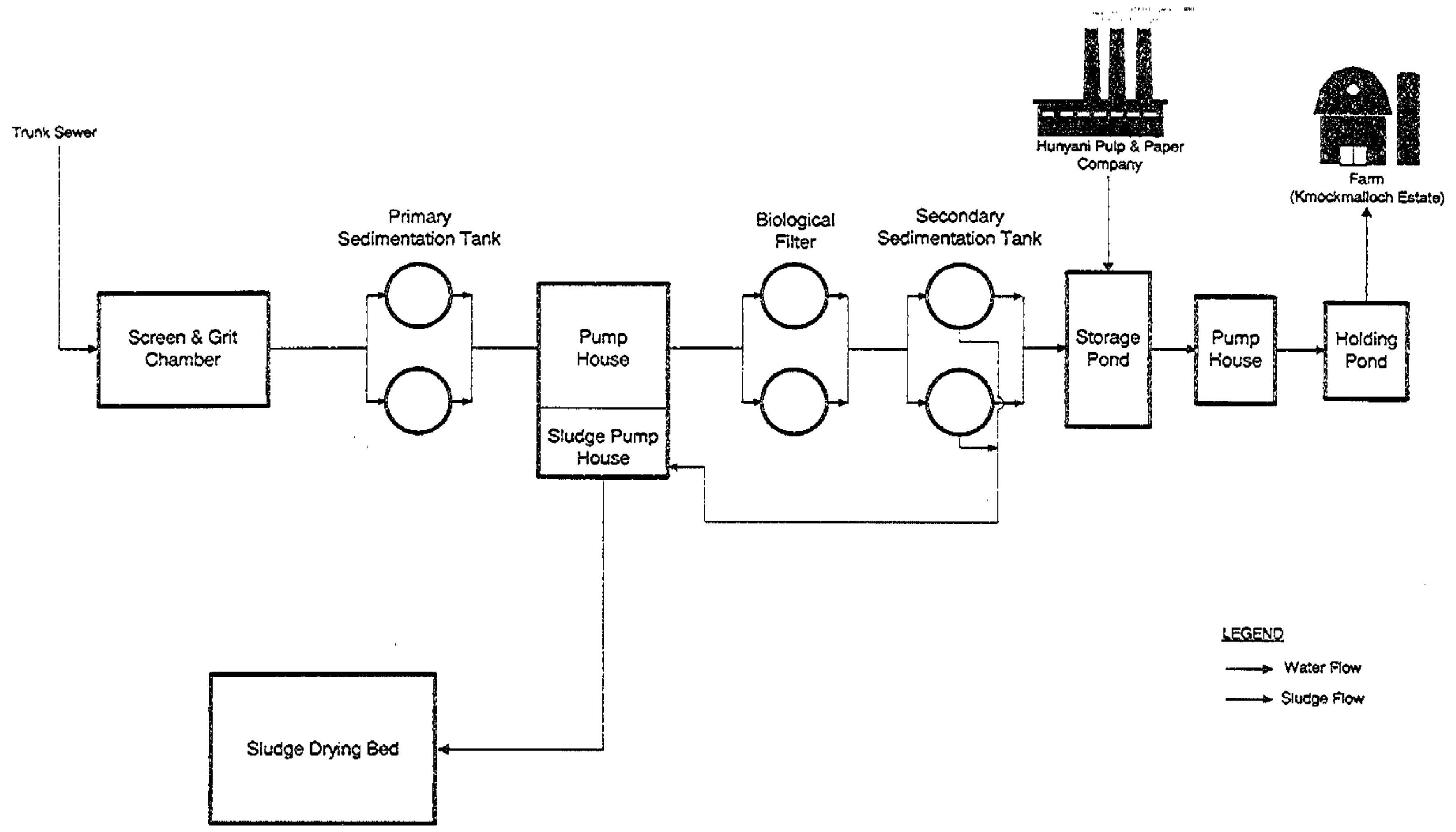

Figure 4.2.10 Existing Norton STW Flow Diagram (Design Capacity: 3,400 m^3/day)

Table 4.2.12 Norton STW Treatment Performance (Present)

Design Treatment Capacity	3,400 m^3/d		
Current Flow	2,700 m^3/d		
Current Influent BOD	660mg/L	Current Effluent BOD	520mg/L
Current Influent BOD Load	1,782kg/d	Current Effluent BOD Load	1,404kg/d

Tank	Tank Size	Tank Area Tank Volume	Load	Loading	Typical Loading Rate	Expected Effluent Quality
Inlet Works (I W)						
Primary Sedimentation Tank (PST)	Diameter 12.0m Depth 2.8m Number 2	A = 113 x 2 = 226m2	2,700m3/d 2,700 x 2 = 5,400m3/d	2,700/226 = 11.9m3/m2/d 5,400/226 = 23.9m3/m2/d	28.8 to 43.2 m3/m2/d at PDWF	
Trickling Filter (TF or Biofilter)	Diameter 21.5m Depth 3.4m Number 2	A = 363 x 2 = 726m2 V = 1,234 x 2 = 2,468 m3	From the criteria BOD removal ratio in PST 50% 1,782 x (1-0.5) = 891kg/d 2,700m3/d	891/2,468 = 0.36 kg/m3/d 2,700/726 = 3.7 m3/m2/d		From the criteria BOD removal ratio in TF 660 x (1 - 0.50) x (1 - 0.60) = 132mg/L 891 x (1 -0.60) = 356kg/d
Secondary Sedimentation Tank (SST or Human Tank)	Diameter 14.0m Number 1	A = 154m2	2,700m3/d 2,700 x 2 = 5,400mg/d	2,700/154 = 17.5m3/m2/d 5,400/154 = 35.1m3m2/d	43.2m3m2/d at PDWF	
Storage Pond	42m x 142m x H 1.4 m	A = 6,000m2 V = 6,700m3				
Pump Station for Irrigation						
Current Influent COD	1,496 mg/L	Current Effluent COD	1,192 mg/L			
Current Influent COD Load	4,039 kg/d	Current Effluent COD	3,218 kg/d			
Current Influent T - N	83.3 mg/L	Current Effluent T-N	65.8 mg/L			
Current Influent T -N Load	225 kg/d	Current Effluent T-N Load	178 kg/d			
Current Influent P - P	7.6 mg/L	Current Effluent P-P	7.6 mg/L			
Current Influent P - P Load	21 kg/d	Current Effluent P-P Load	21 kg/d			

BOD removal

Although the rehabilitation works are on-going, there will be no substantial changes in its treatment capacity even after rehabilitation. In accordance with the trickling filter design criteria, the quality of the treated effluent is attempted to be estimated.

Current flow rate	: 2, 700 m^3/day
Current influent BOD	: 660 mg/l
Current influent BOD volume	: 1,782 kg/day
BOD removal ratio in primary tank	: 50 % (from the Criteria)
Trickling Filter influent BOD	: 660 x (1-0.50) = 330 mg/l
BOD removal ratio in Trickling Filter	: 60 % (from the criteria)
Final Settling Tank effluent BOD	: 330 x (1-0.60) =132 mg/l

The monitoring record shows a BOD value of 520 mg/l; however, this was measured when the sewage works were out of order. When the reconstruction/rehabilitation works will be completed, it is expected that the treated effluent quality will be almost the same as the theoretical value.

COD removal

COD removal is estimated assuming the same removal ratio as that of BOD.

COD removal ratio, average flow	: 80 %

T-N and P-P removal

T-N removal ratio, average flow	: 30 % (referring to the Criteria)
P-P removal ratio, average flow	: 30 % (referring to the Criteria)

3) Performance in reduction of pollutant loads

Pollution reduction by the respective component is as follows :

	Unit	Influent	Effluent	Reduction
BOD Reduction	kg/day	1,782	1,404	378
COD reduction	kg/day	4,039	3,218	821
T-N reduction	kg/day	225	178	47
P-P reduction	kg/day	21	21	0

All the treated effluent is used to irrigate pulp-wood forestry land and pasture. Due to the limited capacity of the pump, a certain amount of overflow occurs and flows into Lake Manyame, although what amount is unknown.

(7) Ruwa STW

1) Influent wastewater flow rate and quality

The sewered area covers mostly residential areas. According to the latest data (March 1996), the influent flow is 2,865 m^3/day, which is remarkably large compared to the population. It is suspected that it is mixture of rainwater or unidentified water.

According to the records collected during the period from October 1994 to September 1995, the BOD concentrations of the influent raw sewage were 657 and 580 mg/l for average flow and 75 % NEPF, respectively. Such a high BOD concentration is supposed to be caused by industrial wastewater.

Figure 4.2.11 and Table 4.2.13 present the schematic flow diagram and features of the STW, respectively.

2) Treatment status

In light of the Evaluation Criteria, the treatment status of this STW is evaluated as follows :

<u>BOD removal</u>

Retention time	: 20.6 days
BOD removal ratio	: 80.0 %

At the existing STW, the expected BOD values of the treated effluent are 53 and 46 mg/l for average flow and 75 % NEPF respectively, while the actual recorded values are 134 and 185 mg/l. Such a large discrepancy could be attributed to industrial wastewater and to the unstable operation of the sewage works at its initial stage. According to the investigation carried out in July 1996, the quality of the treated effluent is judged to be almost the same value as the expected value.

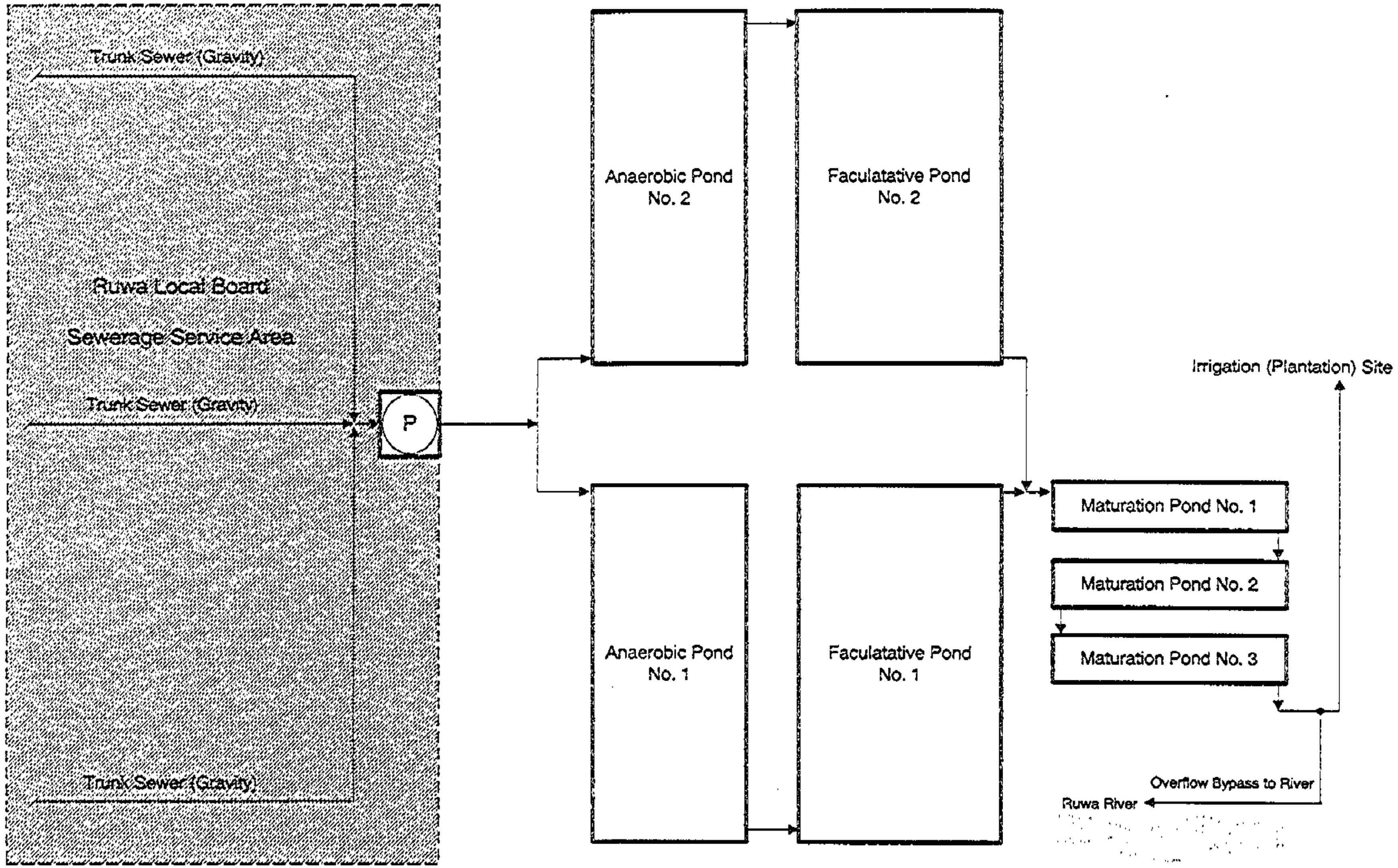

Figure 4.2.11Existing Ruwa STW Flow Diagram (Design Capacity: 5,300 m ^{3}/day)

Table 4.2.13 Ruwa STW Treatment Performance (Present)

Design Treatment Capacity	5,300m3/d				
Current Flow	2,863m3/d				
Current Influent BOD	657mg/L (Avg.)	380mg/L (75%)	Current Effluent BOD	134mg/L (Avg.)	185mg/L (75%)
Current Influent BOD Load	1,882kg/d (Avg.)	1,662kg/d (75%)	Current Effluent BOD Load	384kg/d (Avg.)	530kg/d (75%)

Pond	Pond Size	Pond Area Pond Volume	Load	Loading	Typical Loading Rate	Estimated Effluent Quality
Anaerobic Pond (AP)	No.1, No.2 92.5m x 43.5m x H2.5m	A = 4,020 x 2 = 8,040m^2 V = 6,765 x 2 = 13,530m3	2,863m3/d 1,662kg/d	13,530/2,863 = 4.7 days 1,662 x 1000/13,530 =123gBOD/m3/d	1 -5 days > 100g BOD/m3/d	
Facultative Pond (FP)	No.1 , No.2 92.5m x 177.5m x H1.5m	A = 16,420 x 2 = 32,840m2 V = 20,540 x 2 = 41,080m3	From the criteria BOD removal ratio 60% 1,662 x (1-0.60) =665kg/d	665/3.28 = 203kg/ha/d	135kg/ha/d	
Maturation Pond (MP)	No.1, No.2, No.3 92.5m x 37.5m x H1.5m	A = 3,670 x 3 = 11,010m2 V = 3,320 x 3 = 9,960m3 FP + MP Total A = 43,850m2 = 4.39ha Total V = 51,040m3	2,863m3/d	51,040/2,863 = 17.8 days	3 - 45 days	From the criteria BOD removal ratio in FP 80% 380 x (1 -0.60) x (1-0.80) = 46mg/L (75%) 2,863 x 46 x 10^{3} = 132kg/d 657 x (1-0.60) x (1-0.80) = 53mg/L (avg.) 2,863 x 53 x 10^{3} = 152kg/d
Pump Station	200mm x 4.5m3/min x55kw x 3 unit (including 1 standby)					
Current Influent COD Current Influent COD Load Current Influent T-N Current Influent T-N Load Current Influent P-P Current Influent P-P Load	N/A N/A 44.7mg/L (Avg.) 310mg/L (75%) 128kg/d (Avg.) 88.8kg/d (75%) 10.2 mg/L (Avg.) 8.4mg/L (75%) 29.2kg/d (Avg.) 24.1kg/d (75%)		Current Effluent COD Current Effluent COD Load Current Effluent T-N Current Effluent T-N Load Current Effluent P-P Current Effluent P-P Load	N/A N/A 2.8mg/L (Avg.) 3.1 mg/L (75%) 8.0 kg/d (Avg.) 8.9 kg/d (75%) 2.4mg/L (Avg.) 3.2mg/L (75%) 6.9kg/d (Avg.) 9.2kg/d (75%)		Estimated Effluent Quality COD 106 to 263mg/L 2,863 x (106 to 263) x 10^{3} = 304 to 759 kg/d T-N 44.7 x (1-0.50) = 22.4 mg/L 128 x (1-0.50) = 64kg/d P-P 10.2 x (1-0.30) = 7.1mg/L 29.2 x (1-0.30) = 19.0kg/d

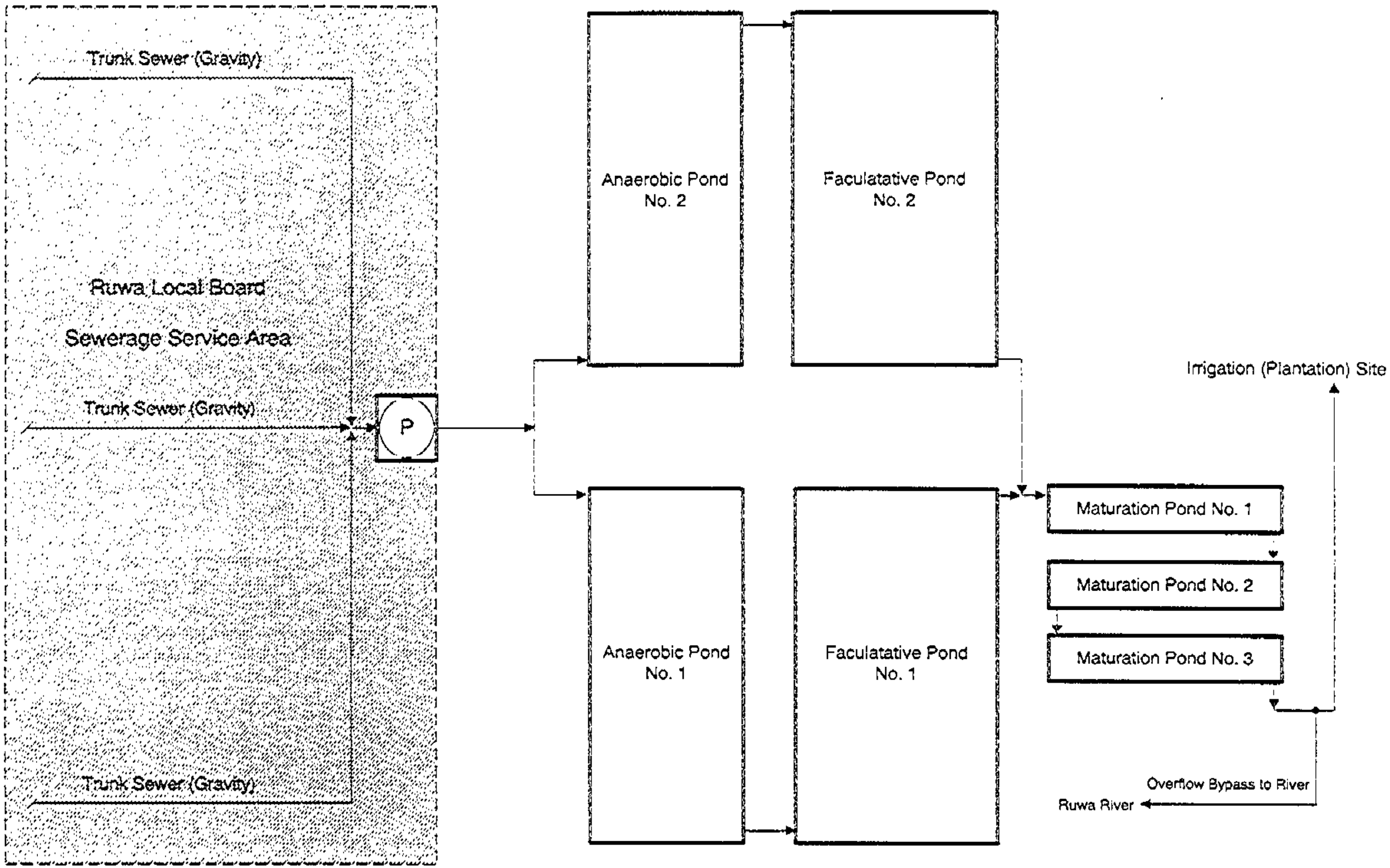

Figure 4.2.11 Existing Ruwa STW Flow Diagram (Design Capacity: 5,300 m ^{3}/day)

Table 4.2.13 Kuwa STW Treatment Performance (Present)

Design Treatment Capacity	3,300m3/d			
Current Flow	2,863m3/d			
Current Influent BOD	657mg/L (Avg.)	580mg/L (75%)	Current Effluent BOD	134mg/L (Avg.)	185mg/L (75%)
Current Influent BOD Load	1,882kg/d (Avg.)	1,662kg/d (75%)	Current Effluent BOD Load	384kg/d (Avg.)	530kg/d (75%)

Pond	Pond Size	Pond Area Pond Volume	Load	Loading	Typical Loading Rate	Estimated Effluent Quality
Anaerobic Pond (AP)	No.1, No.2 92.5m x 43.5m x H2.5m	$A = 4,020 \times 2 = 8,040m^2$ V = 6,765 x 2 = 13,530m3	2,863m3/d 1,662kg/d	13,530/2,863 = 4.7 days 1,662 x 1000/13,530 =123gBOD/m3/d	1 - 5 days > 100g BOD/m3/d	
Facultative Pond (FP)	No.1, No.2 92.5m x 177.5m x H1.5m	A = 16,420 x 2 = 32,840m2 V = 20,540 x 2 = 41,080m3	From the criteria BOD removal ratio 60% 1,662 x (1-0.60) =665kg/d	665/3.28 = 203kg/ha/d	135kg/ha/d	
Maturation Pond (MP)	No.1, No.2, No.3 92.5m x 37.5m x H1.5m	A = 3,670 x 3 = 11,010m2 V = 3,320 x 3 = 9,960m3 FP + MP Total A = 43,850m2 = 4.39ha Total V = 51,040m3	2,863m3/d	51,040/2,863 = 17.8 days	5 - 45 days	From the criteria BOD removal ratio in FP 80% 580 x (1-0.60) x (1-0.80) = 46mg/L (75%) $2,863 \times 46 \times 10^3 = 132kg/d$ 657 x (1-0.60) x (1-0.80) = 53mg/L (avg.) $2,863 \times 53 \times 10^3 = 152kg/d$
Pump Station	200mm x 4.5m3/min x55kw (x 3 unit (including 1 standby))					
Current Influent COD Current Influent COD Load Current Influent T-N Current Influent T-N Load Current Influent P-P Current Influent P-P Load	N/A N/A 44.7mg/L (Avg.) 310mg/L (75%) 128kg/d (Avg.) 88.8kg/d (75%) 10.2 mg/L (Avg.) 8.4mg/L (75%) 29.2kg/d (Avg.) 24.1kg/d (75%)		Current Effluent COD Current Effluent COD Load Current Effluent T-N Current Effluent T-N Load Current Effluent P-P Current Effluent P-P Load	N/A N/A 2.8mg/L (Avg.) 3.1 mg/L (75%) 8.0 kg/d (Avg.) 8.9kg/d (75%) 2.4mg/L (Avg.) 3.2mg/L (75%) 6.9kg/d (Avg.) 9.2kg/d (75%)		Estimated Effluent Quality COD 106 to 265mg/L $2,863 \times (106 \text{ to } 265) \times 10^3 = 304 \text{ to } 759$ kg/d T-N 44.7 x (1-0.50) = 22.4 mg/L 128 x (1-0.50) = 64kg/d P-P 10.2 x (1-0.30) = 7.1mg/L 29.2 x (1-0.30) = 19.0kg/d

COD removal

COD removal is estimated assuming the same removal ratio as that of BOD.

COD removal ratio, average flow : 92 %

T-N and P-P removal

T-N removal ratio, average flow : 50 % (referring to the Criteria)

P-P removal ratio, average flow : 30 % (referring to the Criteria)

3) Estimate in reduction of pollutant loads

Pollution reduction by the respective component is as follows :

	Unit	Influent	Effluent	Reduction
BOD Reduction	kg/day	1,882	384	1,498
COD reduction	kg/day	3,764	768	2,996
T-N reduction	kg/day	128	8	120
P-P reduction	kg/day	29	7	22

The treated effluent is used for irrigation. When the treated effluent is not used for irrigation, it is discharged into the river.

2. Evaluation Criteria by Treatment Method

(1) Objective

1) Introduction

The purpose of this section is to provide evaluation criteria, in terms of BOD, COD, T-N and P-P removal rate, for the following treatment method: Wastewater Stabilisation Pond (WSP), Trickling Filter (TF) and Biological Nutrient Removal (BNR). These criteria can be used to evaluate or appraise the present and future contribution of STWs to water pollution control. The general conditions for their processes are illustrated in Table 4.2.14, which examines the effectiveness in removing organic matter and nutrients.

2) The relation between COD and BOD

The relation between COD and BOD can be examined by utilizing actual data and by referring to the Sanitation Manual, Design Procedures No. 5 in Zimbabwe (hereinafter referred to as "the manual").

Table 4.2.14 Performance for the Removal of Organic Matter and Nutrients by Treatment Methods

Items	WSP	TF	BNR
BOD	Effective	Effective. PST (or AP) and TF (including SST) are considered separately.	Effective. PST (AP) and reactors are considered separately. Removal rates are obtained from actual data.
COD	Effective; removal rates are estimated by the relation to BOD.		
T-N	Slightly effective. Removal rates are obtained from actual data.	Removal in PST (or AP) is ignored. Removal rates of TF (including SST) are obtained from actual data.	Removal in PST (or AP) is ignored. Removal rates of reactor (including SST) are obtained from actual data.
P-P	Slightly effective. Removal rates are obtained from actual data.	Removal in PST (or AP) is ignored. Removal rates of TF (including SST) are obtained from actual data.	Removal in PST (or AP) is ignored. Removal rates of reactor (including SST) are obtained from actual data.

A summary of COD data from each treatment works is provided in Table 4.2.15. This table shows the ratio of COD and BOD in influent quality as COD/BOD=2.10. This corresponds the manual's statement that "COD is about twice BOD_5." Thus, for raw sewage, the ratio of COD and BOD can be assumed to be 2.0.

For treated effluent, Table 4.2.15 shows the following:

- BOD ≤ 30mg/L COD/BOD=4.33
- BOD ≤ 25mg/L COD/BOD=4.66
- BOD ≤ 20mg/L COD/BOD=5.47.

According to this data, COD/BOD ratio can be roughly assumed to be 5.0. Incidentally, the Effluent Standard states that COD must be less than 60mg/l, from which it appears that if COD = 60mg/l, BOD = 12mg/l. Thus, it can be estimated that if BOD is 30 mg/l or less, COD/BOD will be 5.0.

Table 4.2.15 Relation between COD and BOD

			Influent			Effluent			Note
			COD mg/L	BOD mg/L	COD/BOD	COD mg/L	BOD mg/L	COD/BOD	
Crowborough	Unit 1	Avg.	1,355	619	2.19	282	128	2.2	
	Unit 2	75%	1,726	792	2.18	341	157	2.17	TF
	Unit 3	Avg.	1,355	619	2.19	92.5	21.7	4.26	
		75%	1,726	792	2.18	104.5	30.1	3.47	BNR
Firle	Unit 1	Avg.	1,026	483	2.12	268	153	1.75	
	Unit 2	75%	1,225	641	1.91	338	209	1.62	TF
	Unit 3	Avg.	997	461	2.16	107.6	23.6	4.56	
		75%	1,225	640	1.91	106.2	27.4	3.88	BNR
	Unit 4	Avg.	975	496	1.97	94.7	17.3	5.47	
		75%	1,161	661	1.76	108.3	25.0	4.33	BNR
Norton		Avg.							
		75%	1,496	660	2.27		520	2.29	TF
Hatcliff		Avg.	1,725	705	2.45		268.7	1.96	
		75%	1,793	810	2.21		351	1.64	AL
					1.91 - 2.45	BOD <= 30mg/L		3.47 - 5.47	
				Average	2.10	BOD		4.33 (Avg.)	

Table 4.2.16 BOD Removal Ratio in Anaerobic Pond

Retention time (d)	BOD_5 reduction (%) Influent BOD		
	< = 400mg/L	500 - 600mg/L	>= 800mg/L
1	30	40	50
2.5	40	50	60
5	50	60	70

Note: Adapted from "Sanitation manual Design procedures, No.5 in Zimbabwe"

Table 4.2.17 BOD Removal Ratio in Anaerobic Pond (AP)
(At Zengeza STW)

Date	Raw	AP Effluent			Final Effluent
		SET 1	SET 2	SET 3	
10. 01. 95	820	137.5	135	85	125
24. 01. 95	620	120	145	90	95
07. 02. 95	840	210	205	215	220
20. 04. 95	810	215	185	210	175
08. 05. 95	720	150	150	280	105
06. 05. 95	800	160	130	130	130
Average	768		164		142

BOD Removal Ratio in AP 78.6%
BOD Removal Ratio in TF 13.4%
BOD Removal Ratio in the whole STW 81.5%

(2) Evaluation Criteria for Wastewater Stabilization Pond (WSP)

The criteria was formulated based on the manual and relevant documents.

1) BOD removal

a. BOD removal rate in Anaerobic Pond

The manual states that a removal rate of 50-70% is possible with 5 days retention time. Removal rates tends to be higher for longer retention times and higher BOD concentrations. Moreover, at least 30% removal rate can be expected by sedimentation. Table 4.2.16 shows the BOD removal rate in Anaerobic Pond by influent BOD concentration and retention time.

Actual local data was available from the Zengeza Sewage Treatment Works and the data is summarized in Table 4.2.17. Retention time of Anaerobic Pond (AP) is 3.0 days.

As shown in Table 4.2.17, influent BOD is about 800mg/l, and the removal ratio is about 80%. Other data in relevant documents also shows the removal ratio of over 70 %. Taking seasonal variation into consideration, a maximum removal ratio can be estimated as 70%.

b. BOD Removal Ratio in Facultative Pond

To calculate the BOD removal ratio for each retention time, the Wehner and Wilhelm method are adopted. BOD removal ratio is presented in Table 4.2.18,using a water temperature of 14 °C, the average temperature of the coldest month in Harare.

c. Removal Ratio of T-N and P-P

The removal ratios for T-N and P-P have been estimated based on current data from WSPs. Data from Marlborough and Donnybrook (Block 1-4) STWs has been arranged and summarised in Table 4.2.19. Removal ratio for T-N and P-P are roughly 50% and 30%, respectively.

(3) Evaluation Criteria for Trickling Filter (TF)

The criteria was formulated based on the manual and relevant documents.

Table 4.2.18 BOD Removal Ratio in Facultative Pond

BOD Removal (%)	kt	k (d^{-1})	t (days)
95	8.0	0.18	44
90	5.0	0.18	28
80	2.8	0.18	16
70	1.8	0.18	10
60	1.3	0.18	7
50	0.85	0.18	5
40	0.7	0.18	4
30	0.6	0.18	3

Note: k; First - order reaction constant $k_T = k_{20°C}\,\theta^{T-20}$
θ; Temperature coefficient θ = 1.06 at 20°C
T; Pond temperature in winter T = 14°C
(Mean temperature of the coldest month)
t; Detention time (days)
d; Dispersion factor d = 1.0

Note: The value is calculated by using the first - order removal-rate equation developed by Wehner and Wilhelm, Figure of values of kt in the Wehner and Wilhelm equation versus percent remaining. Adapted from "Wastewater Engineering, Treatment. Disposal and Reuse, Third Edition." Metcalf & Eddy, INC. pp.644 - 646.

Table 4.2.19 T-N, T-P Removal Ratio in WSP

		Influent		Effluent		Removal Ratio	
		T - N	T - P	T - N	T - P	T - N	T - P
		mg/L	mg/L	mg/L	mg/L	%	%
Marlborough	Avg.	58.1	6.3	36.4	3.8	37.3	39.7
	75%	73.0	7.3	42.0	4.8	42.5	34.2
Donnybrook	Avg.	195	16.8	106	11.7	45.6	30.4
Block 1	75%	230	20.0	110	13.5	52.2	32.5
	Avg.	219	13.3	99.6	11.0	54.5	17.3
Block 2	75%	268	17.8	108.0	12.0	59.7	32.6
	Avg.	188	15.5	93.7	9.6	49.8	38.1
Block 3	75%	270	18.0	86.0	11.7	68.1	35.0
	Avg.	186	14.6	77.8	9.1	58.2	37.7
Block 4	75%	210	17.0	92.0	10.5	56.2	38.2
	Avg.					49.1	32.6
Average	75%					55.7	34.5

Table 4.2.20 Hydraulic loading rate in Primary Settling Tank

	At Average Dry Weather Flow (ADWF)	At Peak DWF	Remarks
Zimbabwe design manual		1.2 - 1.8m3/m2/h (= 28.8 - 43.2m3/m2/d)	BOD Removal ratio 30 - 50%
Zimbabwe design manual Dortmund type	1.2m3/m2/h (= 28.8m3/m2/d)	2.4m3/m2/h (= 57.6m3/m2/d)	
Wastewater Engineering	1.5 - 2.0m3m2/h (= 35.6 - 48.8m3m2/d)	3.4 - 5.1m3/m2/h (= 81.4 - 122.1m3m2/d)	
Adoption	1.2m3/m2/h (= 28.8m3/m2/d)		

1) Removal of BOD

a. Hydraulic Loading Rate in Primary Sedimentation Tank

Referred to the manual and other relevant documents, results of calculations are shown in Table 4.2.20.

b. Loading Rate in Trickling Filter

Referred to the manual and other relevant documents, results of calculations are shown in Table 4.2.21.

The actual data from the Crowborough and Firle STWs are summarised in two tables. Table 4.2.22 shows the loading rate and Table 4.2.23 presents the BOD removal rate.

Applying this data to Table 4.2.21, it reveals that the hydraulic loading is in the intermediate rate range, and the BOD loading is at the high end of the intermediate rate range in Crowborough. BOD removal rate of 60% is comparatively high and it attributes to high influent BOD concentration. In Firle, the hydraulic loading rate belongs to the high rate range and the BOD loading rate is above the upper limit of the high range. Apparent from these actual data, Firle STW is over-loaded and it resulted in low removal rate.

c. Hydraulic Loading Rate in Secondary Sedimentation Tank

Referred to the manual and other relevant documents, results of calculations are shown in Table 4.2.24.

2) Removal of T-N and P-P

The object of trickling filter is removal of organic matter, not nutrients. However, nutrient removal also can be expected slightly. The removal rate is assumed to be fairly constant, even in overload conditions.

As summarised in Table 4.2.25, some rates exceed 30% on both T-N and P-P. Thus, it can be estimated that trickling filter has about a 30% removal rate for T-N and P-P.

Table 4.2.21 Loading Rate in TF

	Hydraulic Loading m3/m2/d or m3/m3/d	BOD Loading kg/m3/d	Note
Zimbabwe design manual	0.5 m3/m3/d	0.1	Wothoit recirculation
		0.2	with recirculation
Wastewater Engineering Low - rate	1.17 - 3.52 m3/m2/d	0.08 - 0.40	BOD removal efficiency 80 - 90%
Intermediate - rate	3.52 - 9.39 m3/m2/d	0.24 - 0.48	BOD removal efficiency 50 - 70%
High - rate	9.39 - 37.6 m3/m2/d	0.48 - 0.96	BOD removal efficiency 65 - 85%
Adoption	0.5 m3/m3/d	0.1	Without recirculation
		0.2	With recirculation

Table 4.2.22 Hydraulic and BOD Loading Rate in TF, PST (Actual)

	PST	TF	
	Hydraulic Loading Rate	Hydraulic Loading Rate	BOD Loading Rate
Firle	at ADWF 69.8m3/m2/d	12.8m3/m2/d	1.11kg/m3/d
Crowborough	at ADWF 26.2m3/m2/d	4.82m3/m2/d	0.52kg/m3/d

Table 4.2.23 BOD Removal Rate in TF, PST (Actual)

		Primary Sedimentation Tank			TF		
		Influent BOD mg/L	Effluent BOD mg/L	Removal Rate %	Influent BOD mg/L	Effluent BOD mg/L	Removal Ratio %
Firle Unit 1, 2	Avg.	483	257	46.8	257	153	40.5
	75%	641	301	53.0	301	209	30.6
Crowborough Unit 1, 2	Avg.	619	315	49.1	315	128	59.4
	75%	792	397	49.9	397	157	60.5

Table 4.2.24 Hydraulic Loading Rate in Secondary Settling Tank (In case of Trickling Filter)

	At Average Dry Weather Flow	At Peak DWF
Zimbabwe Design manual	-	1.2 - 1.8m3/m2/h (= 28.8 - 43.2m3/m2/d)
Zimbabwe design manual Dortmund type	1.2m3/m2/h (= 28.8m3/m2/d)	2.4m3/m2/h (= 57.6m3/m2/d)
Wastewater Engineering	0.7 - 1.1m3/m2/h (= 16.3 - 24.4m3/m2/d)	1.7 - 2.0m3/m2/h (= 40.7 - 48.8m3/m2/d)
Adoption Dortmund type	1.2m3/m2/h (= 28.8m3/m2/d)	

Table 4.2.25 T-N-P-P Removal Ratio in Trickling Filter

		Influent T-N mg/L	Influent P-P mg/L	Effluent T-N mg/L	Effluent P-P mg/L	Removal Ratio T-N %	Removal Ratio P-P %
Firle Unit 1, 2	Avg.	64.1	8.0	38.7	4.5	39.6	43.8
	75%	78.0	9.0	48.0	5.5	38.5	38.9
Crowborough	Avg.	55.0	6.7	38.1	5.0	30.7	25.4
	75%	66.0	7.8	47.0	5.7	28.8	26.9
Average	Avg.	59.6	7.4	38.4	4.8	35.6	35.1
	75%	72.0	8.4	47.5	5.6	34.0	33.3

P - P: Phospate

Table 4.2.26 BOD Removal Ratio in BNR

STW		Primary Sedimentation Tank Influent BOD mg/L	Primary Sedimentation Tank Effluent BOD mg/L	Primary Sedimentation Tank Removal Ratio %	BNR Influent BOD mg/L	BNR Effluent BOD mg/L	BNR Removal Ratio %
Firle Unit 3	Avg.	461	243	47.3	243	23.6	90.3
	75%	640	298	53.4	298	27.4	90.8
Firle Unit 4	Avg.	496	243	51.0	243	17.3	92.9
	75%	661	298	54.9	298	25.0	91.6
Crowborough Unit 3	Avg.	619	315	49.1	315	21.7	93.1
	75%	792	397	49.9	397	30.1	92.4
Average	Avg.	525	267	49.1	267	20.9	92.2
	75%	698	331	52.6	331	27.5	91.7

Table 4.2.27 T -N, P -P Removal Ratio in BNR

		Influent T - N mg/L	Influent P - P mg/L	Effluent T - N mg/L	Effluent P - P mg/L	Removal T - N %	Ratio P - P %
Firle Unit 3	Avg.	62.4	8.9	13.7	2.8	78.0	68.5
	75%	77	11.0	19.2	3.2	75.1	70.9
Firle Unit 4	Avg.	62.2	8.1	13.0	2.2	79.1	72.8
	75%	75.0	10.6	20.8	2.6	72.3	75.5
Crowborough Unit 3	Avg.	55.0	6.7	9.3	1.4	83.1	79.1
	75%	66.0	7.8	16.8	1.5	74.5	80.8
Average	Avg.	59.9	7.9	12.0	2.1	80.0	73.4
	75%	72.7	9.8	18.9	2.4	74.0	75.5

(4) Evaluation Criteria for Biological Nutrient Removal (BNR)

1) BOD Removal

The criteria was formulated based on the actual data from the Firle and Crowborough STWs.

a. BOD Removal Ratio in Primary Sedimentation Tank

The influent BOD concentrations are 400-600mg/l, medium rate. From Table 4.2.26, removal rate of 50% can be expected.

b. BOD Removal Ratio in BNR

The influent BOD concentrations are 200-300mg/l. From Table 4.2.26, removal rate of 90% seems to be appropriate.

c. Removal of T-N and P-P

Based on Table 4.2.27, removal rates of T-N 80% and P-P 75% can be expected respectively.

4.2.2 Re-use of Treated Effluent and Sludge

1. Re-use of Treated Effluent

(1) Present Condition of Reuse of Treated Effluent

Most treated sewage is used for irrigation, but this is more a part of the sewage treatment process than a form of reuse. The reason for this is the very strict 1977 Water (Effluent and Wastewater Standards) Regulations (GN687/77), the content of which is shown in Table 4.2.28.

At the time when the 1977 Water Regulations were instituted, the treatment technology was not sufficient treatment technology to meet these requirements, so the only option was to conduct irrigation following secondary treatment. This method is similar to the Overland Flow Land Treatment System, one of the natural systems that were developed in the United States as systematised treatment technology. It is known as a very effective method for the removal of organic matter and nutrients.

Table 4.2.28 Effluent Regulation to Discharge into River (Zone II)

Water (Effluent & Wastewater Standards) Regulations: (GN 687/77)	
Parameter	Limit
pH	6-9
Temperature	< 35 deg C
Diss Oxygen	≥ 60% sat
COD	≤ 60 mg/l
SS	≤ 25 mg/l
TDS	≤ 500 mg/l
Ammonia (free)	≤ 0.2 mg/l
Chlorine	≤ 100 mg/l
Total N	≤ 10 mg/l

Also limits heavy metals, oils, pesticides and other toxic chemicals

For instance, the standards set forth that COD and T-N shall be less than 60.0 and 10.0 mg/l, respectively. It is hardly possible to attain such stringent regulation by means of the ordinary sewage treatment processes and, as an economic way of disposing the treated effluent, the reuse for irrigation supply is widely employed.

Later, the BNR treatment method was developed, which made it possible to clear the standards of the effluent regulations. Consequently, it became possible to release treated effluent directly into rivers. It may be assumed that this practice will continue in the future as well.

The Use of treated effluent for irrigation is controlled by the Public Health (Effluent) Regulations (GN637/72). The items covered by the regulations are BOD, DO, and E.Coli, and the requirements are relatively easy to meet. The contents of these regulations are shown in Table 4.2.29.

Table 4.2.29 Effluent Regulation for Irrigation Reuse

Public Health (Effluent) Regulations GN637/72	
Conventional Works Effluent	Pond System Effluent
(A) Surface irrigation of non-edible crops, pastures & orchards/plantations.	
BOD ≤ 70 mg/l	DO ≥ 1 mg/l at all times
(B) Spray irrigation of ditto	
BOD ≤ 30 mg/l	BOD ≤ 30 mg/l
(C) Surface or spray irrigation of the above plus pastures for dairy cattle, and cut flowers.	
BOD ≤ 10 mg/l	DO ≥ 1 mg/l at all times
E. Coli ≤ 10/100ml	E. Coli ≤ 10/100ml
(D) Public Amenities, Playing fields, etc.	
Same as (C) above, plus chlorination	

Table 4.2.30 summarises the present features of flow and quality of treated wastewater for irrigation in Harare, Chtitungwiza, Norton and Ruwa.

The present method of the sewage treatment is described in more detail for the respective authority as follows :

1) City of Harare

   In Harare, the quantity of treated effluent is approximately 160,000 m^3/day during the dry season under the present facilities, of which only 40,000 m^3/day or 25 % of the total is discharged into the rivers after treatment. The remaining 120,000 m^3/day is transmitted to the pasture lands for irrigation purpose. Harare holds pasture lands extending over approximately 670 ha, where livestock graze.

2) Chitungwiza Municipality

   The treated effluent is reused in the same method as Harare. The pasture lands are presently owned by the government.

Table 4.2.30 Flow and Quality of Treated Wastewater for Irrigation

STW	Flow x 1000m3/d	Effluent Quality mg/L	Note
Harare City			
Crowborough STW	44 - 64	BOD 128 (Avg.), 157 (75%)	1993 - 1995
Firle STW	55 - 71	BOD 153 (Avg.), 209 (75%)	1993 - 1995
Marborough STW	2	BOD 120.7 (Avg.), 74.3 (75%)	
Donnybrook STW	5	BOD 95-136 (Avg.), 120-195 (75%)	
Hatcliff STW	1	BOD 269 (Avg.), 351 (75%)	
Total (Harare)	107 - 143		
Chitungwiza municipality			6 pond in the farm
Zengeza STW	36	BOD 141 (Avg.), 180 (75%)	Retention time about 9 days BOD Removal Ratio about 65%
Norton Town			
Norton STW	3	BOD 520	
Ruwa Local Board			
Ruwa STW	1	BOD 55	Measured this time
TOTAL	131 - 167		

3) Norton Town Council

The sewage is generated not only from the STW but also the pulp industry. After treated all of them are conveyed into the pasture lands and afforestation areas by the transmission facilities installed by the said industry.

4) Ruwa Local Board

The existing sewage treatment works were constructed in 1993 in the vicinity of pasture lands and its treated effluent is reused in the same method as Harare.

(2) Treated Effluent Quality

It is deemed rational and efficient to make reuse the treated effluent containing organic matters and nutrients for the purpose of irrigation of the pasture lands. The qualitative standards of irrigation water is as shown in Table 4.2.29, whereas the actual quality of the treated effluent is also presented in Table 4.2.30.

The quality of the treated wastewater is preliminarily assessed as reported below:

1) City of Harare

According to the monitoring records, the BOD of the treated effluent is very high, being in the range of 150 to 200 mg/l, which is almost the same as that of raw sewage in developed countries. Such a high concentration of BOD means that the sewage treatment works are operated under severely overloaded conditions. The Public Health (Effluent) Regulation stipulates that the BOD concentration from conventional STWs shall be less than 70 mg/l. In order to meet this regulation, every STW are being planned to be expanded.

A simple attempt was made to determine whether or not the existing pasture lands, with the area of 670 ha, were sufficient to remove the nutrients of the treated effluent. The required area for the removal of the nutrients was calculated in accordance with Overland Flow Land Treatment System, and the result was compared to the actual area of the pasture lands.

a. Design values for Overland Flow Land Treatment System

Minimum pre-treatment	:	Screening
Annual hydraulic loading rate	:	7.32 - 56.7 m/year
Area required for removal of nutrients	:	0.64 - 4.81 ha/1,000 m^3/day

b. Comparison with the actual area

The required area is calculated as presented below:

	Flow Rate (m^3/day)	Calculated Area (ha)	Actual Area Available (ha)
Crowborough	44,000-64,000	106 - 154	150
Firle	55,000-71,000	132 - 170	400
Entire Harare	107,000-143,000	257 - 343	670

It is verified that the existing pasture lands are spacious enough to remove the nutrients of the treated effluent under the present condition.

2) Chitongwiza Municipality

The treated effluent contains relatively high BOD levels, being about 180 mg/l, which was recorded at the outlet of the STW. It is however further polished by six existing stabilization ponds so that the BOD concentration is decreased to somewhat. However, during the rainy season, the treated effluent runs off the irrigated lands and flows directly into the rivers, resulting the contamination of the river water during such times. Accordingly, it is not exaggeration to say that there may be an outbreak of water-oriented epidemics or water-borne diseases in the downstream reaches of the rivers. In fact, it is reported that the Beatrice water treatment works on the bank of the Muptre River has been incurring high costs to ensure proper water treatment for a safe and potable water supply.

3) Norton Town Council

Due to over-loading, the treated effluent is very poor in quality and is also highly contaminated by the wastewater from the pulp industry that is flowing into a storage pond in the STW, resulting in the creation of a nuisance for the residents in the surrounding areas due to generation of offensive odours. At present, rehabilitation of the STW is in progress and measures to improve the pulp industry's wastewater are under negotiation between the local administrative authority and the industry.

4) Ruwa Local Board

The actual quality of the treated effluent is good as those presented in Table 4.2.30.

(3) Technical Evaluation for Reuse of Treated Effluent

It is a common issue in the Study Area that the treated effluent directly runs into the rivers at the end of the irrigation areas during rainy periods, resulting in the contamination of the receiving water body. Another major problem is that during the dry season, there is a deficiency in the amount of river maintenance flow, which is accelerated by the fact that a portion of the treated effluent is diverted into a different river basin and that a major portion of the STWs effluent is used for the irrigation of the pasture lands.

1) City of Harare

In order to cope with the above issues, Harare is now strengthening the sewage treatment process by means of BNR, although it is deemed to be technically feasible to remove nutrients by means of reuse of the treated effluent for irrigation of the pasture lands as long as the land area required is ensured. The city administration however is in the opinion that BNR be used together with the irrigation of the pasture lands, since BNR would cause the city administration large amount of annual operation costs, especially in electricity charges. This approach is considered to be financially and technically reasonable.

2) Chitungwiza Municipality

In order to upgrade the treated effluent quality, Chitungwiza is now constructing one anaerobic pond. The treated effluent will continuously be used as irrigation supply throughout the future. However, in order to avoid the risk of an epidemic and/or water-borne diseases and to meet the effluent regulations, Chitungwiza would be required to expand the capacity of the stabilization pond and to extented the pasture lands. It is also necessary to take into account the need to sustain a certain amount of river maintenance flow in the Nyatume River throughout the year.

3) Norton Town Council

The town administration is addressing how adequately to cope with the increasing sewage quantity and has opted to adopt the trickling filter process. In view of the need to keep costs to a minimum , it is considered to be a sound option to adopt the trickling filter process and to reuse the effluent for irrigation. There is however, a special consideration to be dealt with large amount of wastewater is discharged from the pulp industry, which is one of the major sources of pollutants and the owner of the treated effluent transmission facilities from the STW. The pulp industry s operation method should be re-addressed from the viewpoint of environmental conservation.

4) Ruwa Local Board

It is advisable to construct a temporary storage pond in order to retain the raw sewage or treated effluent during the rainy season so that the direct run-off of the treated effluent into the river could be minimized.

2. Reuse of Sludge

(1) Present Condition of Reuse of Sludge

The present conditions of reuse of sludge and disposal method of the respective areas are shown below:

1) City of Harare

The existing STW can be classified into two (2) groups as follows:

a. Group A: Crowborough and Firle STWs

The sludge generated from the primary and secondary treatment processes is continuously treated by sludge digestion tank. The digested sludge is injected into the force main of the treated effluent feeding the irrigation area. The quantity of the sludge was 1,230 m^3/day on average in February 1996, corresponding to about 2 % of the incoming sewage volume.

b. Group B: Marlborough, Donnybrook and Hatcliff STWs

These STWs have less treatment capacity than the Group A but are provided with anaerobic ponds. Sludge normally accumulates in anaerobic ponds, which are periodically emptied and dried at intervals of several years for the removal of the sludge. The sludge removed from the anaerobic ponds is disposed of by means of reuse for land over agricultural lands and national parks.

2) Chitungwiza Municipality

The sludge treatment and disposal at the Zengeza STW are the same as those of the Group B in Harare. However, this STW is provided with sludge drying beds for dewatering. The dewatered sludge is wholly collected and transported by farmers for reuse in the land over their cultivation areas.

3) Norton Town Council

The sludge is generated in the trickling filter process and treated using drying beds. About half of the dried sludge is consumed by means of reuse for land, while the remaining volume is stock piled in an open space next to the sewage works.

4) Ruwa Local Board

Sludge treatment and disposal have not yet taken place to date in the existing sewage works.

(2) Technical Evaluation for Reuse of Sludge

Land acquisition is the most important for disposal of the sludge, which particulary in the Study area is considered to be appropriate and rational. Every STWs is closely located to wide pasture lands, which are isolated from the densely populated areas. Such geographic location is of great advantage to the transportation of the treated sludge from the STW to the pasture lands and to the environment.

1) City of Harare

The optimum method is considered to be rational and sound, especially from the following points of view:

- Both the sewage and sludge are properly treated separately, and used as fertilizer for the agricultural lands.
- Both the treated effluent and digested sludge are transported to the pasture lands together through the force pipe. This is a very economical way of sludge disposal and further does not require the process of dewatering.

This technology is technically highly sound and appropriate to the local conditions such as climate, land availability and use, environment of the surrounding areas, and to the local agronomy.

2) Chitongwiza and Norton Town Council

The sludge treatment method would also be continued into the future unless there are substantial changes in circumstances in the vicinity of the sewage treatment works.

3) Ruwa Local Board

The administration authority has no particular approach to sludge digestion and disposal. It is considered that the same method as Group B of Harare could be adopted here.

5.2 Present and Future Land Use

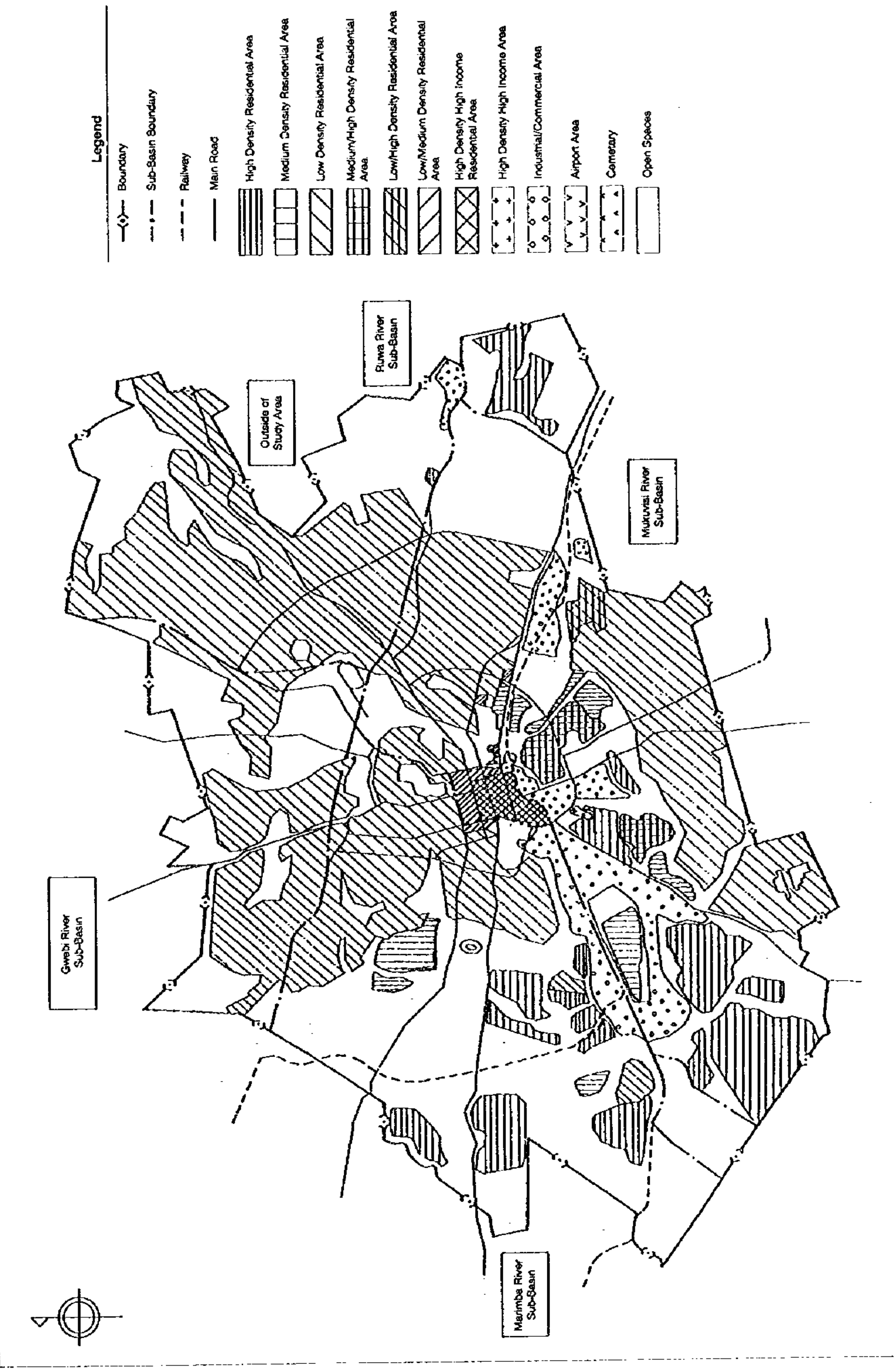

Figure 5.2.1 (1) Present Land Use in Harare City

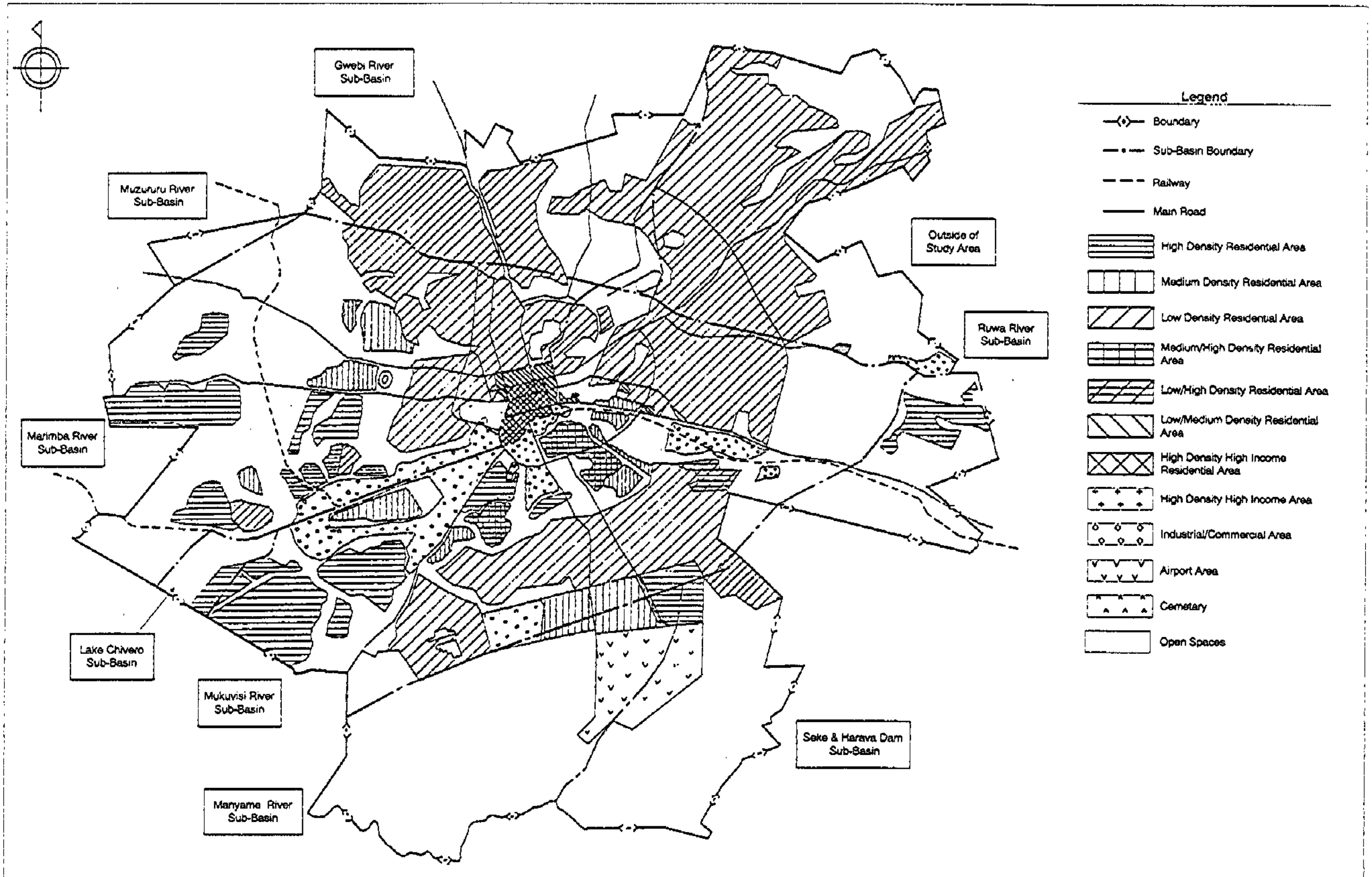

Figure 5.2.1 (2) Year 2000 Land Use Plan in Harare City

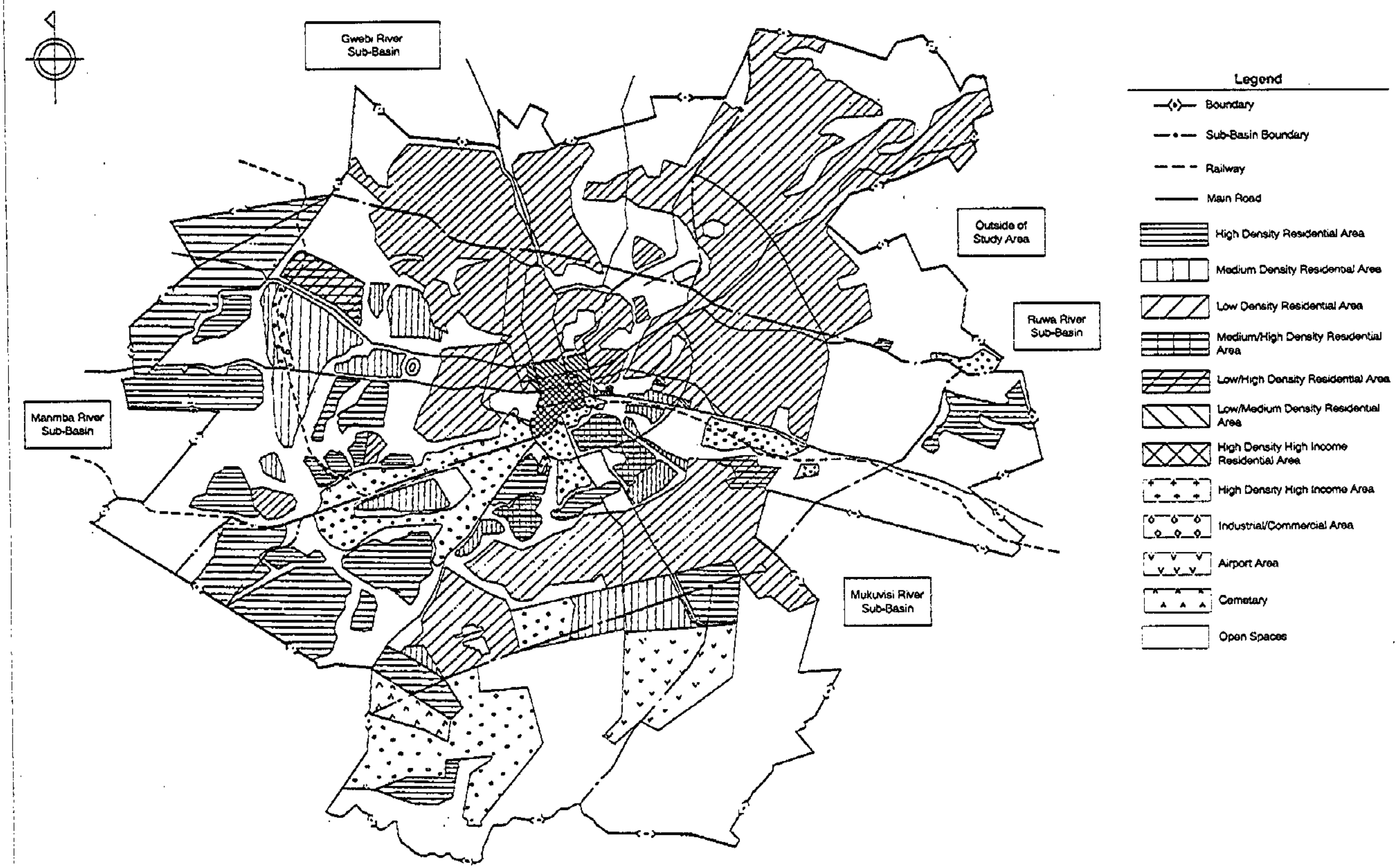

Figure 5.2.1 (3) Year 2005 Land Use Plan in Harare City

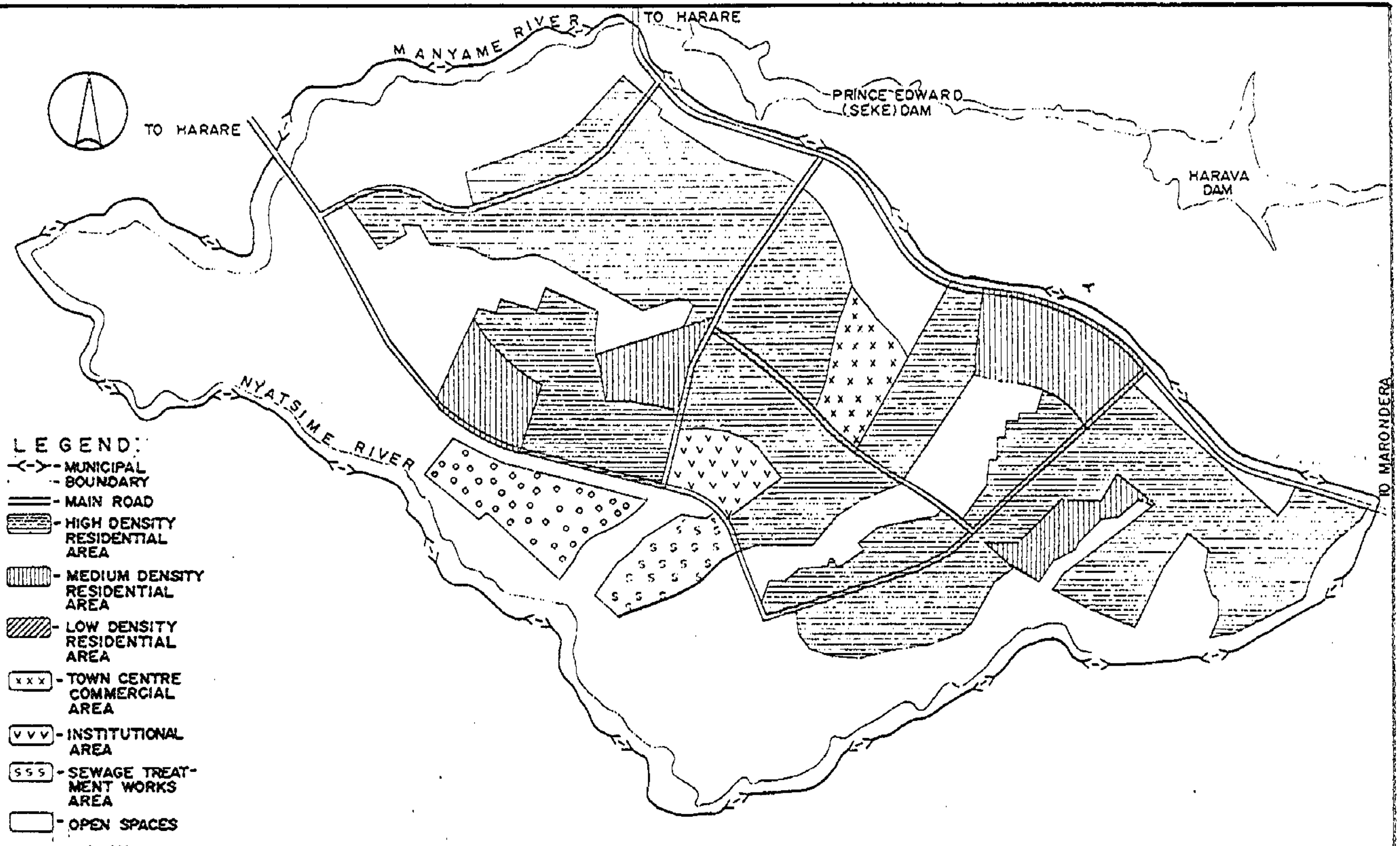

Figure 5.2.2 (1) Present Land Use in Chitungwiza Municipality

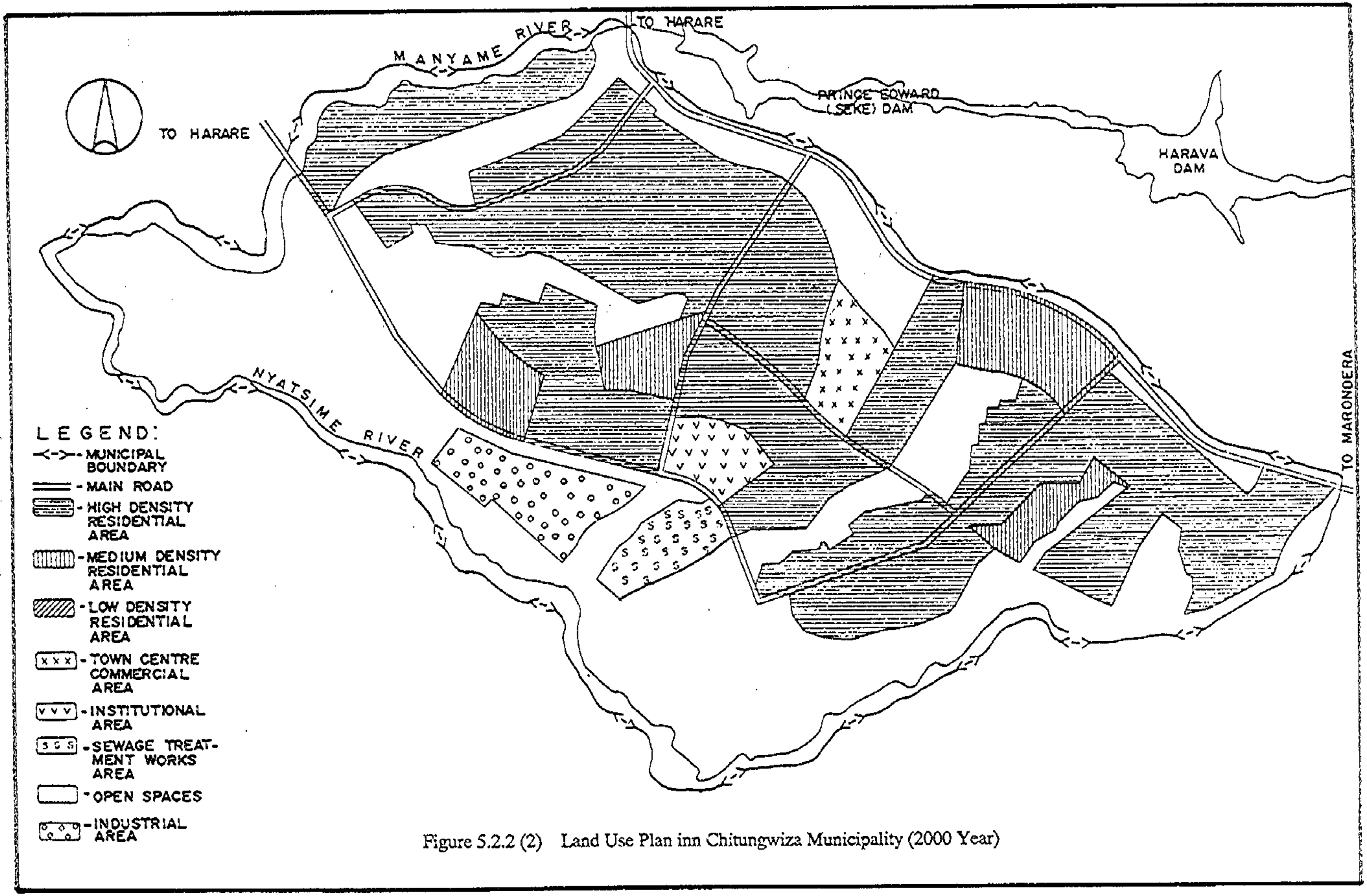

Figure 5.2.2 (2) Land Use Plan inn Chitungwiza Municipality (2000 Year)

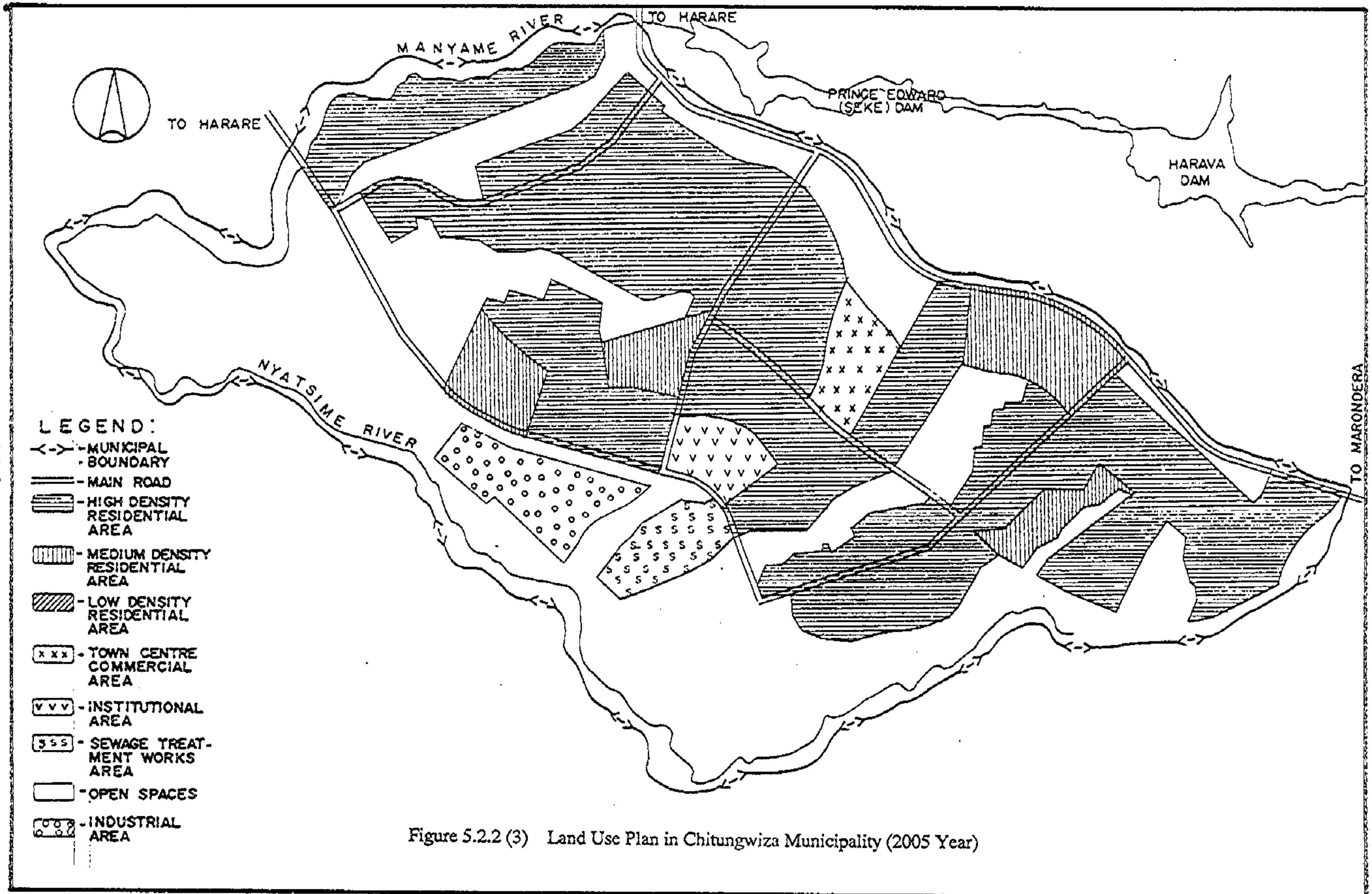

Figure 5.2.2 (3) Land Use Plan in Chitungwiza Municipality (2005 Year)

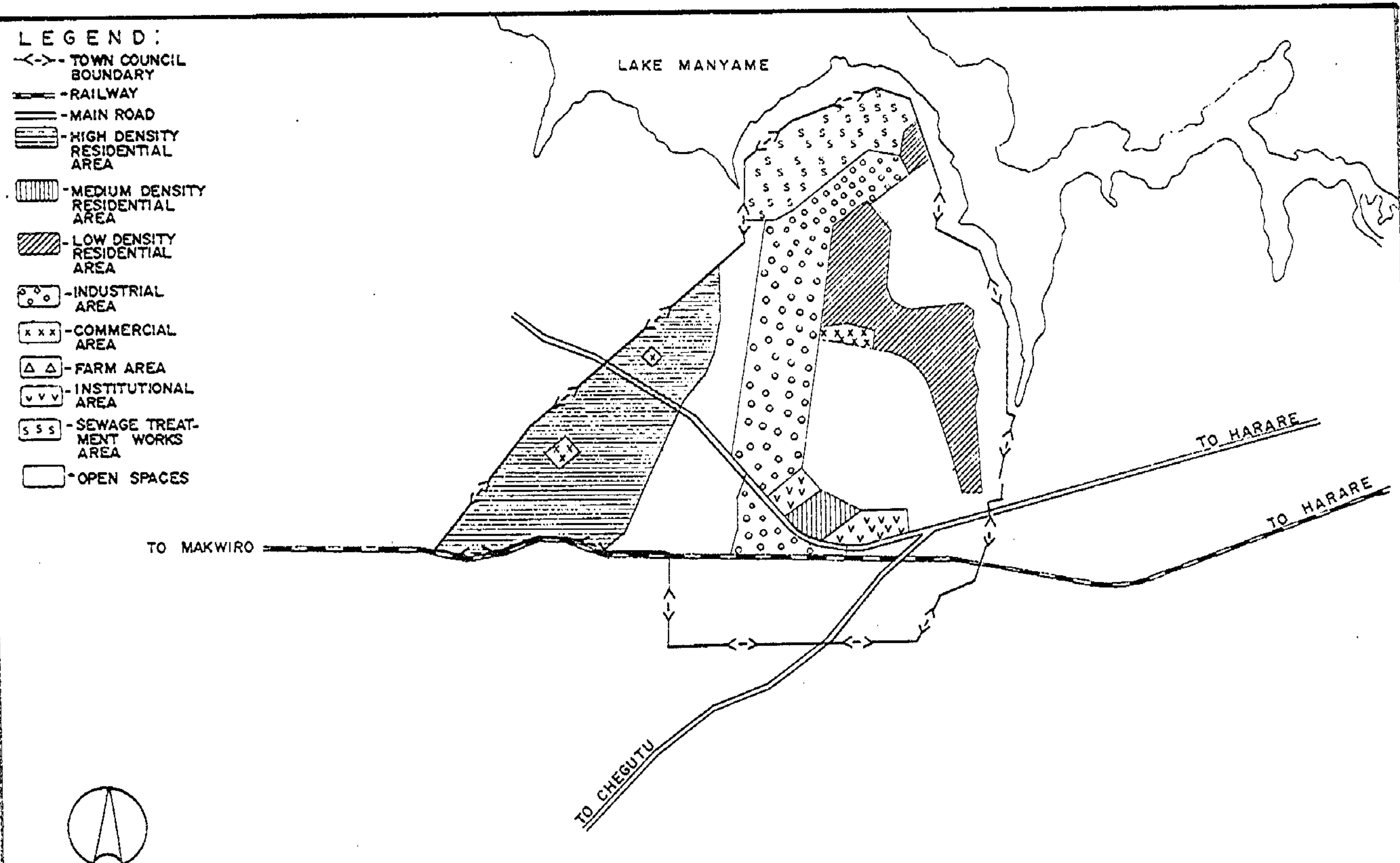

Figure 5.2.3 (1) Present Land Use in Norton Town Council

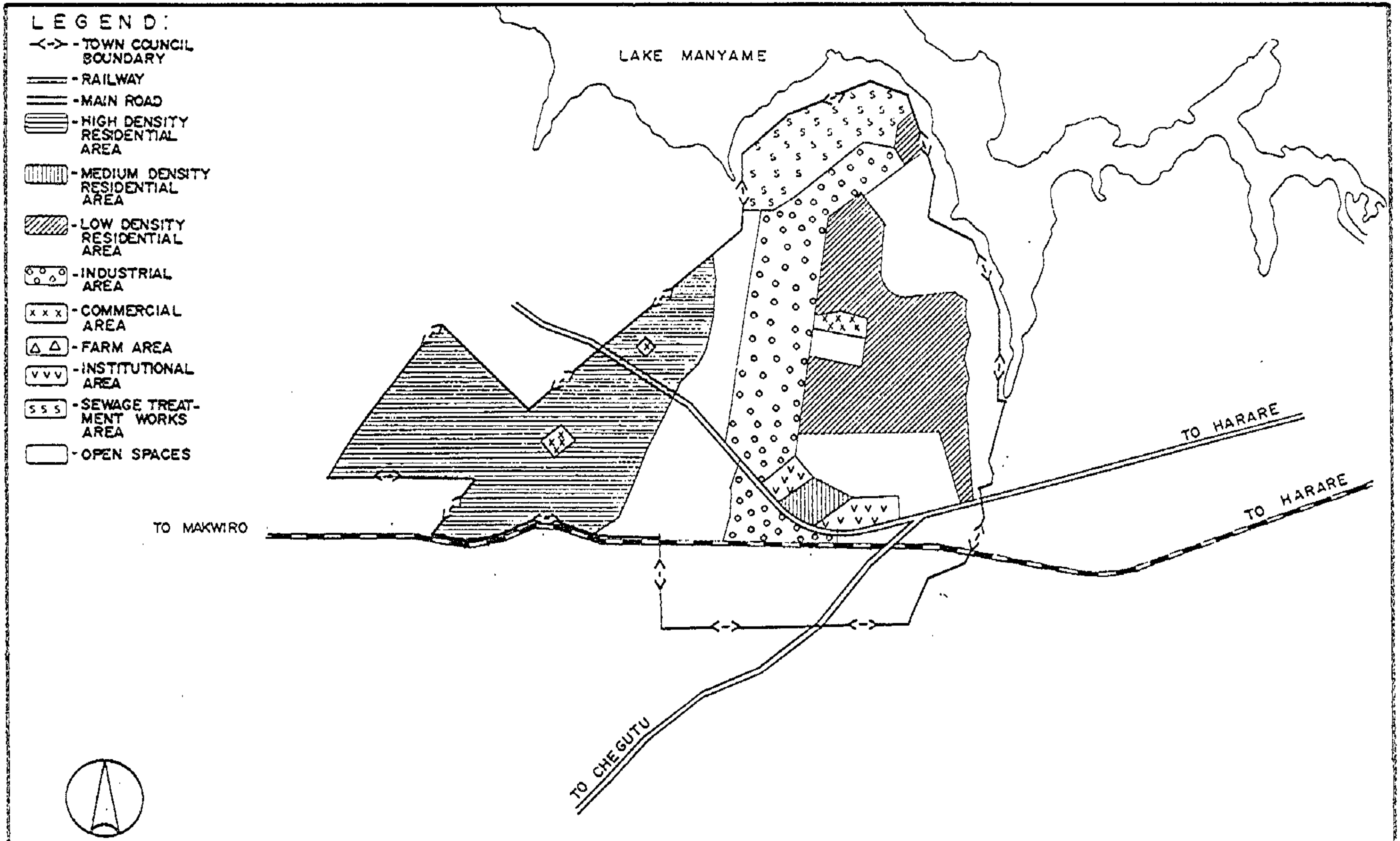

Figure 5.2.3 (2) Land Use Plan in Norton Town Council (2000 Year)

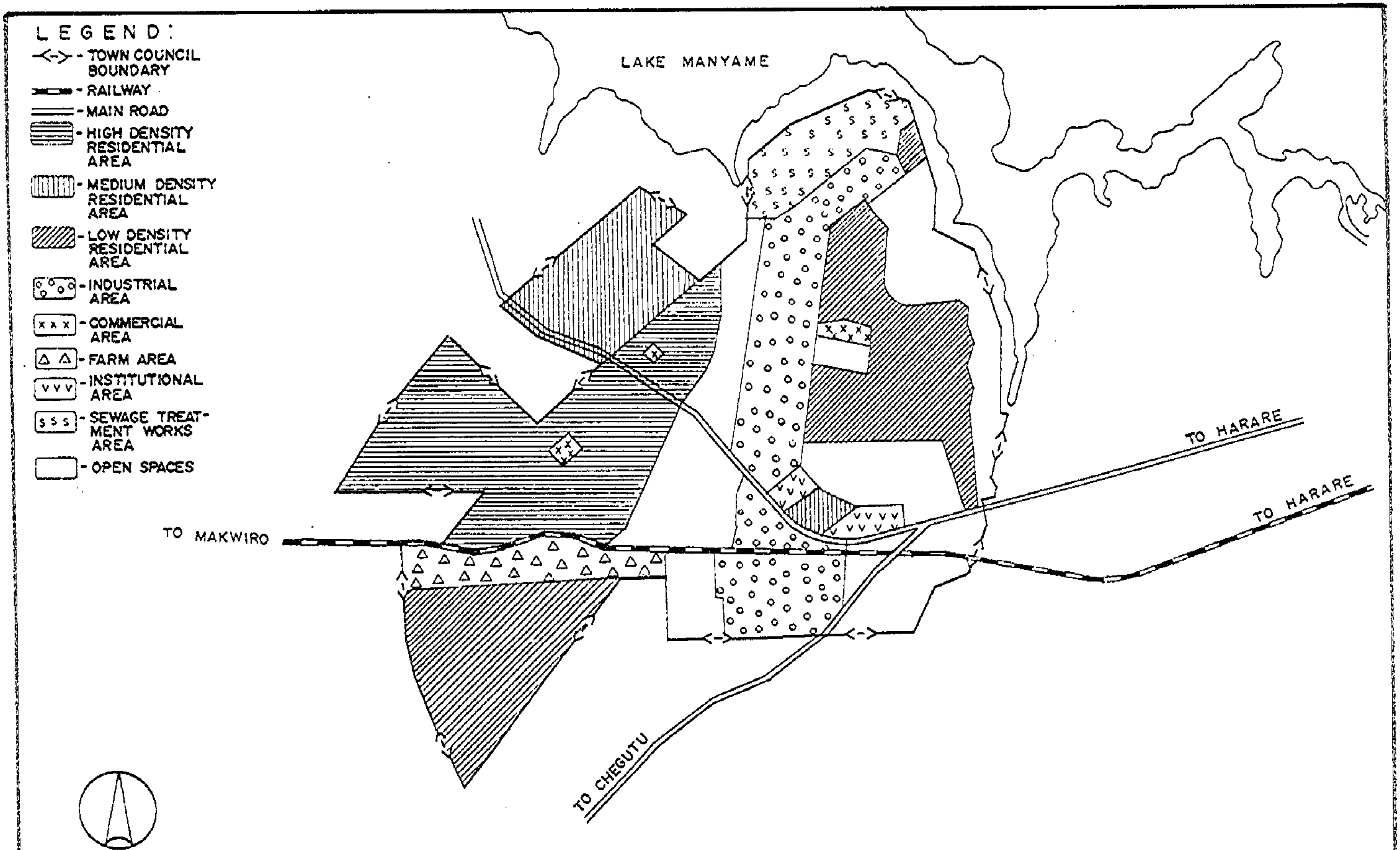

Figure 5.2.3 (3) Land Use Plan in Norton Town Council (2005 Year)

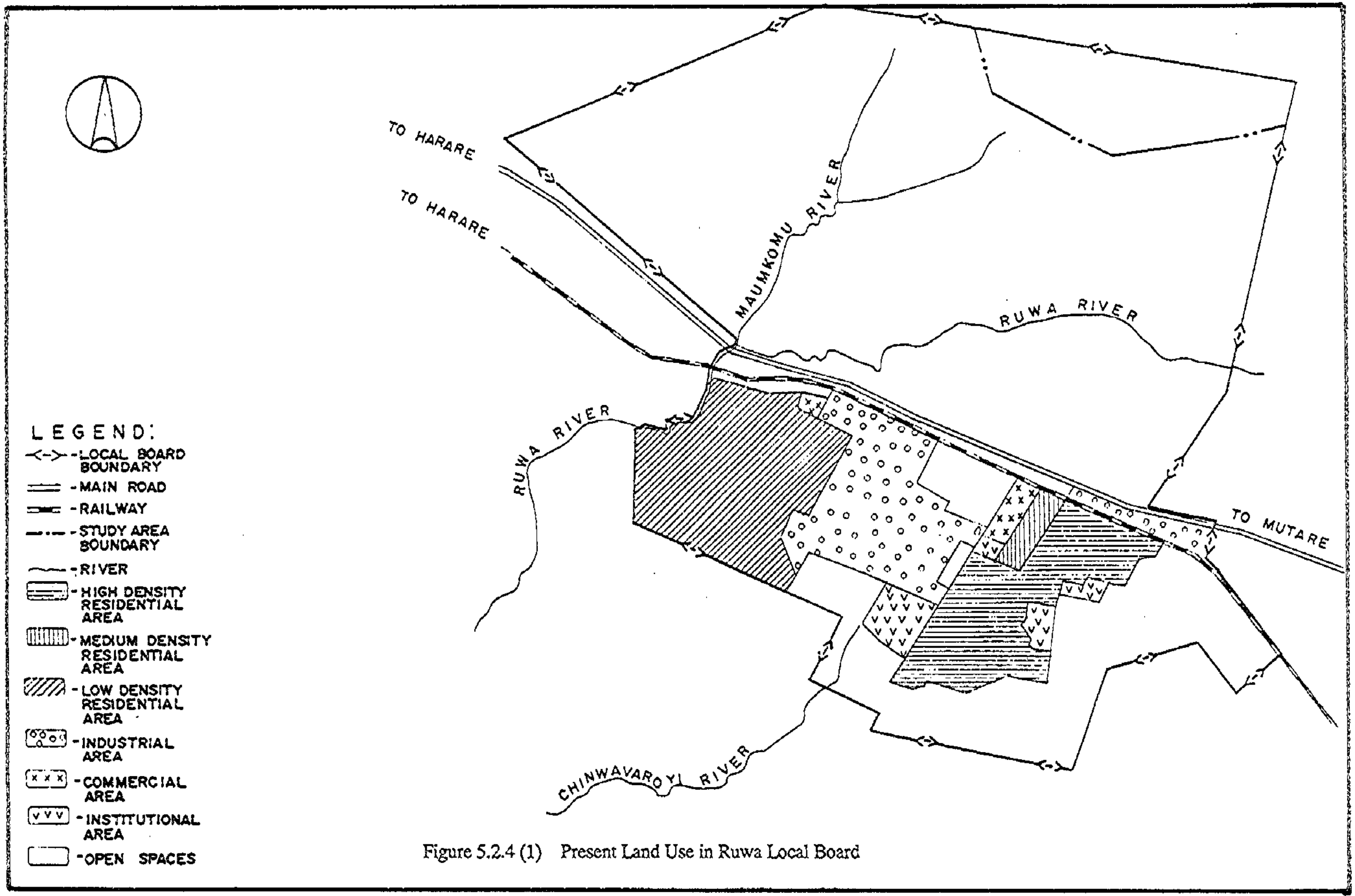

Figure 5.2.4 (1) Present Land Use in Ruwa Local Board

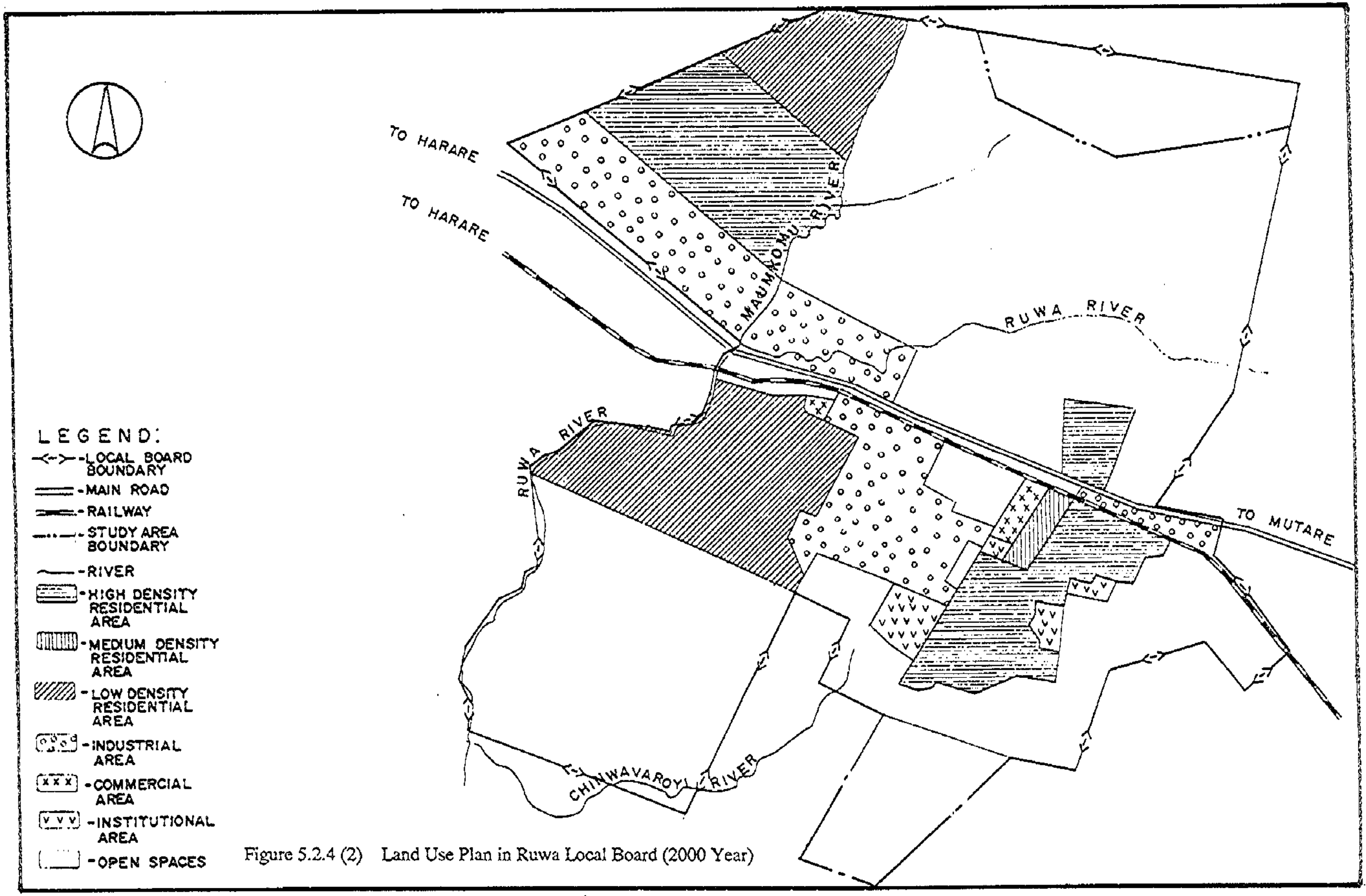

Figure 5.2.4 (2) Land Use Plan in Ruwa Local Board (2000 Year)

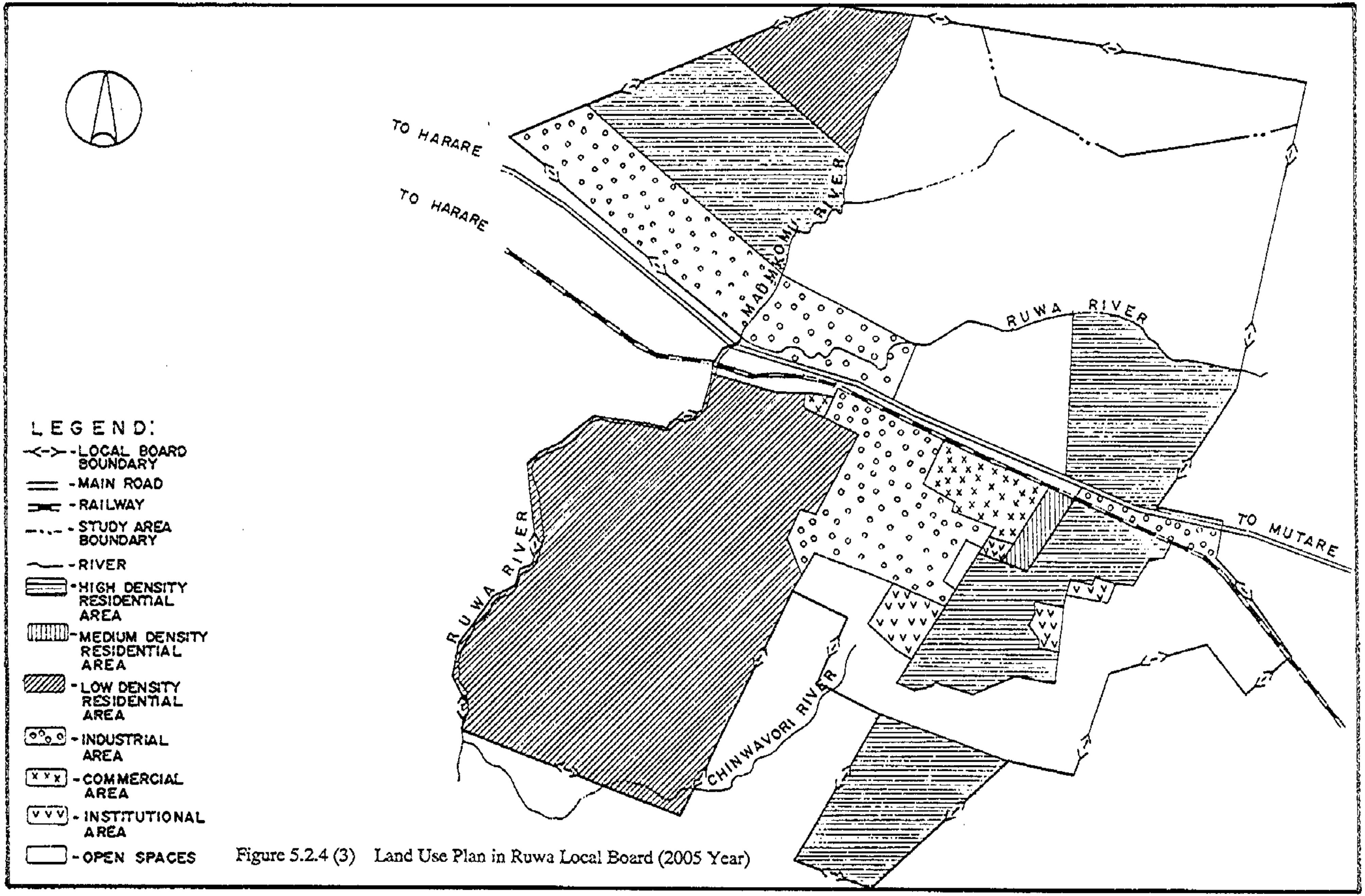

Figure 5.2.4 (3) Land Use Plan in Ruwa Local Board (2005 Year)