CHAPTER 5 EVALUATION OF CURRENT ISSUES

5.1 Water Supply

This chapter describes the current issues for water supply including management after the discussion of the current situation and condition of the water supply system and its operations in Section 4.1.

5.1.1 Harare Metropolitan Area

(1) The major issues in Harare metropolitan areas are:

1) Insufficient water resource,
2) Water resource contamination,
3) Insufficient water production capacity,
4) Deterioration of facilities in Morton Jaffrey (MJ) WTP and Prince Edwards (PE) WTP and P/S including the measurement instruments due to inadequate repair and non-replacement,
5) Deterioration of water transmission and distribution lines resulting to a large amount of leakage from the pipelines, and
6) Insufficient budget allocated to address facilities' deterioration and the increasing water demand.

The evaluation for each item is described below.

(2) Water resource shortage and contamination

1) Evaluation of water resource

Figure 5.1.1 shows the schematic layout of Harare Water Distribution Network including water resource, dams:

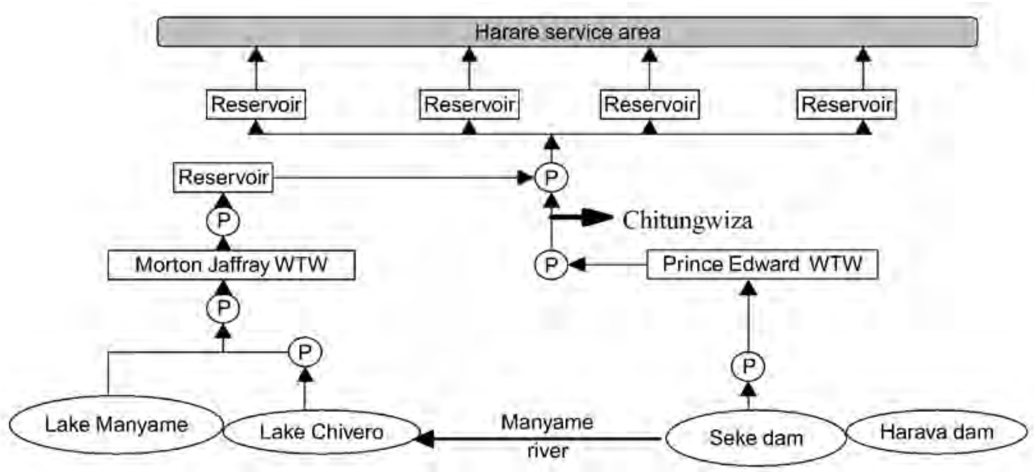


Figure 5.1.1 Schematic Layout of Harare Water Distribution Network

Source: Water Policy 12 (2009)

Table 5.1.1 shows the yield capacity of each dam with the risk levels of 4%, 10%, and 20%. In the table, although the capacity and catchment area of Manyame Dam are much larger than Chivero Dam, the yield capacity of the latter is larger because it is located upstream. In evaluating the practical risk level, a comparison between the intake amount of WTPs and yield capacity of each dam is shown in Table 5.1.2:

Table 5.1.1 Yield Capacity of each Dam

Item/ Dam	4% yield		10% yield		20% yield	
	1000 m^3/y	1000 m^3/day	1000 m^3/y	1000 m^3/day	1000 m^3/y	1000 m^3/day
Manyame	60,379	165.4	85,083	233.1	116,096	318.1
Chivero	93,916	257.3	119,159	326.5	155,146	425.1
Seke	1,153	3.2	2,471	6.8	3,038	8.3
Harava	3,928	10.8	7,175	19.7	8,560	23.5
Total	159,376	436.6	213,888	586.0	282,840	774.9

Source: ZINWA in 2012

Table 5.1.2 Comparison between WTP Intake Amount and Yield Capacities

WTP/Item	Intake Amount (1000 m^3/d)		Yield Capacity (1000 m^3/d)			Capacity (mil.m^3)	Storage Year (year)	
	Design	Actual	4%	10%	20%		Design	Actual
Morton Jaffray	630	550	422.7	559.6	743.1	727.4	3.16	3.62
Prince Edward	95	60-45*	13.9	26.4	31.8	12.6	0.36	0.63

* Intake during ordinary season is 60,000m^3/d while during dry season is 45,000m^3/d

JICA Project Team recommended to employ 15% (of 537,050 m^3/d) as the total yield capacity. However, Table 5.1.2 shows that at 10% yield capacity, the recommended 15% is already exceeded. It is caused by the difference of rainfall. On the other hand, the intake amount at PE-WTP even in dry season is much higher than the 20% yield capacity because of the dam's shorter retention time. From the above comparison, the yield capacity of 10% for MJ-WTP and 20% for PE-WTP are adapted in this report. The calculation of yield capacity of each WTP is shown below.

MJ-WTP: 233,100（Manyame Dam）+326,500（Chivero Dam）+200,000 (recycled water from STPs) = 759,600 m^3/d

PE-WTP; 23,500 （Harava Dam）+ 8,300（Seke Dam） =31,800 m^3/d

The actual storage volume fluctuations of the four dams are shown in Figure 5.1.2 (1) – (4):

i) Chivero Dam Lake has never been empty, while Lake Manyame sometimes becomes empty, especially between 1994 and 1995.
ii) Seke Dam Lake storage has occasionally been very low therefore Lake Harava was used as a complementary storage for Seke Dam, and has occasionally been empty.

Water production volume of MJ-WTP was average 585,000 m^3/d in 2011, and from past records of dam lake level, the yield capacity of Chivero and Manyame dam cannot be judged if it is enough or not, because past intake was much smaller. Then since above mentioned 10% risk of yield capacity plus recycled water from STPs are decided to be safety intake amount, current production can be increased to be 18% with 10% of loss. (759,600/1.1/585,000 =1.18)

In the case of PE-WTP, the dam water storage has frequently been almost empty; meaning, the intake amount of the WTP is more than what the actual water resource could supply from the very beginning. Based on the hearings, the WTP operations are discontinued almost yearly from the middle to the end of October, and sometimes for an entire stretch of two months. It must be noted that in times of severe droughts, even the risk level of 4% yield is not sufficient.

On the other hand, the water intake amounts for MJ-WTP (Withdrawn from Chivero and Manyame Lakes) and PE-WTP (from Seke Lake) are shown in Figure 5.1.3(a). The production amounts of WTPs are shown in Figure 5.1.3(b). Note that the recent reduction (in 2001) of Manyame intake is caused by the breakdown of the intake pumps.

Although less than 5% of water loss from WTP is desirable, the loss of MJ-WTP exceeds 20% and that of PE-WTP is 10% as shown in Figure 5.1.4. It is not serious from the point of view of water resource for MJ-WTP, because the discharged water flows back to the river and to the dams. However the discharged water is injected with various chemicals and its treatment uses electricity during the treatment process, and is therefore a waste of chemicals and power.

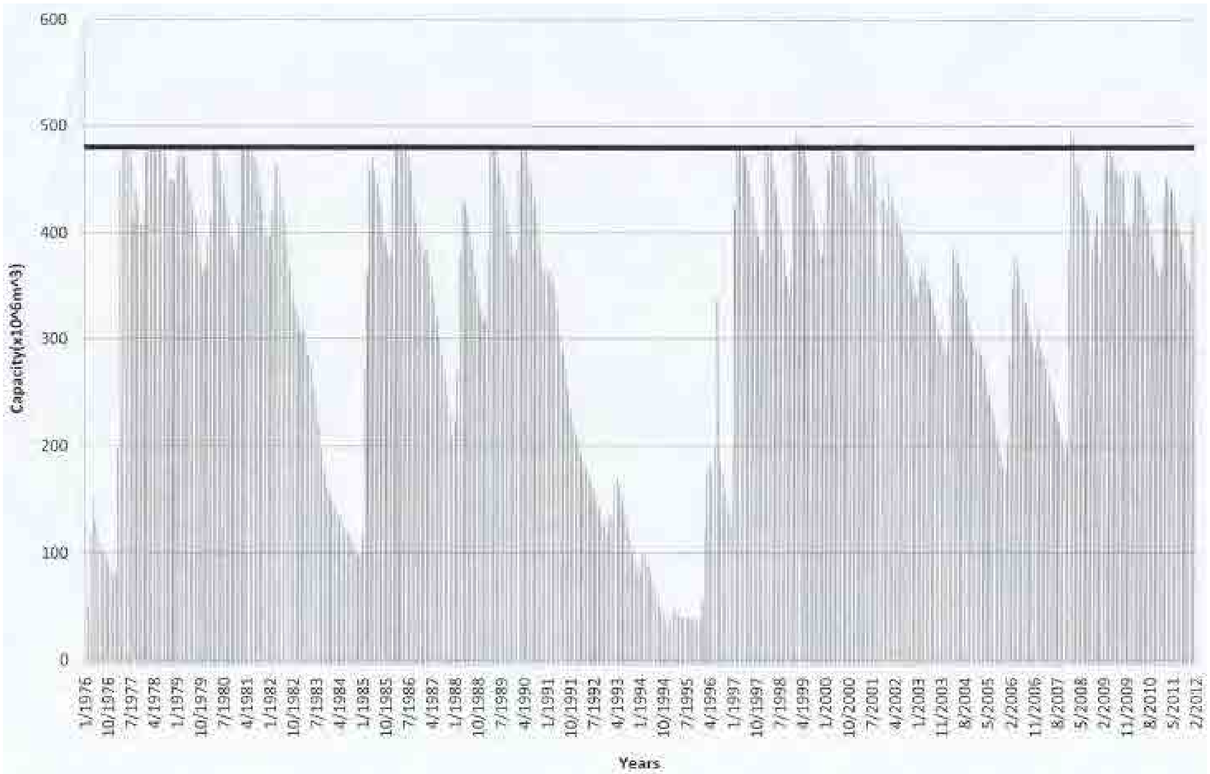


Figure 5.1.2 (1) Storage Volume Fluctuation of Manyame Dam Lake

Source: ZINWA

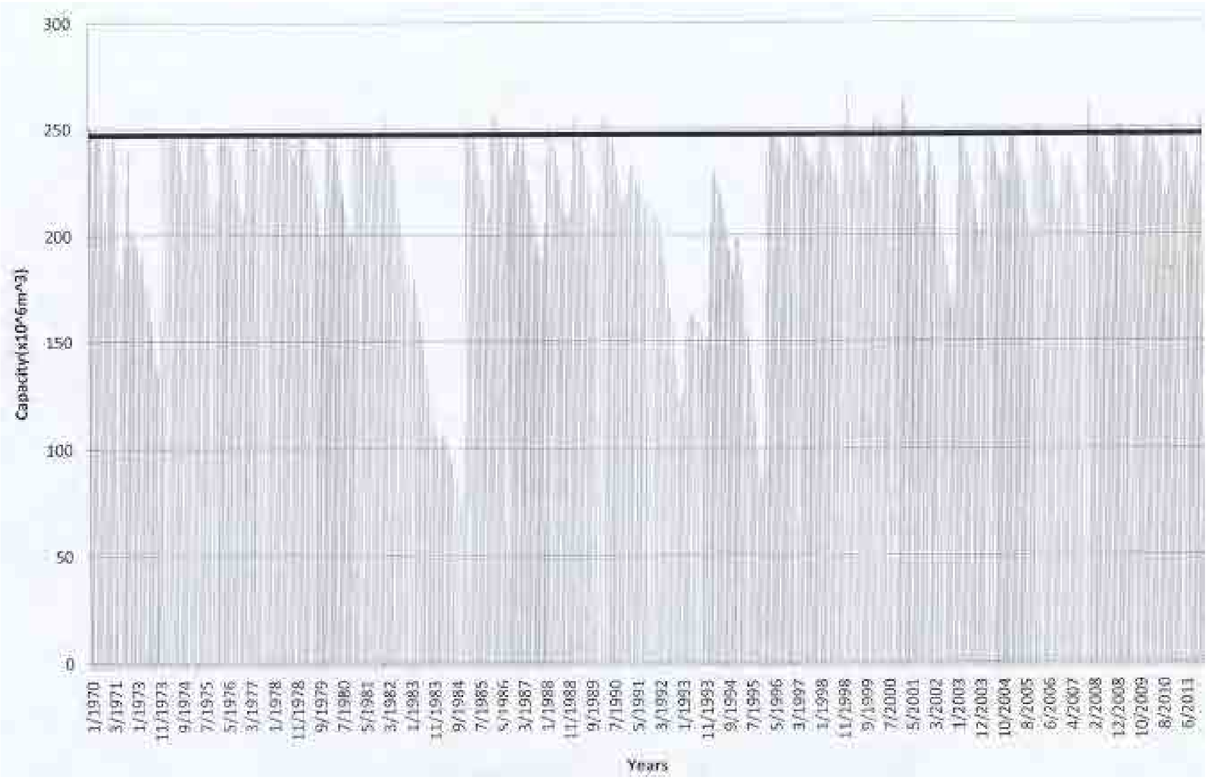


Figure 5.1.2 (2) Storage Volume Fluctuation of Chivero Dam Lake

Source: ZINWA

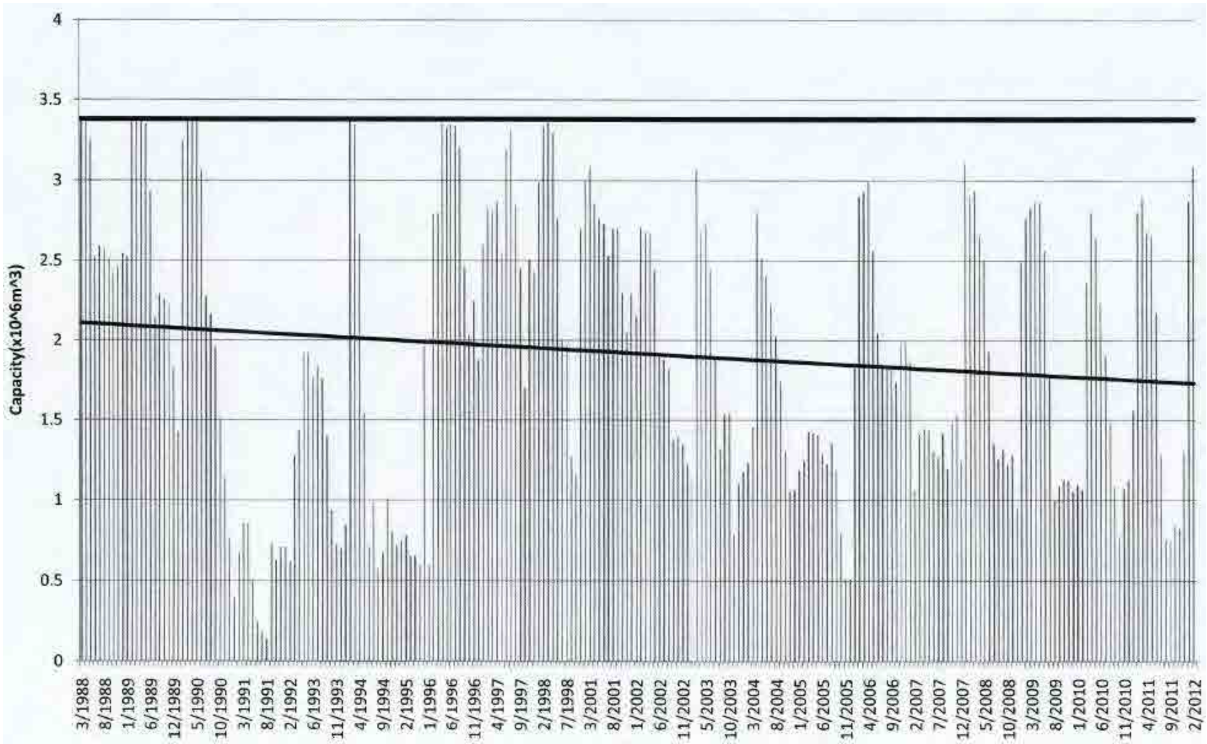


Figure 5.1.2 (3) Storage Volume Fluctuation of Seke Dam Lake

Source: ZINWA

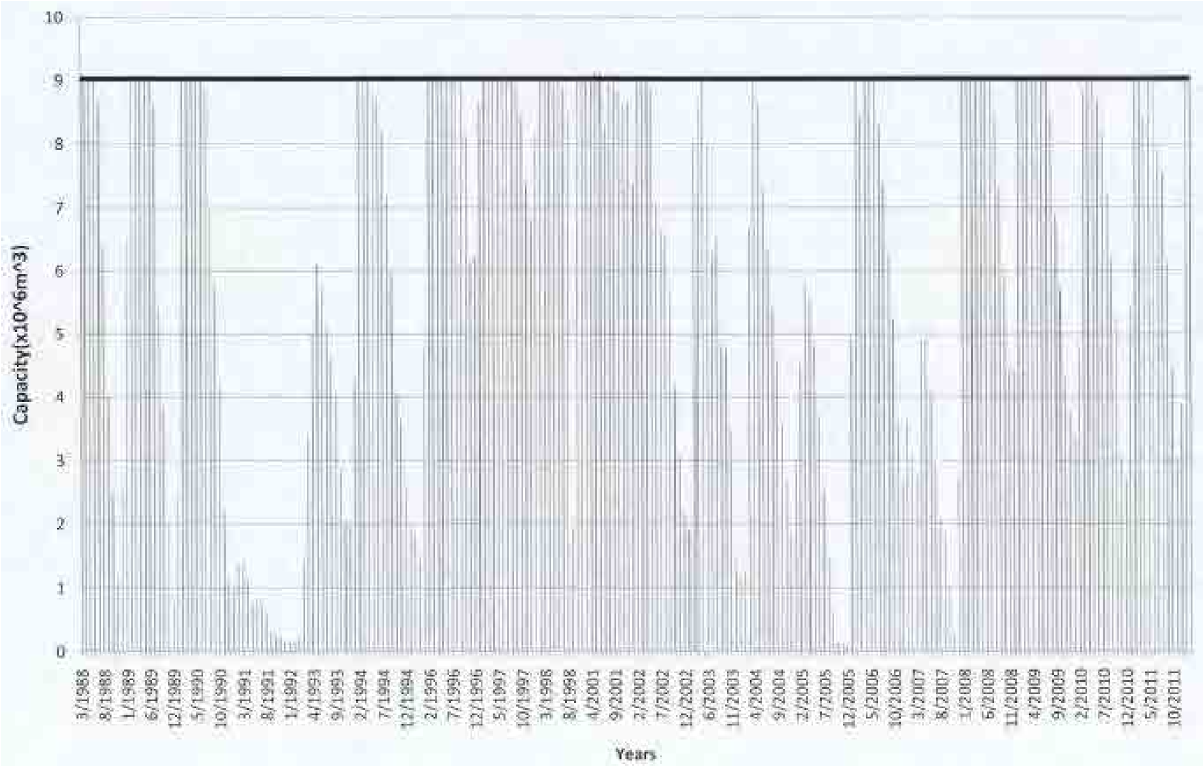


Figure 5.1.2 (4) Storage Volume Fluctuation of Harava Dam Lake

Source: ZINWA

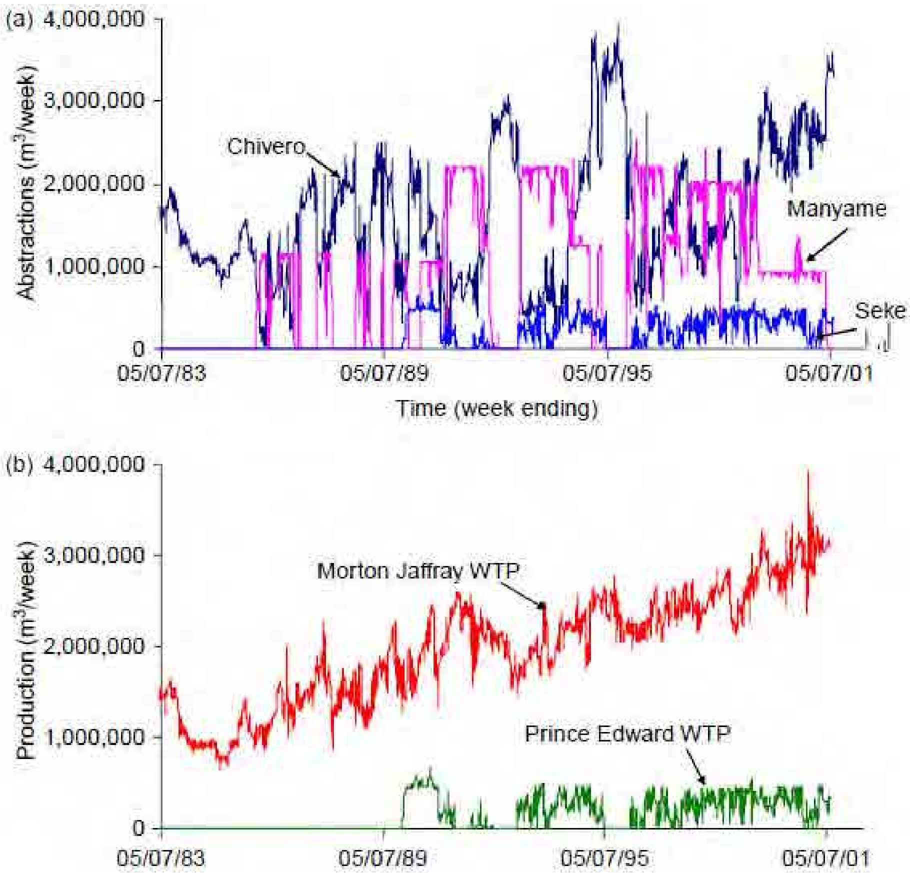


Figure 5.1.3 Intake and Production Amount of WTPs

Source: I.Nhapi/Water Policy II (2009)

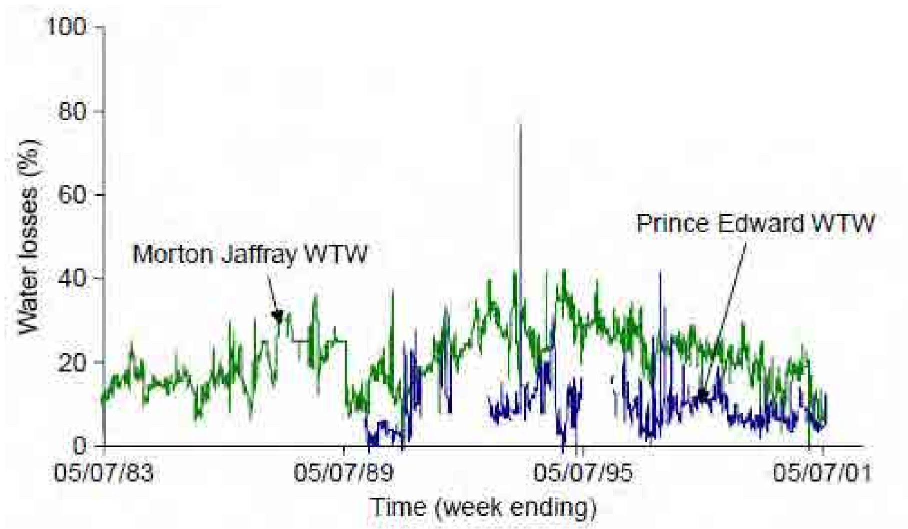


Figure 5.1.4 Water Losses from WTPs

Source: I.Nhapi/Water Policy II (2009)

2) Pollutions of Water Resource

The water source of MJ-WTP is Lake Chivero (60%) and Lake Manyame (40%). The reasons of the water pollution of Lake Chivero are shown below:

i) Most of pollution loads discharged from Harare Metropolitan Area goes into Lake Chivero,
ii) The overflow from Lake Chivero to Lake Manyame has been limited only for wet season as shown in Figure 5.1.2 (1) with limited volume, and
iii) The pollution loads are to be accumulated in Lake Chivero.

Table 5.1.3 shows the raw water qualities of MJ and PE WTPs. The water quality is much worse in MJ-TWP than in PE-WTP, and the possible causes and problems are listed below:

i) The MJ-WTP pH is sometimes very high due to highly progressed eutrophication,
ii) The MJ-WTP colour is very high, and it usually remains in the treated water, and
iii) The MJ-WTP NH_4-N is very high, and it requires high injection ratio of chlorine. It may generate "trihalomethane", which is usually found in treated water from WTPs taking the raw water from dam lakes

Table 5.1.3 Raw Water Quality of WTPs (In 2010)

Items/WTP	MJ-WTP				PE-WTP			
Parameter/Date	Jan-10	Feb-10	Mar-10	Ave.	Jan-10	Feb-10	Mar-10	Ave.
pH	8.9	7.6	7.4	8.0	7.3	7.1	7.4	7.3
Total Solids (mg/l)	294	237	-	266	106	117	233	152
Dissolved Solids (mg/l)	288.5	229.3	-	258.9	100.5	109.7	90.0	100.1
Suspended Solids (mg/l)	5.5	7.7	156.0	56.4	5.5	7.3	224.0	78.9
Turbidity (NTU)	10.9	35.0	12.5	19.5	1.9	3.8	5.0	3.6

Items/WTP	MJ-WTP				PE-WTP			
Parameter/Date	Jan-10	Feb-10	Mar-10	Ave.	Jan-10	Feb-10	Mar-10	Ave.
Colour (Hazen Units)	30	>70	>70	>70	30	30	30	30
Total Hardness (mg/l $CaCO_3$)	160	164	132	152	58	74	50	61
Dissolved Oxygen (mg/l)	2.8	1.2	1.7	1.9	6.8	4.5	6.5	5.9
BOD_5 (mg/l)	1.3	0.4	1.7	1.1	2.1	0.8	0.8	1.2
Free NH_3 (N)	0.16	0.76	0.92	0.61	TR	TR	0.08	TR
Iron (mg/l Fe)	Nil	Nil	Nil	Nil	TR	0.01	0.01	Nil
Manganese (mg/l Mn)	0.11	0.09	0.31	0.17	0.14	0.13	TR	0.14
Fluoride (mg/l F^-)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Conductivity (ms/m)	150	220	540	303	100	150	180	143
Temperature ^{O}C	28.0	25.8	26.5	26.8	26.5	25.5	22.0	24.7

Source: Harare Water Works

3) Kunzwi Dam Development Plan

The Kunzwi Dam development plan is the highest priority plan for Harare Water Works. The construction of the dam was reported to have commenced, but only the camp/barracks of a Chinese company was constructed as of September 2012. The development plan for Musami Dam is not as clear as compared to the Kunzwi Dam. The outlines of both dam plans are shown is Table 5.1.4, and the location of the dams are shown in Figure 5.1.5.

Table 5.1.4 Outlines of Kunzwi and Musami Dam

Items	Unit	Kunzwi Dam	Musami Dam
Catchment Area	km^2	730	1040
Average annual rainfall	mm	950	920
Average annual runoff	mm	210	210
Distance from Harare	km	40	50
Storage Capacity	mil.m^3	158	307
4% Yield	1000 m^3/d	192	304
Full supply level*1	m	1,230.0	1,336.7
Construction cost *2	mil.USD	14.2	23.1
No. of families affected	no.	165	200

*1: Elevation of proposed supply area is around 1,500m or more
*2: 1USD=10.85Z$ in 1997
Source: SAPROF Study -Harare Water Supply project

Based on the SAPROF Study of Harare Water Supply Project, the features of the Kunzwi dam development plan are:

- Yield capacity of the dam was assumed to be 201 thousands m^3/d, which is 90% of 4% yield, including pumping water from Nora river,
- 10% of 4% yield is used for irrigation,

Figure 5.1.5 Location of Proposed Dams

- The capacity of proposed Water Treatment Plant is 234 thousands m^3/d and it is located in nearby dam,
- Total length is 31.47 km of a transmission main and the diameter of 1,400 mm will be required,
- Two pump stations with the pump head of over 180m for the transmission will be also required, and
- Required power of WTP and transmission P/Ss are approximately 12,400 kW (WTP:3000 kW, 2PS: 6200 kW each).

(3) Insufficient production capacity

As mentioned in Section 4.1.4, the annual average water consumption of Harare Water Works is assumed to be 374,000 m^3/d while the daily maximum consumption is 430,100 m^3/d or 1.15 times larger than the average consumption. The design capacity and actual production capacity of MJ-WTP are 520,000 m^3/day (Plant No.2 , - 220,000 m^3/d $\times$ 2 + Plant No.1 - 80,000 m^3/d) and 585,000 m^3/d, respectively. During the normal and dry seasons, it is PE-WTP 90,000 m^3/d and 55,000 - 40,000 m^3/day, respectively. Thus, the actual water production amount of Harare Water Works is between 640,000 and 625,000 m^3/d. However, it must be noted that the production of PE-WTP is stopped for approximate 0.5 to 2 months, due to insufficient water volume in the reservoir during dry season. NRW (Non Revenue Water) Ratio in the distribution network is assumed to be at 57% by Harare Water Works.

The water balance of Harare Water Works using the 57% water leakage is shown Table 5.1 5. The table reveals that the water production capacity is heavily short to the actual demand, and it explains that many service areas catered by Harare Water Works do not receive sufficient water supply.

Table 5.1.5 Balance between Production and Demand

Item		Production	Consumption /Demand
Production Capacity ($1000\ m^3/d$)	Ordinary	640	
	Dry-season	625	
	PE-WTP stop	580	
Actual Demand ($1000\ m^3/d$)	Annual Ave.		374
	Daily Max		430
NRW		57%	
Demand ($1000\ m^3/d$)	Annual Ave.		813
	Daily Max		932

In addition, since the intake from Lake Manyame was stopped in August 2012 due to heavily contaminated water inflow from Norton STP, the water production of MJ-WTP was affected and was drastically reduced.

Since the current water production capacity of Harare Water works is not adequate because of the large NRW ratio, rehabilitations of pipelines and expansion of the system are recommended, in addition to water preservation measures of all its intake points.

(4) Deteriorated facilities and insufficient repair and replacement

1) WTPs

As mentioned in Section 4.1.1, the two WTPs of PE-WTP and MJ-WTP are old and the facilities do not function as required. In PE-WTP, from 2009 to 2012, the major facilities have been replaced or repaired, but these were targeted only for essential facilities, and the recovery of the automatic and monitoring function of facilities were not implemented. The limited refurbishment of the WTP resulted to the non-recovery of the design capacity of 90,000 m^3/day, but with the limitation of the water resources of the Seke and Harava dams, the production capacity of 55,000m^3/d in normal season and 40,000 m^3/d in dry season is an actual limit.

The facilities of No.1 Plant of MJ-WTP are very old and deteriorated and the half of facilities has been inoperable, causing severe water shortage. The preservation of the capacity of 80,000 m^3/d is very important to Harare Water Works. Plants No. 2 and 3 are relatively new, but there are many signs of deterioration, such as insufficient painting, loss of automatic function, broken monitoring equipment, and sand filters. Since the chlorine injection has been concerns for safety and health, replacement has been studied. The immediate refurbishing/rehabilitation of the other facilities should be also surveyed in detail.

As mentioned in section (2), the assumed yield capacity of water intake (759,600 m^3/d) for MJ-WTP is more than the current actual production amount of 585,000 m^3/d.

Thus, the rehabilitation program of MJ-WTP shall be given even higher priority than the New Dam Plan such as Kunzwi Dam.

2) Transmission facilities

Since there is a large difference in elevation (approximate 150 m) between MJ-WTP and the City of Harare, high pressure pumps have been utilized for the transmission lines. Currently, although these pumps are well maintained, some rehabilitation plan should also be considered since the pumps are already old. The transmission lines from MJ-WTP to the city are also old so regular inspection and maintenance are essential.

3) Distribution facilities

The majority of produced water of MJ-WTP is transmitted to Warren P/S which is a major distribution P/S and transmits the water directly to many reservoirs dispersed in the city. Each transmission pump has been deteriorated due to the unavailability of proper replacement parts even if the staff has conducted scheduled maintenance work.

Based on observation, since the structure of the reservoirs is relatively sound due to fair structural design and construction, urgent rehabilitation may not be necessary.

Leakage ratio in the Harare Water Work's distribution system exceeds 50% particularly in the pipes that were laid over 60 years ago. The majority of water distribution lines are asbestos cement (AC) pipes which gradually corrode in the form of internal calcium leaching by conveyed water and/or external leaching caused by groundwater. Such leaching leads to reduction of the area of cross-section of the pipes resulting to pipe softening and loss of structural strength. As the water distribution system ages, the number of defects of AC pipe will increase. In light of these risks, assessment of AC pipe condition is essential to determine the pipes' remaining service life and develop a suitable, proactive replacement plan for the water distribution system. In addition, since the connections of AC pipes easily leak, leakage detection must be carried out for repairs and replacement work. Generally, reduction of leakage is not easy and requires a huge budget.

To ensure sustainable operation, a comprehensive rehabilitation and gradual implementation plan should be formulated.

(5) Insufficient budget for repair/replacement and future plan

The budget of Harare Water in 2010 for repair and maintenance is 6.3 mil.USD out of the total expenditure of 79 mil. USD. There is no budget allotted for expansion and refurbishment cost. The reason is that many facilities are left without repair and replacement. This situation seriously affects the sustainability of the water supply facilities in terms of proper maintenance and the quality of service provided to the customers.

The annual budget required for repair and replacement stipulates that a minimum of 5% should be allocated to mechanical and electrical construction costs. In this case, the calculation of required costs for the construction of MJ-WTP is shown below:

The design capacity of MJ-WTP: 600,000 m^3/d

Construction costs of the WTP are assumed to be at 150 USD/m^3 and around half of the costs are for mechanical and electrical facilities, therefore:

The costs of mechanical and electrical facilities: 600,000 m^3/d × 150 USD/m^3/d × 0.5= 45,000,000 USD

The required annual cost for repair/maintenance = 45,000,000 × 0.05 = 2,250,000 USD

Therefore, as shown in the calculation, MJ-WTP alone requires 2.25 mil. USD annually for repair/maintenance costs, but it might increase depending on the situation. Compared to the above, the cost of repair and maintenance of Harare Water Works at 6.3 mil. USD seems adequate. But even with the budget allocation, irregular and inappropriate repair and maintenance practices cause the facilities to further deteriorate and will cost more in the log run. On other hand, mechanical/electrical facilities deteriorated more than civil/architectural structures. Usually, these facilities are replaced every 20 years otherwise the repair/ maintenance costs will be increased. Some mechanical/electrical facilities, such as pipes and supports, have longer service life, and the replacement costs can be reduced but not substantially. The replacement costs for MJ-WTP, are assumed as:

The costs of mechanical/electrical replacement: 600,000 m^3/d × 150 USD/m^3/d (construction cost) × 0.5 (the ratio of mechanical/electrical costs) ×0.9 (except for the additional costs of facilities continuously used) = 40,500,000 USD

The annual costs are: 40,500,000 USD÷20 years = 2,025,000 USD/year

These costs for the WTP must to be allocated to maintain the water supply system except for the additional costs of future objected growths of water demands.

5.1.2 Chitungwiza Municipality

(1) A list of major issues in Chitungwiza municipality

1) Frequent interruption of water supply,
2) Almost all housings are connected to distribution pipes with water meters but the number was not grasped properly and meter reading was not carried out regularly**,**
3) Controlled water supply by Harare Water Works,
4) Uncompleted water transmission and distribution network,

5) Deteriorated facilities and lack of proper maintenance, and
6) Low collection rate of the water charge.

Each issue is evaluated in outlined below.

(2) Frequent interruption of water supply

The frequent interruption of the water supply in many areas is either on purpose, or simply because of the lack of water. There are mainly four water supply conditions in the municipality that affect water distribution as shown in Table 5.1.6 and Figures 5.1.6 (a)-(d). Only Case-3 and -5 can be applied to all the areas, while Case-1,-2 and -4 water can be applied to limited areas as shown in Figure 5.1.6 (a), (b) and (c). In the case of Case-1,-2 and -4, branch valves need to be operated in order to distribute to the un-served areas. In the table, Case-1 is apparently intentional and is caused by unpaid water charges to Harare Water Works. Although main valve distributing to the municipality is closed, the flow cannot be stopped completely due to the eroded wedge of the valve.

Even in Case-3 and -5, it is necessary to shut down the valves distributing water to the municipality to enable water to reach the reservoirs. Even under normal operations, water cannot be served to the entire municipality. In addition, the water flow is basically constant against fluctuating consumer demand. Thus, the system is an uncompleted one as shown Section 4.1.2.

Table 5.1.6 Conditions to distribute to the Municipality.

Distribution	Case-1	Case-2	Case-3	Case-4	Case-5
Valve	Close	15% open	30% open	30% open	100% open
PE-WTP	Operating	Operating	Operating	Stop	Operating
Flow (m^3/d)	10,000	30,000	36,000	24,500	44,000
Condition	Fig.-a	Fig.-b	Fig.-c	Fig.-d	Fig.-c

Valve: distribution main valve to the municipality

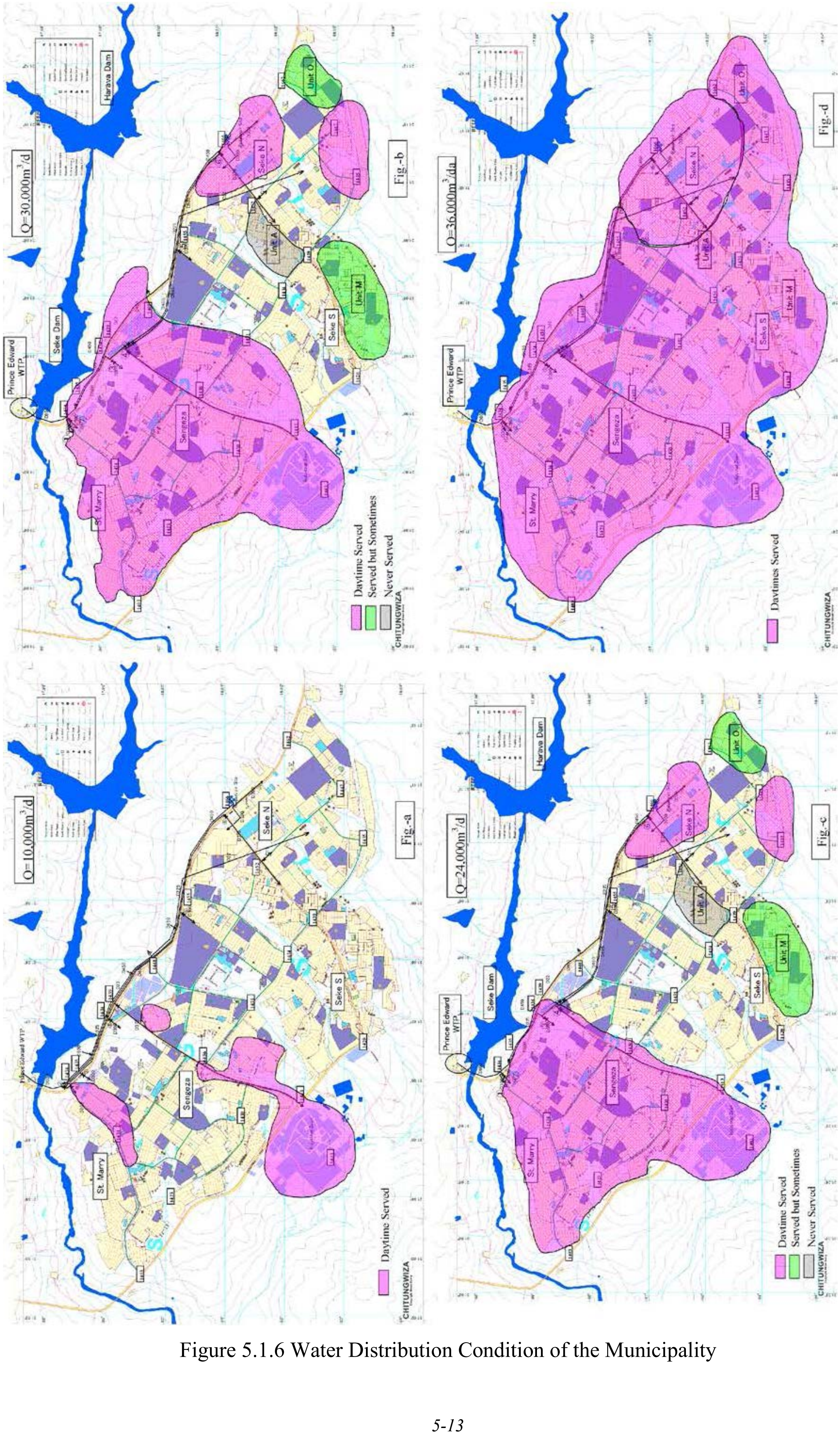


Figure 5.1.6 Water Distribution Condition of the Municipality

In May 2012, water flow to the municipality was determined to be 30,000 m^3/day and the service condition is shown in Figure 5.1.6 (b).

It shows that half the municipality has not been receiving water during the day, and not even every night of the week. Around 36,000 m^3/d of the distribution flow is necessary to serve the whole area except for the areas served by elevated tank. However, even in this case, water cannot still reach the ground reservoirs (V= 41,000 m^3) located at the highest elevation site which has an inflow level of 4m higher than the ground. In September, the maximum flow rate to the municipality has been confirmed to be around 45,000 m^3/day.

(3) Insufficient management of water supply works

Currently, data of meter status of individual housings and other customers in Chitungwiza are kept at the municipality computer system. But the number of individual housings is quite doubtful because the number is said to be around 54,000 although the actual counted number of housings were around 37,000. At the beginning of 2013, the function of water meter has been surveyed by the staff of water supply section, asked by World Bank, and these staffs consider that total number of individual consumers is less than 30,000. In addition, meter readings have seldom been carried out. Accordingly the management of water supply works must be reviewed thoroughly.

(4) Controlled water supply by Harare Water Works

Water distribution to the municipality has been frequently stopped mainly due to non-payment water bill to Harare Water Works as well as the reduction of water production in draught season. Thus the municipality hopes to acquire an independent water resource and to construct a new WTP.

This will necessitate a huge budget and difficult concession with governmental organization. In addition, independent water source management including WTP construction and operation will be less efficient and uneconomical. Furthermore, the cause of water interruption is the municipality's inability to pay its current outstanding obligations, so it is doubtful if it can manage having its own independent WTP.

(5) Uncompleted water transmission and distribution facilities

As mentioned in section (1), water cannot be transmitted to the ground reservoirs without shutting down the branch valves as shown in Figure 5.1.7 except for the valves to Manyame Park and Zengeza Industrial Zone. This situation affects the continuous supply of water to the consumers. The ground reservoirs are used as a pump pit for the lift pump (10 m^3/min) to the elevated tank.

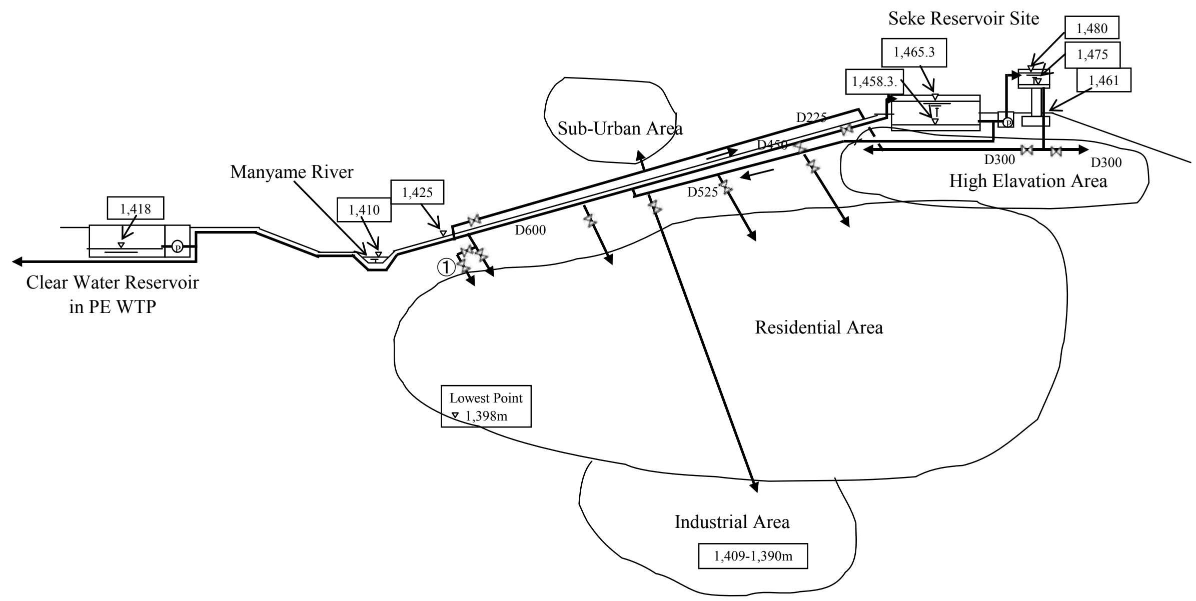


Figure 5.1.7 Water Transmission and Distribution System of the Municipality

The hydraulic evaluation results for the existing pipe network are shown in Figure 5.1.8 with the condition of 45,000 m^3/d of water flow, which was confirmed as the maximum flow to the municipality. As shown in the figure, many pipes show negative pressure, thus, water cannot reach to many areas in the municipality.

A normal water transmission network must be composed as: clear water once inflow reservoirs through the transmission pipe and stored clear water flows out from the reservoirs to the municipality through a distribution pipe network. Then, the pipe system should be modified as shown in Figure 5.1.9, but pipe capacities should meet the necessary flow rate, which is double to daily maximum flow. Flow capacities for many pipes cannot meet the increased flow rate, as shown from the hydraulic evaluation results (Figure 5.1.8).

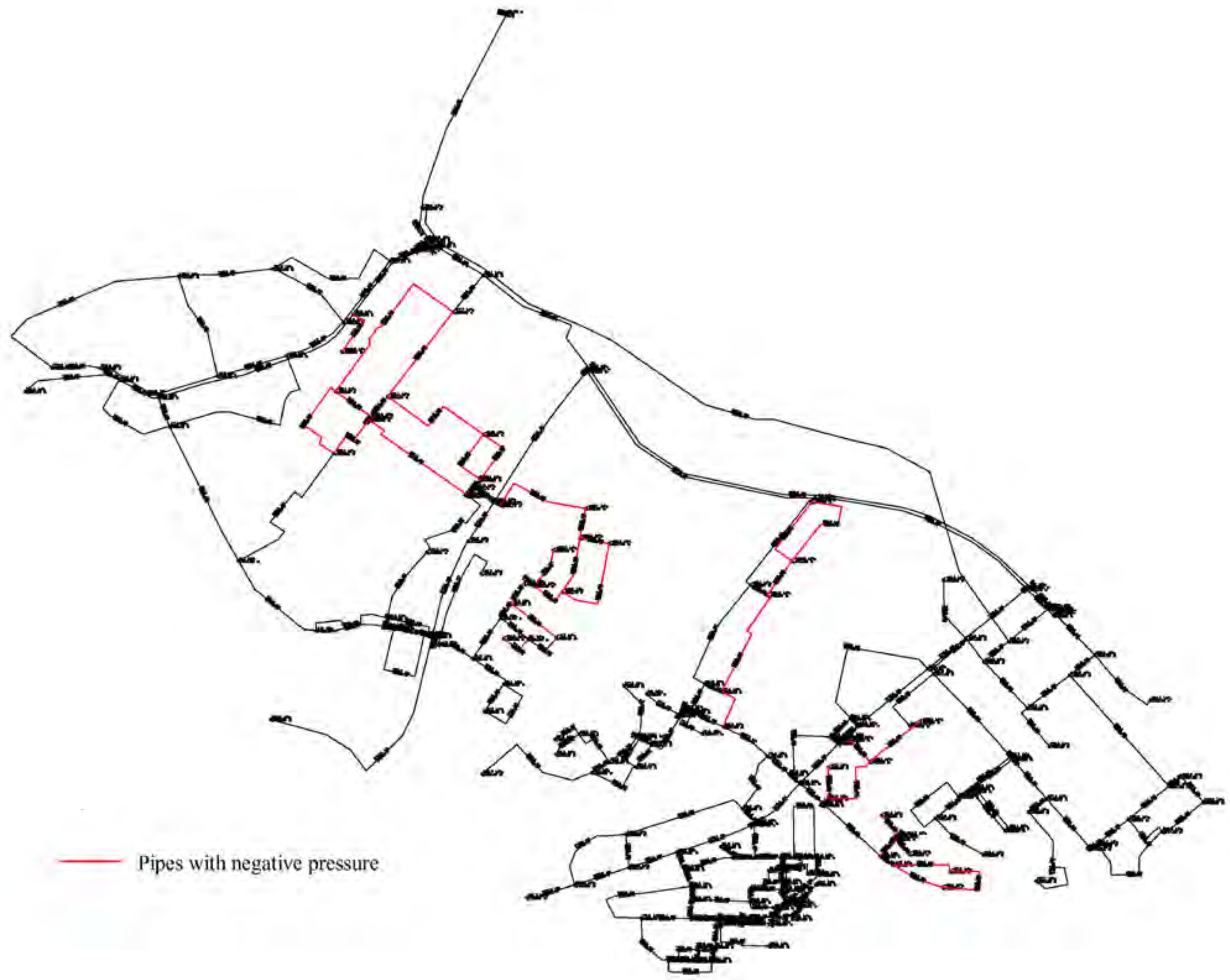


Figure 5.1.8 Hydraulic Evaluation Results of the Pipeline Network

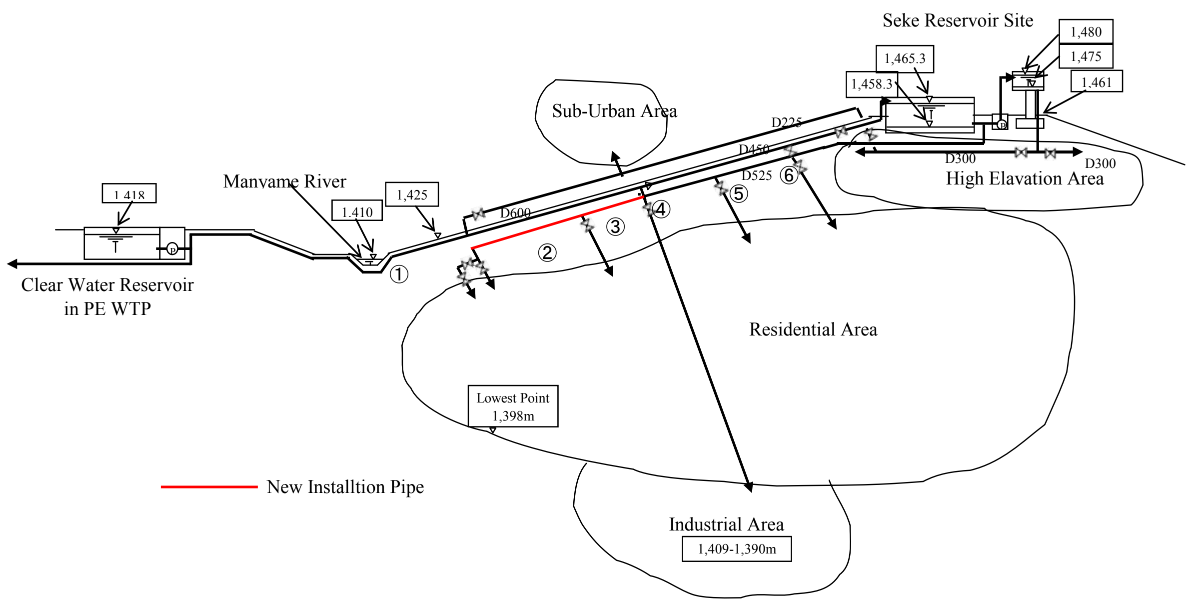


Figure 5.1.9 Modified System of Water Transmission and Distribution

(6) Insufficient maintenance of facilities and low collection rate of water charges

The facilities which the municipality manages are the water transmission and distribution facilities; water transmission lines with various valves, four ground reservoirs structures, one small scale P/S, one elevated reservoir and water distribution lines from the diameter of 50 to 525 mm. Almost all the facilities and pipes were constructed after the 1980s and are relatively new. The life span of these pipes and civil structures is relatively long, and only pumps with electric facilities usually require daily maintenance. As mentioned in the previous section, daily operation of branch valve is required in order to supply the entire area due to the uncompleted system.

Currently, the condition of lift pumps is very poor, while the stand-by pump has been left without repair, and the operating pump and electric panel are heavily deteriorated. In spite of the poor condition of mechanical/electrical facilities, the condition of structures, such as reservoirs is still good.

Table 5.1.7 shows the unpaid bill amount to Harare Water Works for the bulk water charge. As shown the table, the unpaid bill amount is continuously increased after taking over of water supply works from Zinwa to Harare Water Works and the municipality. Table 5.1.8 shows budgetary balance of the Chitungwiza water works.

As shown the table, it seems the balance is sound, but below explanation must be noted;

i) The items in the revenue such as water sales is just the amount of issued bill, not the received money amount, and the assumed amount is shown in *1 of assumed actual revenue
ii) Since the items of bulk water expenditure *2 in 2010 and 2011 is changed to be actual bills from Harare Water Works, and column*3 of actual paid bulk water is filled shown in Table 5.1.7
iii) As shown in the actual balance *4, the balance in only 2009 made profit and that in 2010 and 2011 made deficits
iv) As shown in the actual balance *5, although the balance of the three years made profits due to unpaid bulk water, the profits were spent for the personal costs of the municipality
v) The repair/maintenance cost was almost zero
vi) The cost for expansion of service is the third in the expenditure items

Table 5.1.7 Unpaid Bill Amount for Bulk Water to Harare Water Works

Period	Billing by Harare (1000USD)	Monthly Average Bill (1000USD/month)	Paid Bill (1000USD)	Payout Ratio (%)
2009(June-Dec)	1,911.7	273.1	286	15.0
2010(Jan-Dec)	3,414.3	284.5	900	26.4
2011(Jan-Dec)	3,414.3	284.5	910	26.7
2012(Jan-Sep)	2,560.7	284.5	0	0.0
2012Oct-2013Feb	1,422.6	284.5	0	0.0
Total	12,723.6			

(shaded) Assumed amount, Modified Table 3.4.28

Table 5.1.8 Income Statement of Balance of the Chitungwiza Water Works

(Unit: 1000 USD)

Year	2011	2010	2009	Note
Sales*1	5,910.6	5,527.3	6,330.7	
Others	35.8	177.0	6.5	
Total Revenues	5,946.4	5,704.3	6,337.2	
Assumed Actual Revenue	3,865.2	3,707.8	4,119.2	Collection Ratio 65%
Personal Cost	652.9	288.2	206.6	
Bulk water*2	3,453.6	3,414.3	3,414.3	Budget
Actual Paid Bulk Water*3	286.0	900.0	910.0	Actual
Repair/Maintenance	1.9	1.9	1.4	
Bank cost	289.4	10.5	3.3	
Others	20.2	954.5	272.5	
Total Expenditures	4,418.0	4,669.4	3,898.1	
Balance	1,528.4	1,034.9	2,439.1	
Actual Balance 1 (including bulk water budget)*4	-552.8	-961.6	221.1	
Actual Balance 2 (including paid bulk water)*5	2,614.8	1,552.7	2,725.4	

Modified Table 3.4.31

5.2 Sanitation and Sewerage

5.2.1 Functional Recovery of the Sewerage System in the Chivero Catchment Area

Harare is the capital city of Zimbabwe and is located in the Lake Manyame catchment area. It discharges STP effluent into the main tributaries of Lake Chivero and also abstracts its raw water from the lake. Wastewater is treated at the two main STPs of Crowborough (capacity 54,000 m^3/d) and Firle (144,000 m^3/d). These two plants treat about 60% of the raw wastewater using modified activated sludge systems, popularly referred to as biological nutrient removal (BNR) systems, whilst the rest (40%) is treated by means of trickling filters (TF). Effluent from Crowborough STP is discharged to Marimba River and that of Firle STP flows into the Mukuvisi River except for effluent for irrigation. The trickling filter effluent and primary and secondary sludge (after digestion for primary sludge only) are mixed and used for pasture irrigation. However, the two major STPs are partly broken and overloaded and often discharge partially treated effluent into the main tributaries of Lake Chivero. As a result, water quality of Marimba River and Mukuvisi River has badly deteriorated in recent years, resulting in serious water quality problems in Lake Chivero. However, since both STPs almost discontinued the use of the BNR facility because of budget problems, the direct discharge has polluted Lake Chivero more.

Zengeza STP in Chitungwiza Municipality was treating about 36,000 m^3/day by TF and BNR processes, however, after 2004, both treatments were discontinued because of serious budget problem affecting proper maintenance. At the same time, effluent transmission pump broke down resulting in the direct discharge of the raw sewage into Nyatsime River polluting its tributaries.

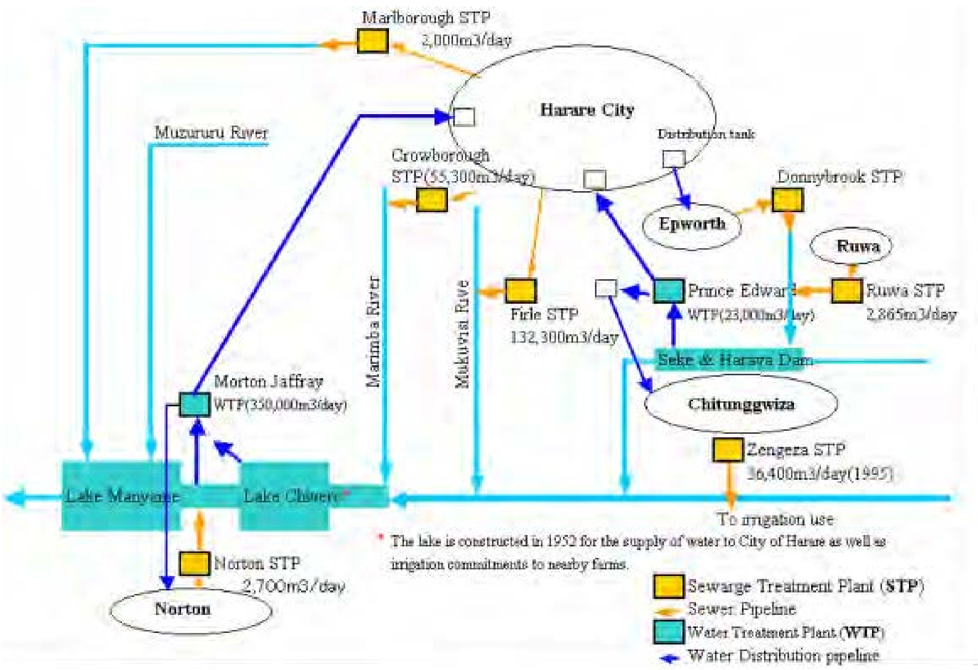


Figure 5.2.1 Manyame Catchment and WTP/STP Facilities

For Norton, TF process was working till 2000, however, treatment was discontinued also because of budget problems. After the breakdown of the transmission pump to the irrigation farm caused by vandalism, raw sewage has been discharged to the Lake Manyame. In August 2012, the Morton Jaffray WTP partially discontinued water intake from the Lake Manyame due to the water pollution, affecting water supply for the City of Harare. The accident was caused by direct discharge of the raw sewage from Norton STP.

Ruwa STP has a stabilization pond process however, satisfactory maintenance work such as sludge removal from the anaerobic ponds has not been done by the township. Half treated sewage has been discharged to the Nyatsime River polluting the Lake Chivero.

Table 5.2.1 Present Sewerage Services and Problem Area

Sewage Works	Served Population / Coverage (%)	Service Area: Sewer Conditions	Service Area: Environmental Problems	Sewage Treatment: Inflow to STP Flow (m3/d) / Influent Quality (mg/l)	Treatment Capacity (m3/d) / Overloaded Flow (m3/d)	Discharge to River Flow (m3/d) / Effluent Quality (mg/l)	Irrigation Use Flow (m3/d) / Effluent Quality (mg/l)	Environmental Problems at STP / Environs of STP
Crowborough S.Ws	405,800 (1992 Census)	- damage of manhole & sewers	- common offensive odor	58,400	54,000	16,800	41,600	- BNR not working
	100	- buried manhole cover rain water intrusion to - manhole BNR breakdown		COD 1,108.9 TN 53.0 TP 7.2	4,400	COD 80.6 TN 12.6 TP 0.6	COD 371.0 TN 39.0 TP 5.2	- A part of TF working
Firle S.Ws	560,000	- raw sewage spill along 6 routes of lateral sewers (14km)	- health hazard - offensive odor along problem sewers	95,000	144,000	30,000	65,000	- trickling filter is overloaded with offensive odor
	100	- BNR Breakdown		COD 943.0 TN 54.0 TP 6.9	23,000	COD 27.9 TN 0.8 TP 0.7-12.0	COD 232.5 TN 39.6 TP 3.4	- BNR not working
Zengeza S.Ws	400,000	- identified problems points along sewer lines	- health hazard - stream pollution by raw sewage	36,400	20,400	None	36,400	- offensive odor pollution of nearby river upon overflow of effluent
	99.9	- BNR not working		BOD 810.0 TN 38.0 TP N.A.	16,000	None	BOD 175.0 TN 57.0 TP N.A.	- BNR not working PS for Farm not working
Norton S.Ws	20,500	no special reports - TF break down -	- no special reports	2,500	3,400	None	2,500	- TF not working
	80			BOD 660.0 TN 83.3 TP 7.6	-900	None	BOD 520.0 TN 65.8 TP 7.6	- WTP treatment stoppage
Ruwa S.Ws	1,400	- intrusion of groundwater and rain water	- no special reports	3,000	5,300	None	3,000	- during rainy season overflow of effluent to nearby river
	99			BOD 510.0 TN 31.0 TP 3.6	-2,300	None	BOD 47.5 TN N.A. TP trace	- no special reports

Note: N.A. - Not Available

The discharge of partially treated wastewater into rivers is obviously not sustainable in the long-run as it could result in the further deterioration of water quality in Lake Chivero. Polluting the water sources by discharge of effluent from unsatisfactory sewage treatment is obvious from the study.

As shown in the pollution analysis, most of the generated pollution loads are considered as coming from Harare and Chitungwiza. Thus, functional recovery of the sewerage system including irrigation of the farms is urgently needed for the improvement of the environment in the catchment. As presented in the Appendix 4 Analysis, sewage is the biggest pollution load for the water sources in the catchment area. And improvement of the water quality is projected in the simulation after the rehabilitation of the STPs. Thus, rehabilitation of the sewerage system will be the urgent measure to be taken. AfDB project for the six cities for the rehabilitation of water, sewage and hygiene and AWF project for the Chitungwiza Municipality will be taken as urgent measures for this project, and complementation between this project and AfDB/AWF projects will be required.

Sewerage will be the major player for environmental improvement since the pollution level had exceeded the environment capacity. Sewerage will also be very important to conserve the ground water, since a lot of people were confirmed to have been depending on underground water, particularly shallow wells.

All the STPs have the problems for the sewage treatment process as shown in Table 5.2.2.

Table 5.2.2 Sewage Treatment Method/Process and Effluent Reuse

Sewage Works	Treatment Process to Discharge Effluent into River	Treatment Process to use Effluent for Irrigation	Problem Areas Operation of Facilities and Environmental Problems
Crowborough STP	Screen & Grit removal - Primary Sedi. Tank - BNR - Final Sedi. Tank : Marinba River	Screen & Grit removal - Primary Sedi. Tank - Trickling Filter - Final Sedi. Tank - Storage Pond - Pump Station	- Rehabilitation has been on-going for the Crowborough - no special reports on environmental problems
Firle STP	Screen & Grit removal - Primary Sedi. Tank - BNR - Final Sedi. Tank : Makuvisi River	Screen & Grit removal - Primary Sedi. Tank - Trickling Filter - Final Sedi. Tank - Storage Pond - Pump Station	- Rehabilitation has been on-going for the Crowborough - no special reports on environmental problems
Zengeza STP	None (BNR Malfunction)	Screen & Grit removal - Anaerobic Pond - Trickling Filter - Pump Station	- BNR facility has been malfunctioned - All the inflow has been discharged to the Nyatsime River
Norton STP	None	Screen & Grit removal - Primary Sedi. Tank - Pump Facility - Trickling Filter - Final Sedi. Tank - Storage Pond - Pump Station (No operation)	- Water quality accident occurred in August in 2012 - unsanitary condition at storage pond (anaerobic condition covered by scum on the pond surface)
Ruwa STP	None	Pump Facility - Anaerobic Pond - Facultative Pond - Maturation Pond	- overflow of effluent into nearby river during rainy season

Multi-donor fund under AfDB has been financing the rehabilitation of facilities for Harare City. AWF project will fund the Zengeza STP aimed at the rehabilitation of five existing units of trickling filters, pump station for irrigation and others for urgent measures. The project will be economically desirable but not sufficient to improve effluent water quality. It will be required to take supplementary measures to get satisfactory water quality as required by regulations. Norton STP is also broken down however, there is no specific rehabilitation plan for the STP.

Table 5.2.3 Planned On-going Sewerage Projects for Immediate-Medium Term Improvement

Sewage Works	Sewer or S.Ws	Item	Planned/Designed	On-going Construction	Recommended Plan	Required measure between Present Needs and Countermeasure
	Sewer	SS1				-needs of continuous rehabilitation and
	System	SS2	Rehabilitation, AfDB	Ditto	N.A	expansion
		SS3				
Crowborough		ST1				
S.Ws		ST2				
	Sewage	ST3	Rehabilitation, AfDB	Ditto	N.A	
	Works	ST4				-Tertiary treatment is adequate.
		ST5				
		ST6				
		SS1				-needs of continuous rehabilitation
	Sewer	SS2	Rehabilitation, AfDB	Ditto	N.A	and expansion
	System	SS3				
Firle						
S.Ws		ST1				-Current shortage of treatment capacity
		ST2				will be solved by on-going project.
	Sewage	ST3	Rehabilitation, AfDB	Ditto	N.A	
	Works	ST4				-Tertiary treatment is adequate.
		ST5				
		ST6				
	Sewer	SS1				-needs of continuous rehabilitation
	System	SS2	Rehabilitation, AfDB	Ditto	N.A	and expansion
		SS3				
Zengeza		ST1				
					Rehabilitated capacity not	
S.Ws		ST2			enough. To increase the	-Increase the treatment capacity
	Sewage	ST3	Rehabilitation, AfDB	Ditto		-Maintenance needed
	Works	ST4				
		ST5				
		ST6				
	Sewer	SS1				-needs of continuous rehabilitation and
	System	SS2	None	None	N.A	expansion
		SS3				
Norton		ST1			-rehabilitation of existing	-Rehabilitation required urgently
S.Ws					TF and Pump station	for conservation of water quality for
	Sewage	ST2				Morton Jaffray WTP
	Works	ST3	None	None		-Maintenance needed
		ST4				
		ST5				
		ST6				
		SS1	None			-needs of continuous rehabilitation and
	Sewer	SS2		None	N.A	expansion
	System					
		SS3				
Ruwa		ST1				-Maintenance needed
S.Ws		ST2				present sewage inflows.
	Sewage	ST3	None	None	N.A	
	Works	ST4				
		ST5				
		ST6				

Note :	SS1 : Trunk Sewer	N.A : Not applicable
	SS2 : Pump Station	N/A : No information Available
	SS3 : Lateral & Service Connection	
	ST1 : Design Flow (m3/day)	ST4 : Effluent Reuse/Disposal
	ST2 : Sewage Treatment Level	ST5 : Major Facilities & Equipment
	ST3 : Sludge Treatment & Disposal	ST6 : Estimated Cost (million Z$)

Remarks: Activity of AfDB for water and sanitation sector

<Emergency Water Supply and Sanitation Project, By Zim Fund>
(1) Harare
Water Supply: 4,925,000 USD (Morton Jaffray WTP etc.)
Sewerage: 4,600,000 USD (Firle STP etc.)
(2) Chitungwiza
Sewerage: 1,430,000 USD(Zengeza STP etc.) Planned. The projecte was floated but adjudicated as of Feb 2013.

<African Water Facility, By Grant-Aid>
Sewerage: 2,900,000 USD (Sewers, Pump Station and Zengeza STP) Up to October 2012

The project was completed at the end of Feb 2013. Zim Fund project will take over the improvement work.

5.2.2 Ambient Water Quality Conservation

The main water management problem in the catchment is that wastewater discharges contribute significantly to eutrophication in Lake Chivero and Manyame, although the current extent is not well known. The problem is compounded by the fact that water released from the lake does not take place frequently in years of low rainfall as the dam floodgates are permanently closed. Spillway discharges normally take place only from January to April, meaning that the lake acts as a sink for pollutants for most part of the year. As the population grows, the lake will increasingly receive a higher fraction of STP effluent whilst raw water abstraction will also go up, posing a water quality and quantity problem.

Data from EMA shows the serious pollution of Lake Harava, Seke, Chivero and Manyame as shown in Chapter 3. Nutrient concentrations (TN=1.6 mg/l, TP=0.02 mg/l, 2012 source: EMA) in the lake Chivero were far higher than the allowable limits of <0.3 mg/L TN and <0.01 mg/L TP for drinking water taken from lakes. This has led to excessive primary productivity and related problems in the lake. Nitrogen and phosphorous inputs need to be controlled to avoid further deterioration in water quality. Ambient water quality level in the catchment is already at a serious level as water sources.

In this context, detailed research is required to understand the current flux of water and nutrients into and out of the catchment qualitatively so that corrective measures can be based on a better understanding of the system. Although the pollution analysis conducted in this study will be helpful for this purpose as well, the JICA Project Team found out that data such as flowrate, ambient water quality and various statistics have not been updated nor recorded from 2000 till 2010 by Authorities due mainly to shortfalls in the budget and/or other reasons.

A big problem is that the population in the catchment depends on the water from Lakes Harava, Seke, Chivero and Manyame, until another water source will be developed. The Zimbabwe Government should reconstruct the water quality monitoring system as well as the functional recovery of sewerage system in order to conserve these water sources.

The establishment of the water conservation measures is the major point in terms of protecting/ safely securing the water sources and improving the environment by water pollution control. Even if the irrigation is used to alleviate the washout of the pollutant and nutrient for the water body, this might pollute the groundwater and soil in the long run.

Direct water purification in the Lakes might be another alternative as shown below:

(1) Installation of aerators in the lakes

This is for providing dissolved oxygen in the water to promote oxidation of organic matter in the water.

(2) Installation of water recirculation device

This will circulate the lake water to break the thermocline and provide dissolved oxygen in the water at the same time. Required power will be less than aerators.

(3) Water purification by vegetation

Vegetation will be utilized to remove nutrient from the water.

(4) Removal of bottom sludge

Removal of bottom sludge will be made by dredging, transferring, treatment and disposal. It will be limited only in specific area since the work is very costly.

5.2.3 Sewer Reticulation

Sewer reticulation in Chitungwiza was roughly confirmed to have capacity required for the future flow till 2030. However, it will need a lot of repair work and rehabilitation. The work includes continuous sand removal. Sand problem is very serious as indicated in the photo 5.2.2.

Since the development of the Ward 1 project would be completed in 2030 as shown in the figure 5.2.2, a new sewer trunk line (Force main) and a sewage pump station must be constructed according to the development plan in parallel with the augmentation of the sewage treatment plant.

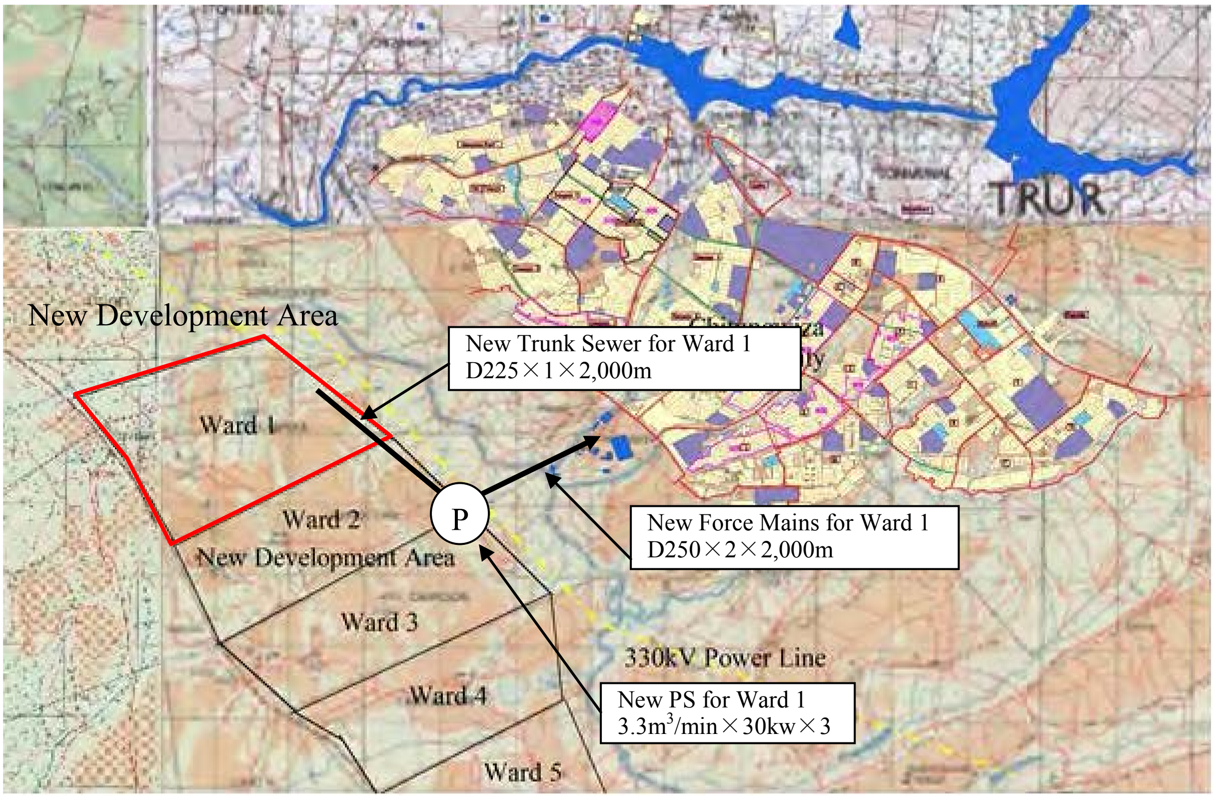


Figure 5.2.2 Ward 1 Development and Plan of Sewerage

Breakdown of the sewers as well as all the sewage pump stations is found in the Municipality. Sewage spills have been seen around the Municipality. From the standpoint of environment conservation, urgent countermeasures must be taken.

To deal this situation, AWF project is underway for rehabilitation of sewer reticulation and three pump stations. Since the budget of AWF project is limited, not all the problematic parts will be covered. For example, Tilcor industrial area is not included in the AWF project. All the sewage from the Tilcor flows into the existing channel in the area thereby polluting Nyatsime River. Then, supplemental measures will be needed in this field as well. The situation of the sewer reticulation is the same in other Municipalities.

5.2.4 Sand Issues

Another issue is the presence of sand in the pipelines and reticulation. Although rehabilitation work has been on-going under the AfDB scheme (Multi donor fund) for city of Harare and Chitungwiza municipality, clogging problems caused by sand deposit in the pipelines or pump stations are prevalent: Clogging of sewers, sewage spilling out from manholes polluting streets, buried grit chamber in the STP by sand deposit and flooding in the pump station due to inappropriate sand disposal method around the sewage facility.

The amount of resources wasted – broken equipment by abrasion, required time for solution, and cost of resultant pollution – brought about by the sand problem even in the sewer network in Chitungwiza is unimaginable. The origin of the sand is thought to be sand used by residents when washing their pots; however, the real reason has not yet been identified. The sand deposit in the sewers is seen to also negatively affect lake capacity. In order to plan the right counter measure for the sand issue, field tests were conducted. Various aspects as to how sand finds its way in the facility were studied. A survey was conducted on the residents' practices, on sewers, manholes and storm water pipelines to find out the actual extent of the problem. In this Pilot Project identifying the unit generation rate of sand in the sewerage and cause of the sand was made. A total of 150 residences were selected from the five areas in Chitungwiza Municipality. Prototype sand traps were planned as shown in the Figure 5.2.3. The structure is similar to the grease trap but it has a sieve bottom to catch the sand. In the survey, effectiveness of the trap and unit sand generation rate per capita was studied. Amount of sand was also surveyed at the grit chamber of the STP.

Photo 5.2.1 Sand and Grease Trap

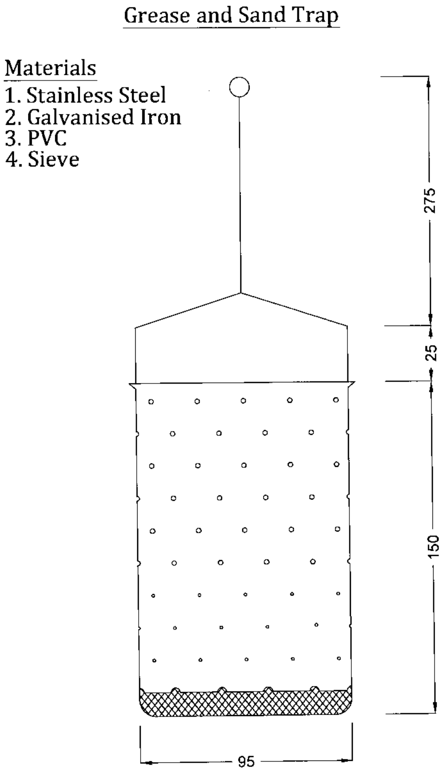


Figure 5.2.3 Configuration of Sand Trap

5.3 Solid Waste Management

5.3.1 Evaluation of Current Issues on Solid Waste Management

(1) Illegal dumping

The illegal dumping was identified in and around the Chitungwiza city in the illegal dumping survey conducted through a subcontractor. The various causes of illegal are a mix of issues, and have been categorized around the following:

- Public awareness: Lack of public awareness on effects of illegal dumping
- Accessibility: Problem of accessibility of the municipality's collection service
- Service capacity: Lack of the municipality's collection capacity
- Cleanup planning: No comprehensive plan to control illegal dumping

1) Lack of public awareness on illegal dumping

According to the municipality, some residents are not aware of the municipality’s collection rules and dump their waste on the road side or drain ditch. The dumped waste has continued to pile up in many areas. Even if some residents are aware of the collection rules / schedule, they no longer depend on the municipality’s scheduled collection service because of its unreliable service caused by vehicle breakdowns. There also seems to be a lack of communication between the residents and the municipality.

2) Problem of accessibility of the municipality’s collection service

In most cases, the non-collection service area is located in the low lying areas where new housing units have been built. The municipality’s collection service vehicles cannot reach these areas because of the muddy condition of the roads during the rainy seasons and the presence of potholes / irregularity of the road condition. The residents have no choice but to resort to illegal dumping. Therefore, the issue is connected not only for the solid waste management section but also linked for other stakeholders such as the department of works which handles road construction works, or the department of urban planning which makes the urban plan. This issue should be shared among such stakeholders.

3) Lack of the municipality’s collection capacity

Currently, the municipality owns only nine operational vehicles which are over 12 years old or since the Japanese government supplied as a grant-aid project. Other vehicles are not operational or malfunctioning. To aggravate the situation, the municipality cannot purchase spare parts required for the repair of the vehicles. Thus, the collection capacity is well below the requirements for actual operation.

4）Lack of cleanup plan for controlling illegal dumping

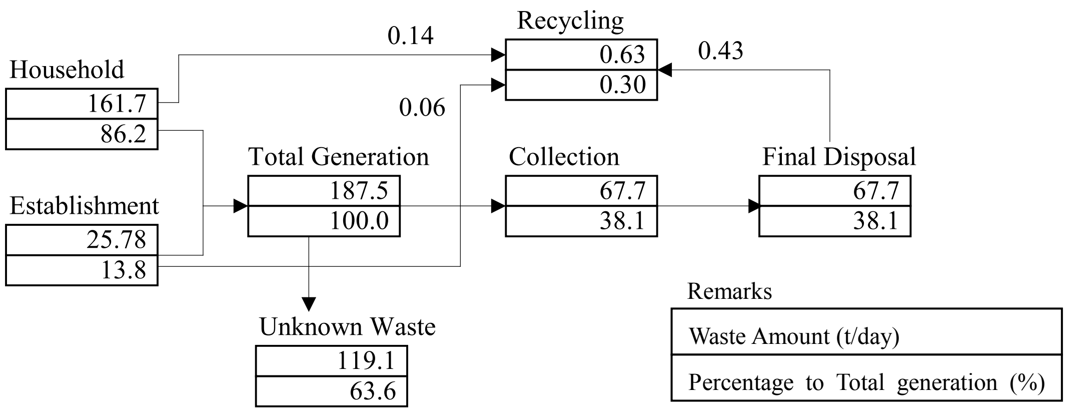
The municipality has no data of actual illegal dumping and appropriate plan for their clean-up. The penalties for controlling the illegal dumping are not currently being enforced.

(2) Collection & transport

1) Insufficient collection capacity

As already mentioned before, the municipality's collection vehicles are over 10 years old and most are either malfunctioning or non-functioning. A waste stream was prepared as shown in Figure 5.3.1 by computation of per capita waste generation amount and the municipality's current collection capacity. The latter was obtained from the waste amount and composition survey, as well as information gathered from the solid waste management section, respectively.

As shown in Figure 5.3.1, the collection level to the current waste generation amount is only 36%, which shows the low capacity of the municipality's collection service.



Source: JICA Project Team

Figure 5.3.1 Waste Stream (Current)

2) Frequency of collection service

The frequency of the municipality's collection service is currently on a weekly basis which presents a problem from the point of view of hygiene, as kitchen waste will have to be stored for the same period in the in household.

3) Lack of capacity of operation and maintenance

In the solid waste management section, fuel or tires are not often supplied. These are necessary for proper operation and maintenance of the vehicles to ensure service vehicles for scheduled solid waste collection. The appropriate budget is not allocated to the normal operation of the solid waste management.

(3) Final disposal

The current final disposal facility is an open dumping which has no fence, truck scale nor function of leachate control system, such as impermeable liner. Soil covering, which is effective for hygiene control such as pest management, is not carried out. In addition, the municipality's facility is not managed appropriately as waste pickers currently operate in the dumping site. The municipality has not done much to improve the existing open dumping site even with the order / recommendation of EMA. As for candidate sites for new final landfill introduced by the municipality, none of the sites was recommended because of their close distance to the future housing areas.

CHAPTER 6 ANALYSIS OF WATER QUANTITY AND QUALITY IN MANYAME CATCHMENT AREA

6.1 Water Quantity and Quality in Manyame Catchment Area

6.1.1 Water Use in the Study Area

(1) Water use in the entire study basin

In the upper Manyame river basin, the major impoundments are Lake Manyame, Lake Chivero, Seke Dam and Harava Dam. Several rivers flow into these water bodies. Their general dimensions and water use are shown in Table 6.1.1.

Table 6.1.1 Water Use in the Entire Study Basin

Water Body	Catchment Area (km^2)	Rated Capacity (×1000m^3)	Flow Rate (×1000m^3/day)	Water Use
1. L. Manyame	590	480,236		Water Supply, Recreation and Fishery
Gwebi R.	770		282,540	Irrigation
Muzururu R.	310		113,900	Irrigation
2. L. Chivero	421	247,181		Water Supply, Recreation and Fishery
Marimba R.	215		131,000	Irrigation
Mukuvisi R.	230		214,000	Irrigation
Nyatsime R.	280		163,200	Irrigation
3. Seke & Harava Dam	115	12,406		Water Supply, Recreation and Fishery
Ruwa R.	195		72,846	Irrigation
Manyame R.	474		174,000	Irrigation

Source: Jica Project Team

The direct use of river water is minimal due to limited availability during dry season. As for irrigation, about 200 private dams are scattered in the Gwebi and Muzururu catchment area, while the reuse of treated effluent is dominant in the entire Study Area. On the other hand, lakes and dams are utilised for water supply, recreation and commercial fishery purposes. Four impoundments are the most valuable water sources for water supply of metropolitan Harare where presently 467,000 m^3/day are availed of.

As for recreational usage, Lake Manyame and Lake Chivero are designated as national recreational parks with a variety of interests including fishing, boating, swimming and game viewing. Commercial fishery is also allowed in both lakes. Since these impoundments are situated at a lower elevation than the urban area and farm land, generated wastewater reach the lakes. As of September in 2012, there is no future plan on water use in the study basin, thus the present manner of water use will continue to be practised

(2) Domestic and industrial water supply

1) Existing water supply system

The Harare water supply system covers Harare City (350 km^2) and its adjoining urban areas; Chitungwiza, Norton, Epworth, and Ruwa. The water supply service for the satellite areas of the city is provided by means of bulk water supply. The present water demand for Harare and Chitungwiza is projected to be 382,900 m^3/day. The industrial water consumption is about 23% of the domestic consumption, while that of commercial/institutional is 5%.

2) Raw water sources

The raw water sources of the Harare water supply system depend on four impounding dams with a yield of 586,000 m^3/day. The total intake amount at present is approximately 640,000 m^3/day. Water quality of the lakes/dams has deteriorated due to grey water and industrial wastewater discharge from urban areas into the Manyame river basin.

3)Water treatment plant

Two existing WTPs, Prince Edward and Morton Jaffray, adopt conventional water treatment system provided with sludge blanket clarifiers and rapid sand filters. The design capacity of the Morton Jaffray WTP and Prince Edward WTP are 614,000 m^3/day and 90,000 m^3/day, respectively. However, the Prince Edward WTP is operated intermittently to supplement peak demand, since its "safe yield" is limited to 23,000 m^3/day. Water production is 40,000 to 550,000 m^3/day

Table 6.1.2 Outline of Water Treatment Works

	Morton Jaffray WTW	Prince Edward WTW
Intake Source	Lake Manyame Lake Chivero	Seke Dam Harava Dam
Design Capacity	614,000m^3/day	90,000m^3/day
Actual Production Capacity	350,000m^3/day	23,000m^3/day

Source: Harare Water

The deterioration of raw water quality has affected the operation of the water treatment plants. The Morton Jaffray WTP, for instance, requires high chemical dosage which is beyond its full capacity for its dosing equipment to handle

4) Transmission and distribution

Treated water is pumped from Morton Jaffray WTP to Warren Pump Station, and is again pumped to service reservoirs through four transmission mains. Water is then distributed through the respective network systems from the concerned service reservoirs to end users. Figure 6.1.1 shows schematic diagram of the water supply system at present.

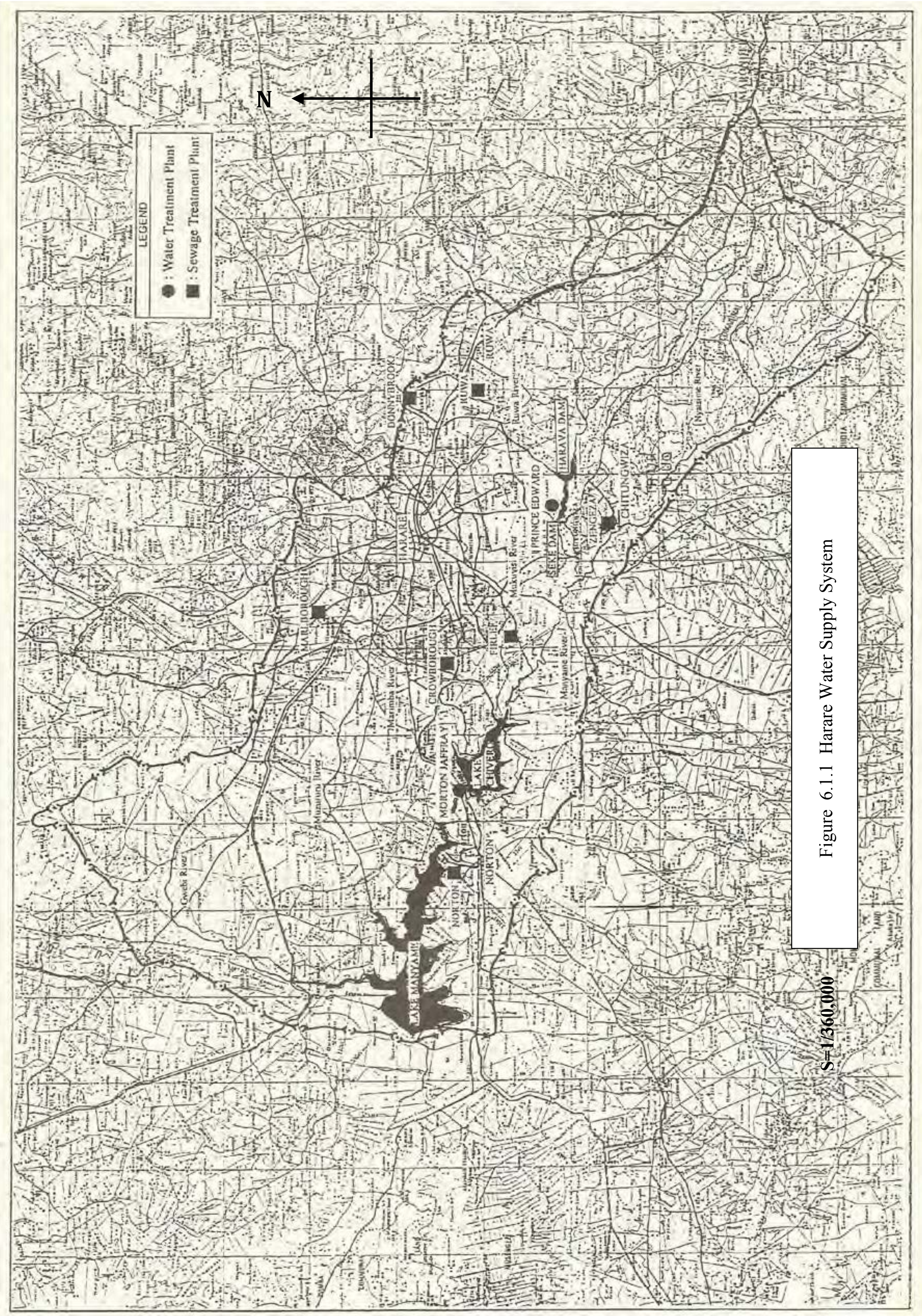


Figure 6.1.1 Harare Water Supply Impounding Dams

(3) Ambient water quality standards

1) General

In Zimbabwe, the regulation of effluent for wastewater has been enacted; however, the ambient water quality standards have yet not been established. Moreover, there is no informational base upon which to evaluate the present water quality in the water bodies of the country, since level of water quality is to be required has not yet been established for the various water uses and for water quality preservation. To prepare the water pollution control plan for the Upper Manyame Basin, the establishment of the Ambient Water Quality Standard would be primarily required. A proposal for the Ambient Water Quality Standard was made in “the Study on Water Pollution Control in the Upper Manyame River Basin in the Republic of Zimbabwe” (hereinafter the Study 1997), in 1997 conducted by JICA. Since the Study 1997 is considered to be sound for the catchment area, proposed standard will be followed in this study.

The subject water basins are to be classified based on water use and water preservation. Staged goals may be introduced as provisional standards due to the current water pollution status of the water bodies. Water quality checking points were established for monitoring purposes in the Study 1997.

2) Ambient water quality standard

Generally, water quality items consist of two categories, i.e., the environmental items represented by BOD and COD as the general indicators of organic pollution load, and human health related items including heavy metals, volatile organic chemicals and agricultural chemicals. These items must be monitored in the water bodies throughout the year.

The ambient items for rivers as adopted in Japan comprise pH, BOD, SS, DO and a coliform group; and for the lakes Total Nitrogen (T-N) and Total Phosphorus (T-P) were added and COD was replaced by BOD. Standard qualities for these items were determined in accordance with the different purposes of the intended water uses. The ambient water quality standard is usually set considering the dilution of effluent with river water (1/10-1/100). The following table shows the effluent standards of Zimbabwe (Refer to Section 3.3 for detail) for the Class Blue, Normal. In the application of 1/10 dilution ratio to the effluent standard, the ambient water quality standards are in the same level as those in Japan. The water quality in the Table 6.1.3 is showing very strict water quality which is allowed to discharge into the river.

Table 6.1.3 Effluent Standard of Wastewater, Zimbabwe

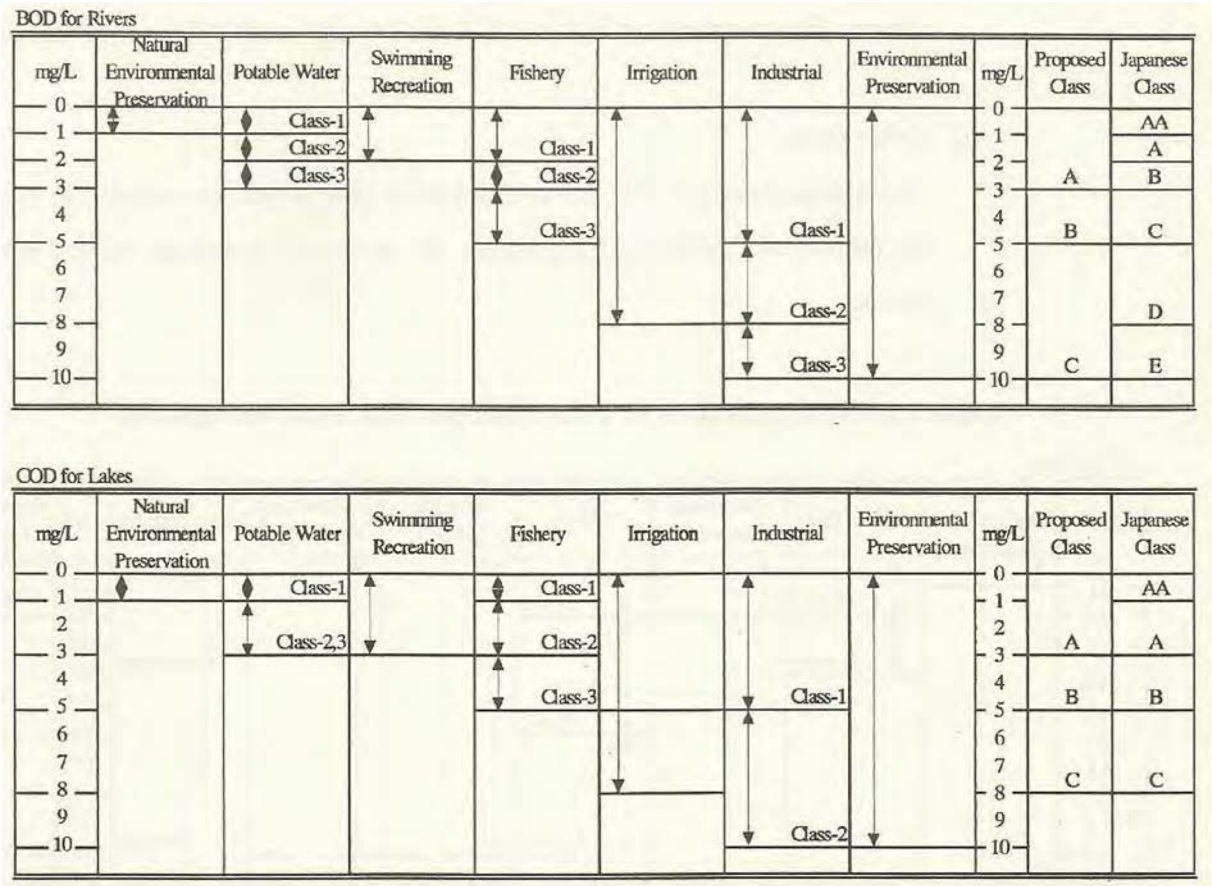
	pH	BOD	COD	SS	DO	T-N	T-P
STP	6.0-9.0	30mg/l	60mg/l	25mg/l	60mg/l	10mg/l	0.5mg/l

Class: Blue, Normal, Source: EMA

a) BOD and COD

Based on the above discussions, the standards for BOD and COD were proposed as shown in Table 6.1.4: Class A, "Not greater than 3 mg/l both for BOD and COD" was applied for natural environmental preservation, and for potable water supply and swimming purposes. Class B, "Not greater than 5 mg/l both for BOD and COD" was applied for fisheries only in consideration of the present guideline for irrigation water "Not greater than 70 mg/f of BOD". Class C, "Not greater than 10 mg/I for BOD and 8 mg/L for COD" was applied for irrigation water, industrial water use and flow maintenance.

Table 6.1.4 Proposed Classification



Source: JICA Project Team

b) Total nitrogen and total phosphorus

The standards for T-N and T-P are shown in Table 6.1.5 in the same manner as the study of BOD and COD. In the classification, three nutrient grades were applied to the lakes: poor, medium and rich. Neither T-N nor T-P are hazardous substances but they cause algal growth. Under these conditions, the classified grades of T-N and T-P are applied for the respective water uses: fisheries, irrigation water, industrial water use and environmental preservation.

Class A, "Oligotrophic Lake", for potable water supply and swimming purposes. There is no need for any treatment of the water to remove nutrients. The Standards of T-N and T-P are not greater than 0.2 mg/l and 0.01 mg/l, respectively.

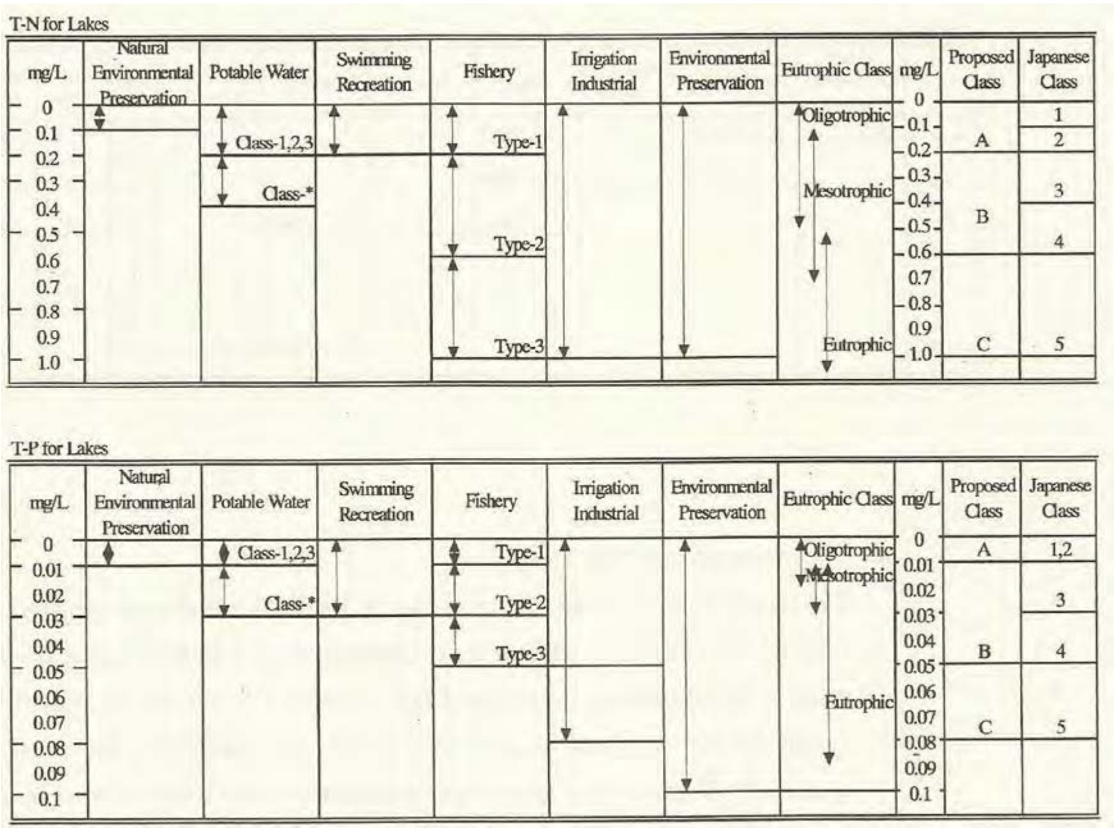
Class B, "Mesotrophic Lake" for fisheries use. The standards of T-N and T-P are not greater than 0.6 mg/l and 0.05 mg/l, respectively.

Class C, "Eutrophic lake" for irrigation water, industrial water and flow maintenance. The standards of T-N and T-P are 1.0 mg/l and 0.08 mg/l respectively.

c) Other items

The standards of pH, DO, SS and Coliform groups that are adopted in Japan are proposed. Table 6.1.5 presents the proposed standards on environmental items.

Table 6.1.5 Classification of Total Nitrogen and Total Phosphorus



Source: JICA Project Team

Table 6.1.6 Proposed Ambient Water Quality Standard

Rivers

Class	Water Use	BOD	pH	SS	DO	Coliforms Group	Remarks
A	Natural Environmental Preservation Potable Water Swimming and Recreation As in "B,C"	L.E. 3mg/L	6.5-8.5	L.E. 25mg/L	G.E. 5mg/L	L.E. 1000MPN/ 100ml	
B	Fishery As in "C"	L.E. 5mg/L	6.5-8.6	L.E. 50mg/L	G.E 5mg/L	-	
C	Irrigation Water Industrial Water Environmental Preservation	L.E. 10mg/L	6.0-8.6	No Suspend Dusts	G.E. 2mg/L	-	

Lakes

Class	Water Use	COD_{Mn}	T-N	T-P	pH	SS	DO	Coliforms Group	Remarks
A	Natural Environmental Preservation Potable Water Swimming and Recreation As in "B,C"	L.E. 3mg/L	L.E. 0.2mg/L	L.E. 0.01mg/L	6.5-8.5	L.E. 25mg/L	G.E. 5mg/L	L.E. 1000MPN /100ml	Oligotrophic Lake
B	Fishery As in "C"	L.E. 5mg/L	L.E. 0.6mg/L	L.E. 0.05mg/L	6.5-8.5	L.E. 50mg/L	G.E. 5mg/L	-	Mesotrophic Lake
C	Irrigation Water Industrial Water Environmental Preservation	L.E. 8mg/L	L.E. 1mg/L	L.E. 0.1mg/L	6.5-8.5	No Suspend Dusts	G.E. 2mg/L	-	Eutrophic Lake

Source: JICA Project Team   Note; LE.: Less than or Equal to, G.E.: Greater than or Equal to

d) Health related items

There are many hazardous substances that pose potential health risks, like heavy metals and agricultural chemicals. These are discharged mainly from specific sources such as industries and farms. Effluent standards for industrial wastewater have been established by the government to control unnecessary influence to the aquatic environment as well as various water uses. In view of assuring the safety of drinking water sources, it is deemed indispensable to monitor the presence of such hazardous substances in the public water body, especially lakes/dams in the Study Area. In this connection, the government has adopted the "Guideline for Drinking Water" of WHO as the national standard.

On the other hand, it is not appropriate to apply all of the prescribed items of the said guideline since some chemicals are not presently used or being used in very limited amounts in Zimbabwe. Human health-related items adopted in the Japanese Standards are less than that of WHO, however these items are designated mainly considering health damage which have been caused by ambient pollution in the past. A similar situation may likely occur in Zimbabwe, if appropriate guidelines and monitoring are not applied in the subject water body when types of industries presently operated in the Study Area are taken into account.

In view of practicability to the present situation in Zimbabwe, it is deemed appropriate to adopt at least the same items and apply respective values based on WHO standards, as presented in Table 6.1.7, while such items, other than the Japanese Standards, shall be subject to be added when they are detected in the subject water body through monitoring and/or being introduced in economic activities.

Table 6.1.7 Ambient Standard for Health Related Items

Unit: mg/l

Item	Proposed Value	Reference Value		
		Guideline for Drinking Water (WHO)	Japanese Standard	Effluent Standard of Waste Water (Zimbabwe)
Arsenic	0.01	0.01	0.01	0.05
Cadmium	0.003	0.003	0.01	0.01
Chromium	0.05	0.05	0.05	0.05
Cyanide	0.07	0.07	ND	0.2
Lead	0.01	0.01	0.01	0.05
Mercury	0.001	0.001	0.001	0.05
Selenium	0.01	0.01	0.01	*
Carbon tetrachloride	0.002	0.002	0.002	*
1,2-dichloroethane	0.03	0.03	0.004	*
1,1-dichloroethylene	0.03	0.03	0.02	*
dichloromethane	0.02	0.02	0.02	*
cis-1,2-dichloroethylene	0.05	0.05	0.04	*
tetrachloroethylene	0.04	0.04	0.01	*
trichloroethylene	0.07	0.07	0.03	*
benzene	0.01	0.01	0.01	*
1,3-dichloropropene	0.02	0.02	0.002	*

*:Items not considered in the effl

Note: Items not considered in the effluent

Source: EMA

3) Water quality classification and checking points

Water quality standards are to be determined for the main river and lakes/dams. In this regard, the study basin comprises three lakes/dams: the Seke and Harava dams, Lake Chivero and Lake Manyame, and two sections of the main river connected to the lakes/dams; Manyame River Origin (upstream from the Harava Dam) and the section between Seke dam and Lake Chivero. Figure 6.1.2 shows the subject sub-water bodies. The water quality checking points are to be established for the above-mentioned respectively water bodies.

- Water quality classification

Water quality classification shall be done taking into account of present and future water use of the subject sub-basins. The following are proposed classifications by lake/dam or river.

-Lake/Dams

Since the lakes/dams in the study basin are used for drinking water supply and recreational purpose, Class A is required.

-Rivers

The water quality of the river is possible to adopt Class C only to ensure maintenance flow. However, the water is the source of the lakes/darns. In this connection, Class B for fishery use is recommended. Under the current status of river water quality, the classification is practical, while, Class A may be adopted for the upstream section from Harava Dam in light of the minimal inflow of pollution load in the sub-basin.

-Water quality checking points

In setting up water quality checking points, two categories will be utilized, i.e., "Checking Points" wherein water quality will be legislatively controlled, and "Reference Points" wherein water quality will be monitored basin-wide as reference for “Checking Point”. Table 6.1.8 and Figure 6.1.2 present the checking/reference points both for lakes/dams and the rivers.

4) Provisional standards

In the above study, the water quality classifications were introduced according to the water uses. However, the standards of some items are considered difficult to comply with under the present situation. The provisional standards as shown in Table 6.1.9 and Table 6.1.10 would be applied under the following conditions:

- The provisional standards are to be applied to the items which the proposed standards are not likely to be achieved. At this stage, the items involved are BOD, COD, T-N, and T-P.
- The provisional standards are required to comply with the present effluent standards of wastewater.
- Finally, the water quality standards should be followed by the year 2030.

Table 6.1.8 Water Quality Checking /Reference Points

Water Body	Water Quality Checking/Reference Point				Water Quality Classification
	No.	River/Lake	Lake/dam basin	Location	
River	CR1	Manyame R.	Harava Dam	Before inflow to Harava Dam	A
	RR1	Ruwa R.	Harava Dam	- do -	
	RR2	Nyatsime R.	Lake Chivero	Before the Confluence to Manyame River	
	RR3	Manyame R.	- do -	Before joining with Mukuvisi river	
	RR4	Mukuvisi R.	- do -	Before the confluence to main river	
	CR2	Manyame R.	- do -	Before inflow to Lake Chivero	B
	RR5	Marimba R.	Lake Chivero	Before the confluence to main river.	
	RR6	Muzururu R.	Lake Manyame	Before inflow to Lake Manyame	
	RR7	Gwebi R.	- do -	- do -	
Lake/Dam	CL1	Seke Dam	N.A.	Center of the lake	A
	CL2	Lake Chivero	N.A.	Water intake tower	A
	CL3	Lake Manyame	N.A.	Water intake point for Harare Water Supply	A

Source: JICA Project Team

Note: CR1-2; Checking Point (River)
CL1-3; -do- (Lake)
RR1-7; Reference Point
N.A.; Not applicable

Table 6.1.9 Provisional Water Quality Standard

Water Body	Name	Period	COD_{Mn}	T-N	T-P
Lake	Seke & Harava	1997	9.4	0.65	0.07
		2015	<5.0	<0.40	<0.05
		2030	<3.0	<0.20	<0.01
	Lake Chivero	1997	14.9	0.51	0.27
		2015	<8.0	<0.40	<0.10
		2030	<3.0	<0.20	<0.01
	Lake Manyame	1997	18.9	0.75	0.044
		2015	<8.0	<1.00	<0.03
		2030	<3.0	<0.20	<0.01
Water Body	Name	Period	BOD		
River	Manyame Origin	1997	1.1		
		2015	<5.0		
		2030	<3.0		
	Manyame River	1997	1.0		
		2015	<5.0		
		2030	<3.0		

Source:JICA Project Team

Table 6.1.10 Water Quality Standard / Provisional Value

Lakes Unit: mg/l

No.	Name	Class	Standard			Provisional (2000/2005)		
			COD	T-N	T-P	COD	T-N	T-P
CL1	Seke & Harava Dam	A	< 3	< 0.2	<0.01	< 5	< 0.4	< 0.05
CL2	Lake Chivero	A	< 3	< 0.2	<0.01	< 8	< 0.4	< 0.1
CL3	Lake Manyame	A	< 3	< 0.2	<0.01	< 8	< 1.0	< 0.03

Rivers

No.	Name	Class	BOD	
			Standard	Provisional (2000/2005)
CR1	Manyame R.Origin	A	< 3 mg/L	(< 5 mg/L)
CR2	Manyame R.	B	< 5 mg/L	(< 5 mg/L)

Source:JICA Project Team

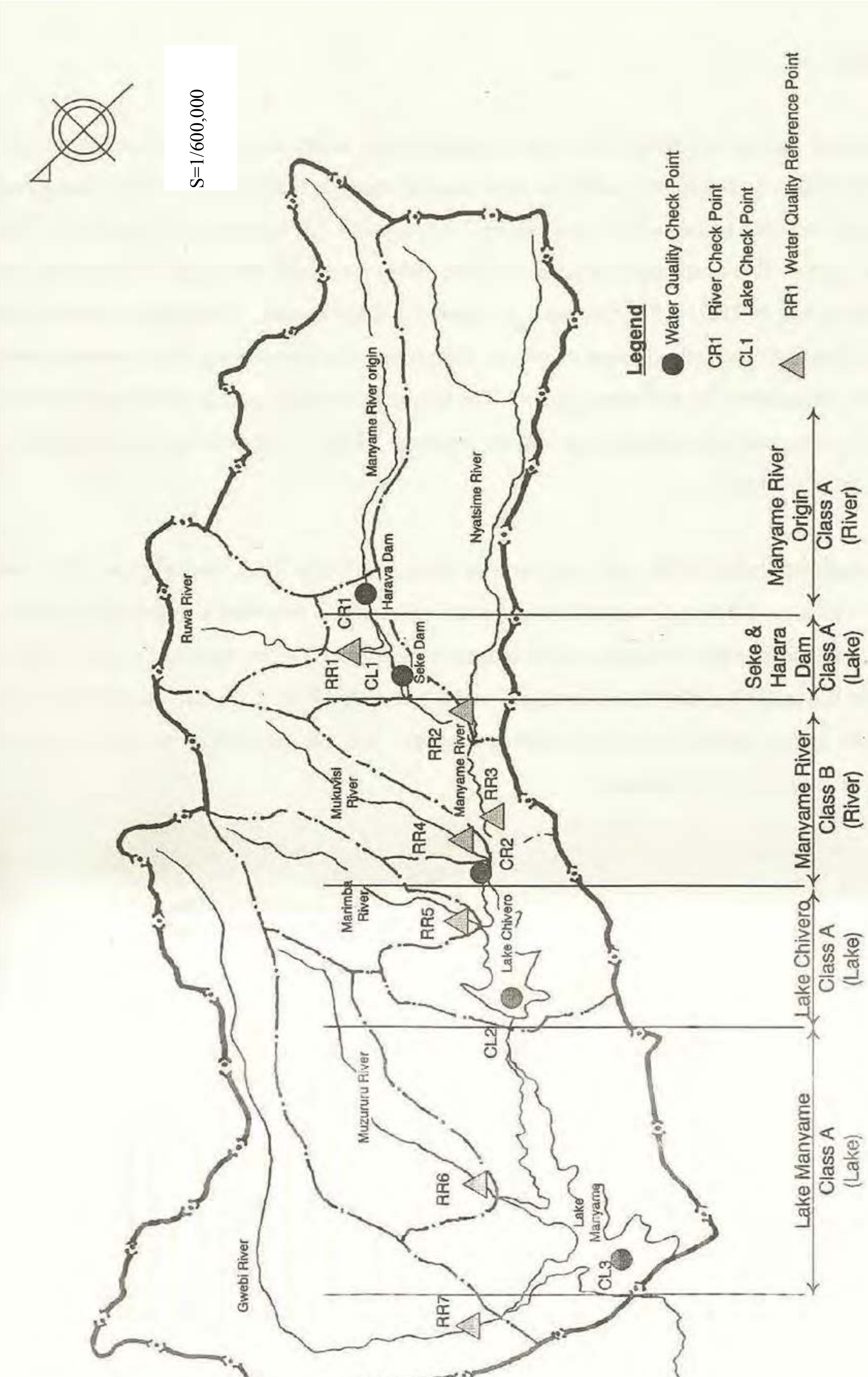


Figure 6.1.2 Ambient Water Quality Classification Check Points and Reference Points

Source: JICA Project Team

6.1.2 Sanitary Condition

(1) Septic tank

Sanitation measures are categorised into on-site treatment (septic tanks) and off-site treatment (public sewerage system). Septic tank has soak way for discharging supernatant of the tank to underground. Sullage in the tank is removed periodically after the sludge becomes full and is treated in the sewage treatment plant. Population served by the septic tank will be dealt separately in the pollution analysis. In the Study Area, a part of the low density residential areas in the urban areas and most of the rural areas use septic tanks, and other types of toilet facilities, while many of the residents in the remaining urban areas are served by the public sewerage system. Table 6.1.11 shows the population presently served by septic tanks in the urban areas in the Study Area.

Table 6.1.11 Septic Tank Served Population in the Study Area

Urban Authority	Population
Harare	95,140
Chitungwiza *1	0
Norton	1,290
Ruwa	20
Epworth	68,490

Source:JICA Project Team
*1: Septic tanks are being used only at 3 schools

As shown in the table, population served by septic tank is around 170,000, or one-tenth of the population in the area.

(2) Sewerage in city of Harare

Some stands (lots) in the low density areas have on-site treatment facilities. The rest of the city is served by a public sewerage system. Figure 6.1.3 shows sewer network, location of STPs and the septic tank area in Harare.

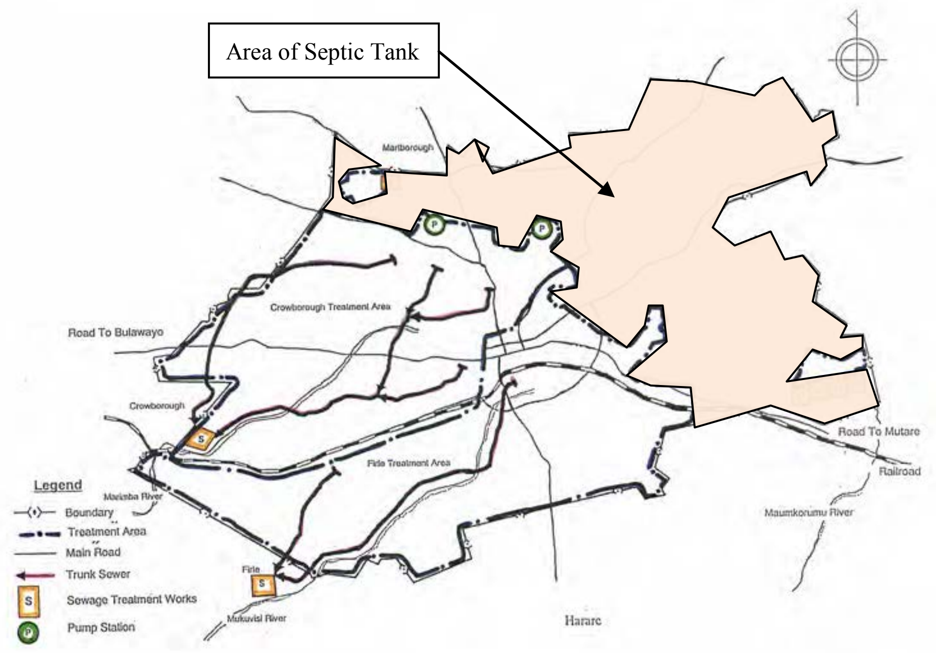


Figure 6.1.3 Sewer Network and Location of STPs in Harare

The main STPs in Harare are Firle, Crowborough, Marlborough and Donny Brook. The city core is covered by the former two STPs. Most of the population are covered by sewerage system. Biological Nutrient Removal (BNR) process was partly employed in the STPs and effluent from the BNR has been discharged to the river directly. Rest of the effluent has been sent to the farms for irrigation. Septic tank is also possible to install, however, in the placement of septic tanks, the minimum stand size is principally regulated at more than 4,000 m^2 with loosened restriction of 2,000 m^2 when soil test results are favourable. (Harare Water) These discharged supernatant from soak way are sometimes polluting underground water. Counter measure will be needed to cope with the septic tank area with the public sewerage system including Epworth.

(3) Chitungwiza municipality

At present, 100% of the municipal area is served by the public sewerage system without depending on septic tanks. However, three schools are utilising septic tanks. These septic tanks are emptied by contractors when they become full. Sullage is transported to and treated in the STP in Harare. All the sewage goes to the Zengeza STP however, due to the breakdown of all pump stations and Zengeza STP, the sewage flow has been discharged to the Nyatsime River and Manyame River polluting the rivers. The current sanitation problem is the overflow of sewage from manholes into the streets due to deposit of sand and sludge in sewers/manholes, as well as increased sewage. The dumping of domestic wastes into sewers/manholes has been another cause of this problem.

Figure 6.1.4 Sewer Network and Location of STPs in Chitungwiza

(4) Norton town council

Approximately 95% of the total residential stands (lots) are served by gravity sewer connected to the Town Council's sewers. Sewage from 47 stands located in the low density areas is pumped to the trunk sewer as well. The rest, 271 houses/stands, rely on septic tanks. These septic tanks have been constructed in conformity with the Council's policy that the minimum size of each stand shall be larger than 2,400 m^2 in the application of septic tanks. All industrial wastewater is also discharged into the Council's sewerage system. Figure 6.1.5 shows the sewerage and septic tank service area in Norton.

Norton sewage treatment plant employs three units of the trickling filters, however the system has been broken down since 2001. Effluent was sent to irrigate farmlands by pump stations for transmitting the effluent. The system is broken down and raw sewage has been discharged to the Lake Manyame affecting the water quality of the Morton Jaffray WTP.

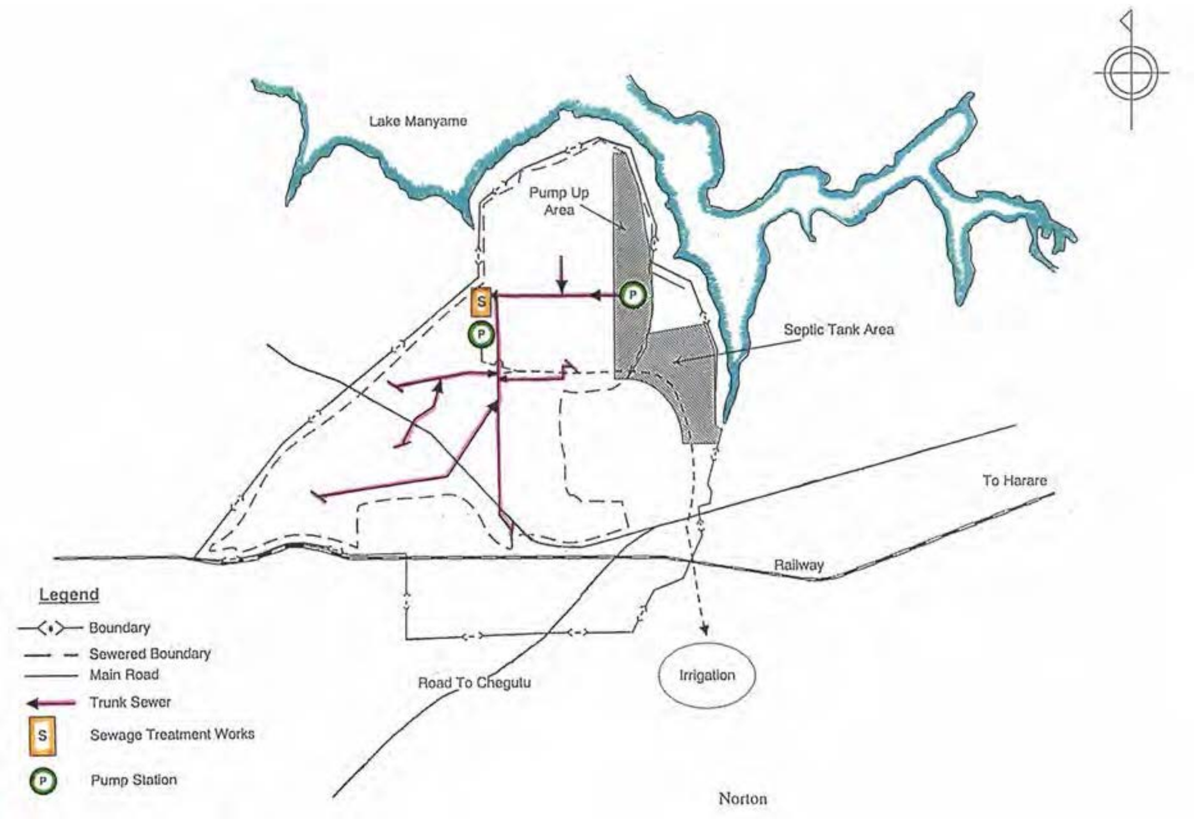


Figure 6.1.5 Sewer Network and Location of STPs in Norton

(5) Ruwa local board

The sanitation conditions of Ruwa have been provided with sewerage services south of the Harare-Mutare Road, excluding 22 stands located in low and high density areas. All industrial wastewater is discharged into the Local Board's sewerage system. Figure 6.1.6 shows the sewerage system in Ruwa. Ruwa has been using stabilization pond for the sewage treatment.

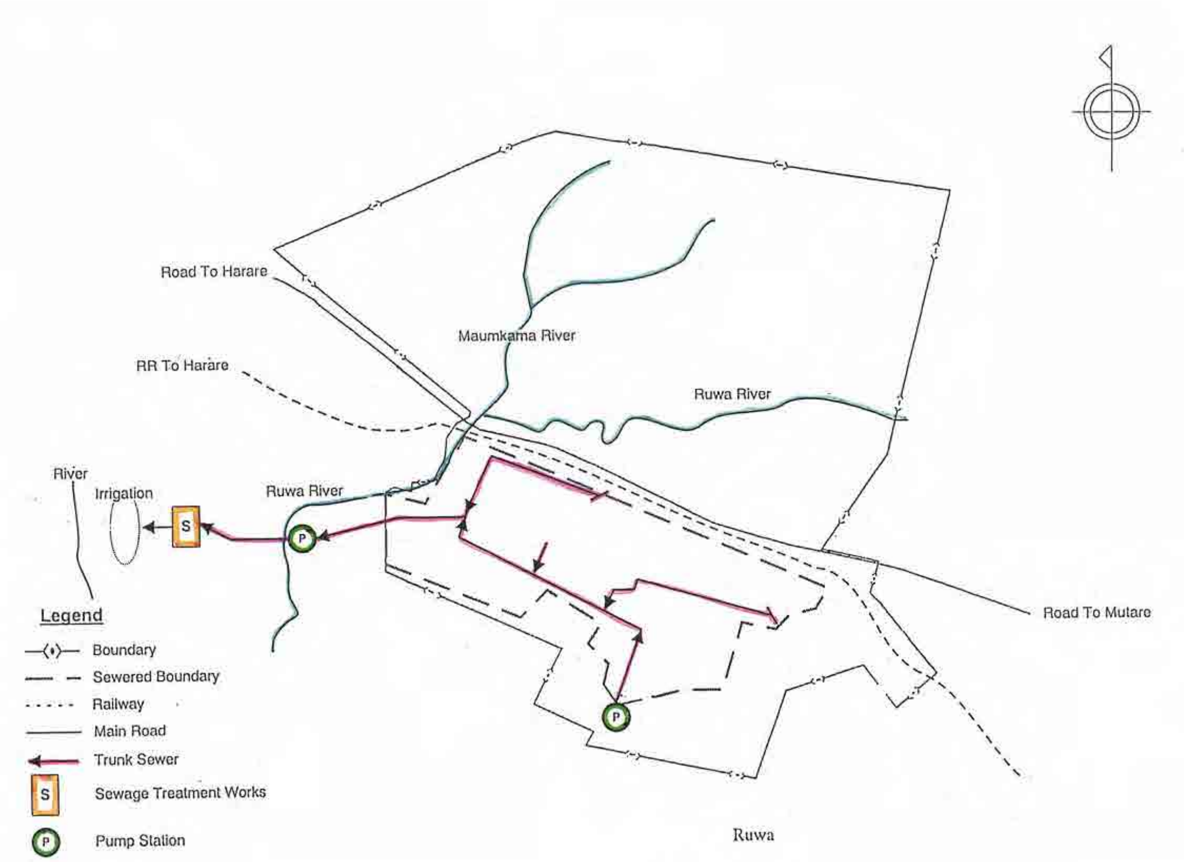


Figure 6.1.6 Sewer Network and Location of STPs in Ruwa

(6) Epworth local board

At present, there is no public sewerage system in Epworth. The majority of houses/stands are therefore using "ventilated improved pit (VIP)" latrines sponsored by the national government. The presence of unacceptable "drop pit latrines" is quite limited. Generally, appropriate stand spacing is maintained to locate septic tanks in order to avoid environmental hazards.

In the northern part of Epworth a series of temporary sewage ponds has been developed to serve as the overflow area for domestic sewage. However, these ponds are located too close to the existing houses. The Epworth Local Government is considering the closure of these ponds upon the construction of a new and larger treatment works south of the Epworth Local Government area on part of the Lyndhurst Farm. The Epworth Local Government also seeks to reduce the use of pit latrines and to introduce a public sewerage system.

6.1.3 Hydrological Condition of the Rivers and Lakes

(1) Rainfall

The rainfall data of the Harare City (Belvedere) located in the centre of the basin is available to analyse hydrological condition. The weather stations located in the Manyame River Basin are included in Figure 6.1.8. According to the Study 1997, the five-year running average fluctuates slightly, while the ten-year running average is almost constant. Thus, a ten-year cycle of rainfall is prevalent in the basin. The monthly rainfall of the past ten years (2000 to 2010) is shown in Table 6.1.12, Table 6.1.13, and Figures 6.1.7. The annual average rainfall in the ten years is 951 mm. The monthly average rainfall indicates a dry season from April to October. About 78% of the annual rainfall is concentrated in the five months of the rainy season, and about 23% of the annual amount is recorded during December. The annual rainfall amount is considerably affected by that of December.

Table 6.1.12 Monyhly Rainfall (2000/2010)

(mm/d)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	7.4	5.3	7.2	3.3	6.4	0.5	0.0	0.0	0.0	0.7	3.6	8.3
2001	3.8	14.7	7.1	0.0	0.0	0.0	0.2	0.0	0.0	0.4	1.7	9.1
2002	3.2	0.1	0.7	2.0	N/A	0.4	N/A	0.0	0.1	3.0	2.8	3.4
2003	1.9	6.5	N/A	N/A	0.0	0.1	N/A	N/A	3.2	1.2	2.8	7.7
2004	0.5	N/A	3.5	5.3	N/A	N/A	N/A	12.8	0.0	3.3	3.1	7.2
2005	N/A	4.7	N/A	0.2	0.7	0.0	N/A	0.0	0.0	0.5	8.0	7.3
2006	8.4	5.6	4.4	0.1	0.0	0.0	0.0	N/A	N/A	0.5	1.4	4.5
2007	4.5	1.6	4.3	11.4	N/A	0.1	0.0	N/A	N/A	N/A	5.7	18.6
2008	N/A	1.3	2.1	1.0	0.0	N/A	0.0	0.0	0.0	0.2	4.1	0.2
2009	5.1	5.3	5.4	0.0	1.6	0.0	N/A	0.0	0.0	0.0	4.4	5.0
2010	6.3	5.0	2.5	3.0	0.4	0.0	0.0	0.0	0.0	0.5	3.8	5.1
Average	4.9	4.8	4.0	2.6	1.1	0.1	0.0	1.6	0.4	1.0	3.8	6.9

Source: Meteorological Department

Table 6.1.13 Annual Rainfall from Monyhly Rainfall

Months	Num. of Days	Average	
		mm/d	mm/month
Jan	31	4.9	152.4
Feb	28	4.8	135.5
Mar	31	4.0	123.1
Apr	30	2.6	79.0
May	31	1.1	35.4
Jun	30	0.1	3.7
Jul	31	0.0	1.0
Aug	31	1.6	49.8
Sep	30	0.4	11.0
Oct	31	1.0	32.0
Nov	30	3.8	113.2
Dec	31	6.9	215.1
		Total =	951.1 mm/year

Source: Meteorological Department

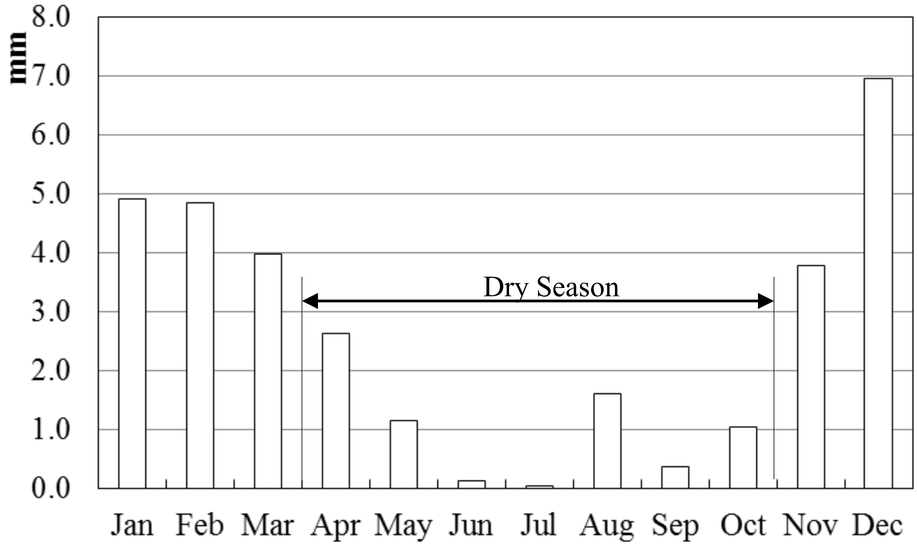


Figure 6.1.7 Monthly Rainfall (2000/2010)

Source: Meteorological Department

(2) Flow rate of the rivers and discharge of the lakes and dams

As shown in Table 6.1.14 and Figure 6.1.8., several gauging stations are set up to measure the flow rates of the rivers and discharges from the lakes and dams. The measurement results are the base of this analysis.

Table 6.1.14 Data Availability on Flow Rate and Discharge

Item	No.	Name	Location	Measured Period	Date Contents
Flow Rate	C81	Manyame Origin	Before the Confluence of Harava Dam	1974 to 2001	Monthly Run-off
	C21	Manyame R.	Before the Confluence of Lake Chivero	1957 to 2001	do
	C22	Mukuvisi R.	do	1953 to 2001	do
	C24	Marimba R.	do	1953 to 2001	do
Discharge	C3	Seke & Harava Dam	Discharge Point	1951 to 1995	do
	C17	L.Chivero	Discharge Point	1953 to 1995	do
	C89	L.Manyame	Discharge Point	1976 to 1995	do

Source: ZINWA

1) Flow rate

The annual average of flow rates in the Manyame River (before the confluence of Harava Dam and Lake Chivero), the Mukuvisi River, and the Marimba River in the last ten years, starting from 1992, is shown in Table 6.1.15. In addition, the fluctuation of the last ten-year monthly average values and rates is shown in Table 6.1.17 with graph of fluctuation ratio in Figure 6.1.10.

Table 6.1.18 and Figure 6.1.11 show the relationship between rainfall and the flow rate. The average run-off ratios in the last 10 years are seven to 8% at the two observatories respectively on the Manyame River, while 14 to 22% on the Mukuvisi and the Marimba River. The average run-off ratio of the rivers in the whole of Zimbabwe is reported at 8%, which coincides with that of the Manyame River. The average run-off ratio of the Mukuvisi and the Marimba Rivers seems to be largely influenced by the STPs' effluent.

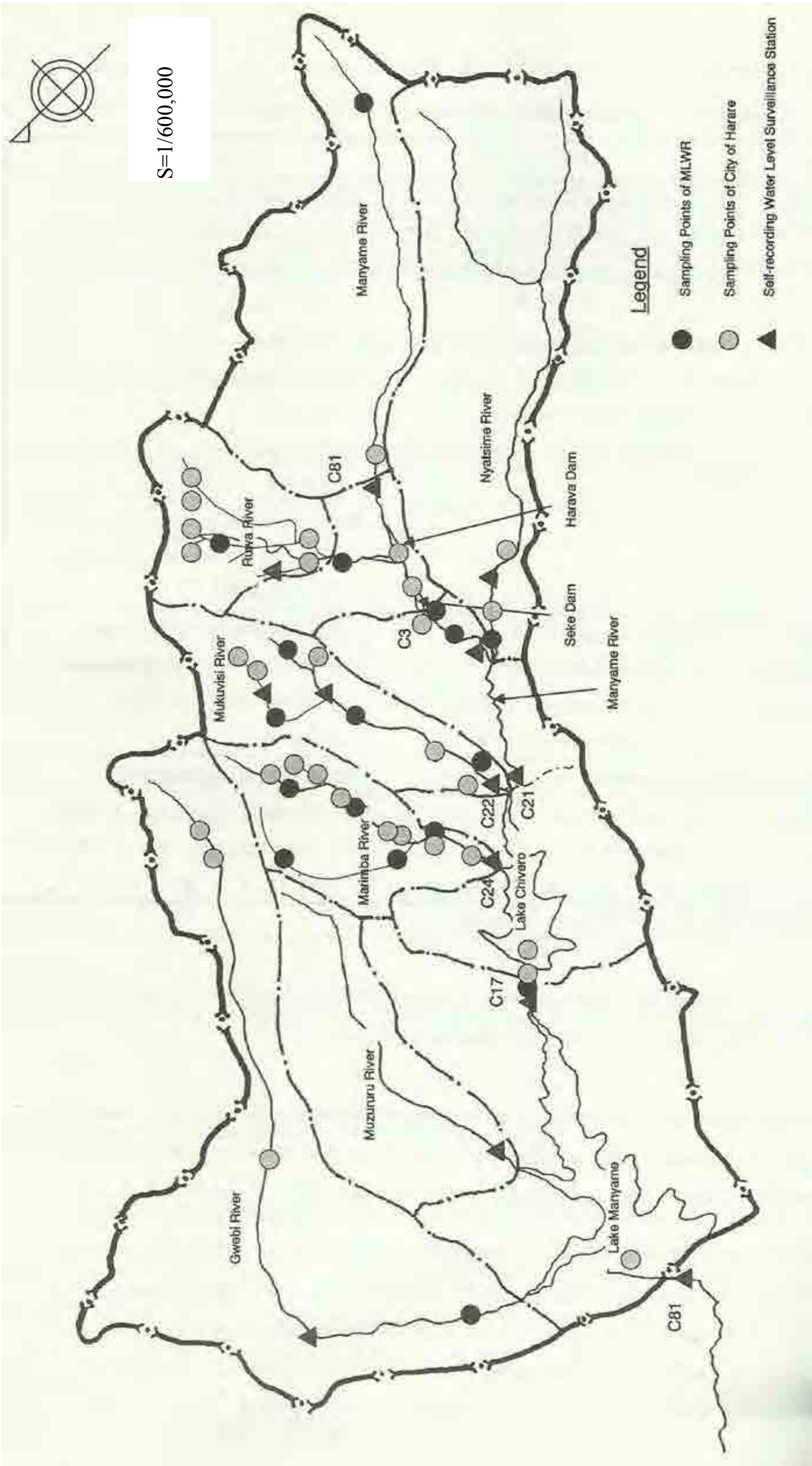


Figure 6.1.8 The Locations of Self-recording Water Level Surveillance Station and Water Sampling Points in the Upper Manyame River Basin

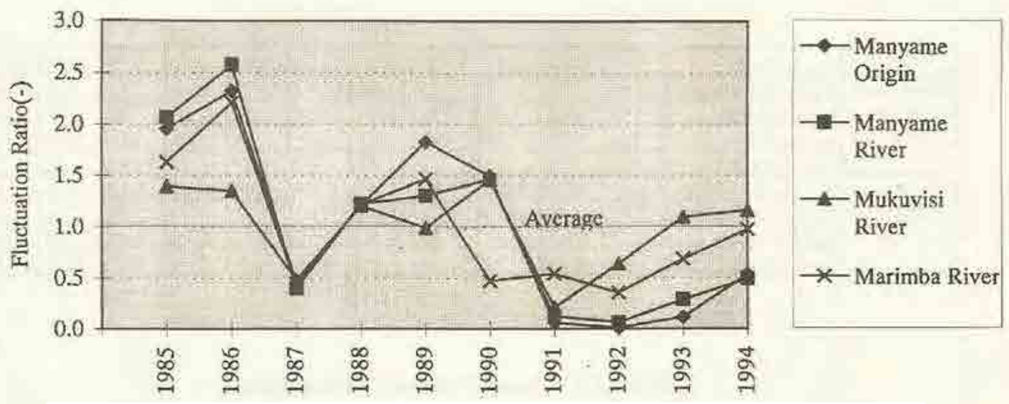


Figure 6.1.9 Flow Pattern (Yearly) *

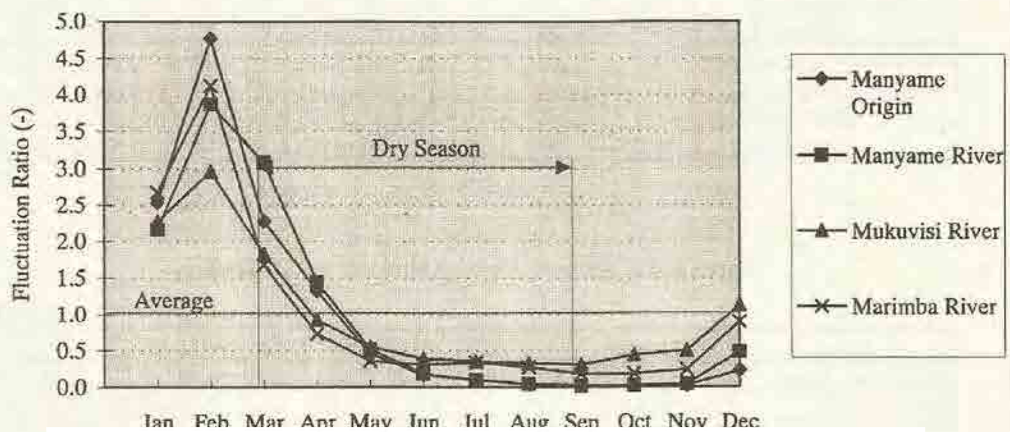


Figure 6.1.10 Flow Pattern (Monthly) *

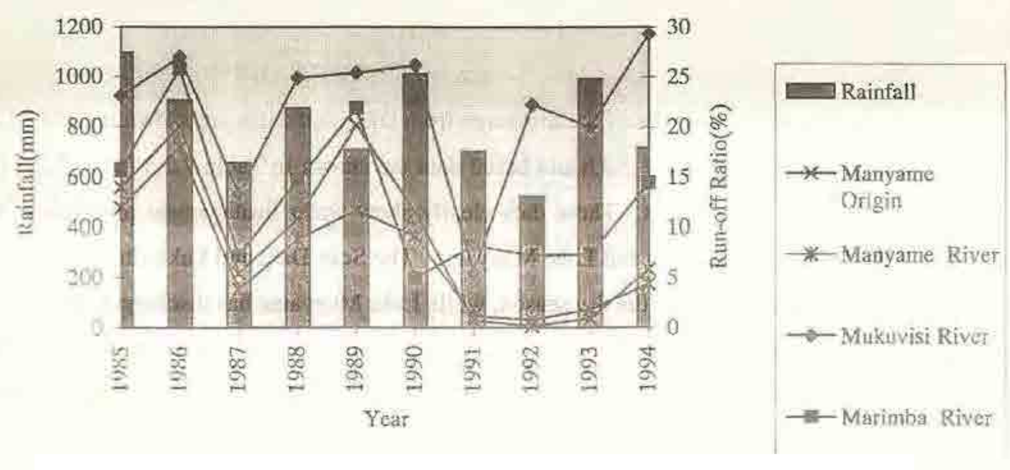


Figure 6.1.11 Rainfall and Run-off Ratio (Rivers) *

*Source: NIPPON JOGESUIDO SEKKEI CO., LTD. & NIPPON KOEI CO., LTD., 1997, "The Study on Water Pollution Control in the Upper Manyame River Basin in the Republic of Zimbabwe", Volume 2 Main Report

Table 6.1.15 Annual Average Flow Rate *

	River	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Ave.
Flow Rate	Manyame Origin	1	12	54	3	112	279	111	454	331	388	174
×1000	Manyame R.	17	76	128	46	317	700	367	1,399	799	1,310	516
m³/day	Mukuvisi R.	72	123	130	91	164	209	197	507	329	313	214
	Marimba R.	22	43	60	43	81	149	136	309	188	284	131

Table 6.1.16 Annual Fluctuation Ratio *

	River	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Ave.
Fluctuation	Manyame Origin	1.95	2.33	0.46	1.21	1.83	1.50	0.06	0.01	0.12	0.54	1.00
Ratio	Manyame R.	2.07	2.57	0.40	1.22	1.30	1.46	0.13	0.07	0.29	0.49	1.00
(-)	Mukuvisi R.	1.39	1.35	0.48	1.20	0.99	1.46	0.21	0.64	1.10	1.16	1.00
	Marimba R.	1.63	2.21	0.44	1.22	1.46	0.47	0.54	0.36	0.69	0.98	1.00

Table 6.1.17 Monthly Average Flow Rate (1952-2001) *

	River	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
Flow Rate	Manyame Origin	440	687	542	258	106	48	22	13	7	5	7	90	185
	Manyame R.	1197	1704	1356	601	261	121	63	35	17	13	209	351	494
×1000	Mukuvisi R.	285	325	274	121	79	47	36	36	29	33	51	160	123
m³/day	Marimba R.	228	278	212	58	34	23	21	19	14	13	29	131	88
Fluctuation Ratio	Manyame Origin	2.54	4.77	2.28	1.33	0.46	0.17	0.10	0.04	0.03	0.02	0.02	0.23	1.00
	Manyame R.	2.17	3.87	3.09	1.45	0.52	0.19	0.10	0.04	0.02	0.03	0.05	0.48	1.00
(-)	Mukuvisi R.	2.27	2.97	1.83	0.92	0.55	0.39	0.36	0.32	0.31	0.44	0.50	1.13	1.00
	Marimba R.	2.68	4.12	1.68	0.73	0.36	0.31	0.34	0.28	0.18	0.19	0.24	0.90	1.00

Table 6.1.18 Annual Average Run-off Ratio (Rivers) *

Unit: %

River	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Ave.
Manyame Origin	14.0	20.1	5.5	10.8	20.2	11.6	0.7	0.2	0.9	5.8	9.0
Manyame R.	11.9	18.0	3.8	8.8	11.6	9.1	1.2	0.8	1.9	4.3	7.1
Mukuvisi R.	23.1	27.0	13.3	24.9	25.4	26.2	5.5	22.2	20.0	29.3	21.7
Marimba R.	15.8	25.8	7.1	14.7	21.9	5.0	8.2	7.2	7.3	14.4	12.7

*Source: NIPPON JOGESUIDO SEKKEI CO., LTD. & NIPPON KOEI CO., LTD., 1997, "The Study on Water Pollution Control in the Upper Manyame River Basin in the Republic of Zimbabwe", Volume 2 Main Report

2) Discharge from lakes and dam

The annual averages of discharge are shown in Table 6.1.19 and Figure 6.1.12. The last ten-year monthly averages of the discharge from lakes and dams are shown in Table 6.1.20 and graphically in Figure 6.1.13, and base data are shown in "The Study on Water Pollution Control in The Upper Manyame River Basin in the Republic of Zimbabwe (1997)" (Herein after referred to the Study 1997). These data clearly show water management practices of the Seke Dam Lake Chivero and Lake Manyame. The Seke Dam and Lake Chivero were not discharging water during the dry season, while

Lake Manyame was discharging throughout the year. The purpose of constant discharge at Lake Manyame is to ensure maintenance flow for the lower reach. The relation between rainfall and discharge is shown in Table 6.1.21 and Figure 6.1.14.

Table 6.1.19 Annual Average of Discharge*

	Lake/Dam	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Ave.
Discharge Flow	Seke Dam	434	482	92	193	278	139	5	0	0	54	168
x1000	L.Chivero	39	92	4	181	56	79	0	0	0	0	45
m^3/day	L.Manyame	134	483	226	171	27	225	80	72	56	76	155
Fluctuation	Seke Dam	2.59	2.87	0.55	1.15	1.66	0.83	0.03	0.00	0.00	0.32	1.00
Ratio	L.Chivero	0.87	2.04	0.09	4.01	1.24	1.75	0.00	0.00	0.00	0.00	1.00
(-)	L.Manyame	0.87	3.11	1.46	1.10	0.17	1.45	0.52	0.46	0.36	0.49	1.00

Table 6.1.20 Monthly Average of Discharge*

	Lake/Dam	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
Discharge Flow	Seke Dam	351	918	487	202	56	10	5	1	6	2	1	5	170
x1000	L.Chivero	28	191	211	102	12	1	0	0	0	0	0	0	45
m3/day	L.Manyame	55	19	40	453	183	155	155	202	191	138	143	109	154
Fluctuation	Seke Dam	2.06	5.39	2.86	1.19	0.33	0.06	0.03	0.00	0.03	0.01	0.01	0.03	1.00
Ratio	L.Chivero	0.62	4.20	4.64	2.24	0.28	0.02	0.00	0.00	0.00	0.00	0.00	0.00	1.00
(-)	L.Manyame	0.36	0.13	0.26	2.95	1.19	1.01	1.01	1.32	1.24	0.90	0.93	0.71	1.00

Table 6.1.21 Annual Average Run-off Ratio (lake and Dams)*

Unit: %

Lake/Dam	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Ave.
Seke Dam	18.3	24.5	6.5	10.2	18.1	6.3	0.3	0.0	0.0	3.5	8.8
L.Chivero	0.6	1.7	0.1	3.4	1.3	1.3	0.0	0.0	0.0	0.0	0.8
L.Manyame	1.2	5.1	3.3	1.9	0.4	2.1	1.1	1.3	0.5	1.0	1.8

*Source: NIPPON JOGESUIDO SEKKEI CO., LTD. & NIPPON KOEI CO., LTD., 1997, "The Study on Water Pollution Control in the Upper Manyame River Basin in the Republic of Zimbabwe", Volume 2 Main Report

3) Relationship between water level and storage

The annual average of the water level compared to the full capacity level of lakes and dams is shown in Table 6.1.22 and Figure 6.1.15, and the monthly average of the water level is shown in Table 6.1.23. In applying these water levels to the storage volume, the H-V curve is obtained, as shown in Table 6.1.24 and Figure 6.1.17. The relationship between level and storage volume is explained by the following equation.

$$y = (x/100)^{1.88} \times 100$$

x: Water level (%), y: Available Volume (%)

The results of the equation with regards to the measured level, and the storage volume of the lakes and dams are shown in Figure 6.1.18 and Figure 6.1.19.

Table 6.1.22 Annual Average Water Level of Lakes/Dams*

Unit: %

Lake/Dam	1989	1990	1991	1992	1993	1994	1995	Avc.	1990/94
Harava Dam	83.7	82.2	16.3	0.0	66.9	86.2	14.9	50.0	50.3
Seke Dam	85.5	75.5	22.0	3.1	50.6	49.8	9.5	42.3	40.2
L.Chivero	96.0	97.8	93.4	78.6	73.0	89.7	68.2	85.2	86.5
L.Manyame	95.4	95.6	80.4	61.2	55.4	37.7	28.0	64.8	66.1

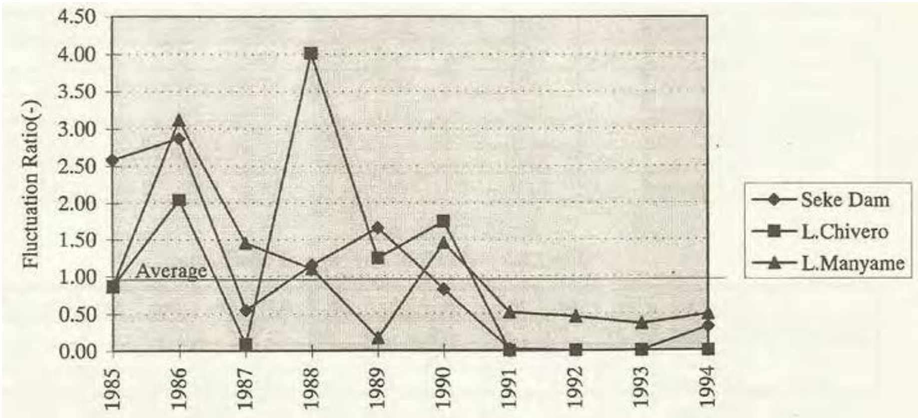


Figure 6.1.12 Discharge Pattern (Yearly)*

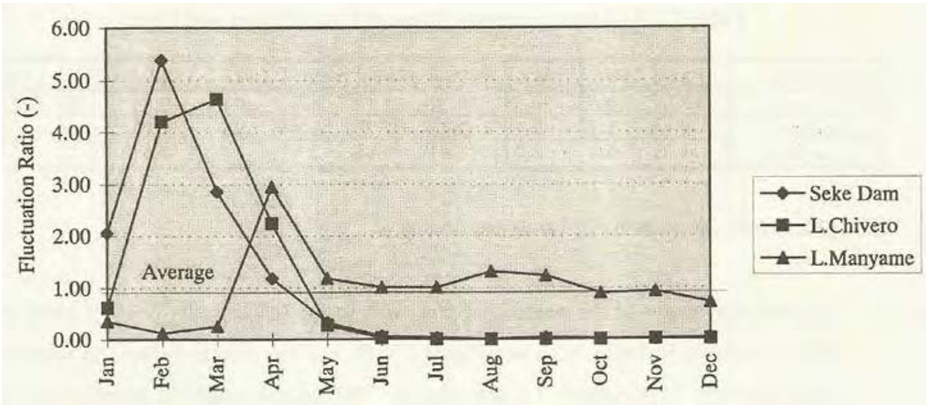


Figure 6.1.13 Discharge Pattern (Monthly)*

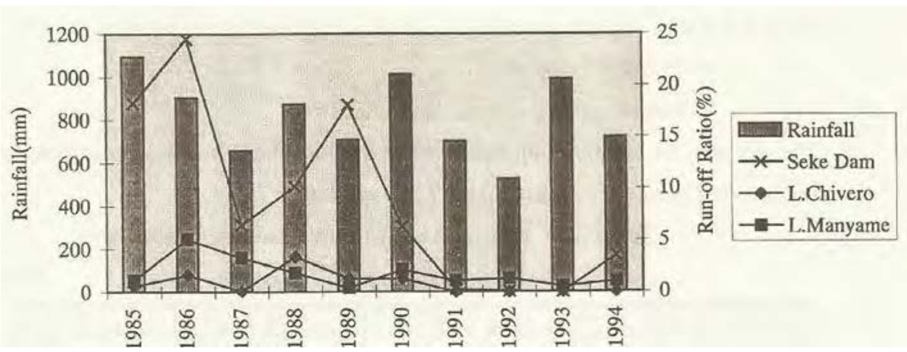


Figure 6.1.14 Rainfall and Run-off Ratio (Lakes and Dam)*

*Source: NIPPON JOGESUIDO SEKKEI CO., LTD. & NIPPON KOEI CO., LTD., 1997, "The Study on Water Pollution Control in the Upper Manyame River Basin in the republic of Zimbabwe",Volume 2 Main Report

Table 6.1.23 Monthly Average Water Level of Lakes/Dams*

Unit; %

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
Harava Dam	58.7	65.1	65.5	60.1	59.4	54.7	52.6	50.2	44.1	35.2	30.3	24.4	50.0
Seke Dam	45.1	61.0	57.9	61.3	49.3	35.6	38.8	32.2	33.9	30.9	35.5	25.7	42.3
L.Chivero	87.7	91.8	91.5	90.8	89.5	87.7	85.8	83.7	81.4	78.6	76.7	77.4	85.2
L.Manyame	67.0	71.0	70.9	69.9	68.2	66.8	65.2	63.2	61.6	59.1	57.5	57.7	64.8

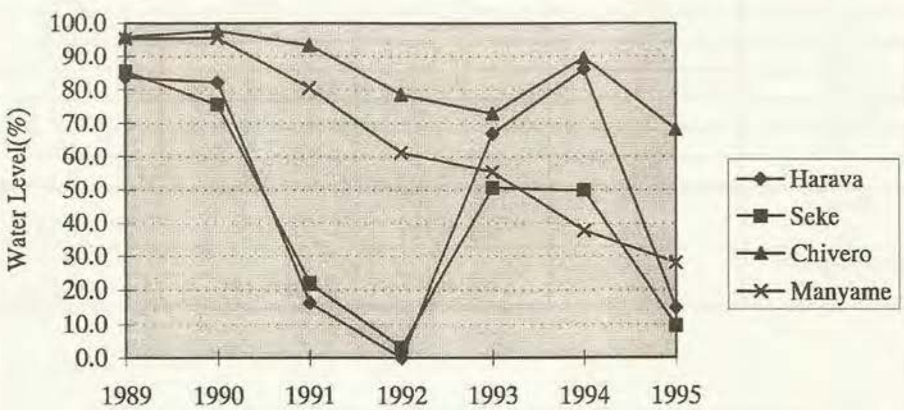


Figure 6.1.15 Annual Average Water Level of Laks/Dams*

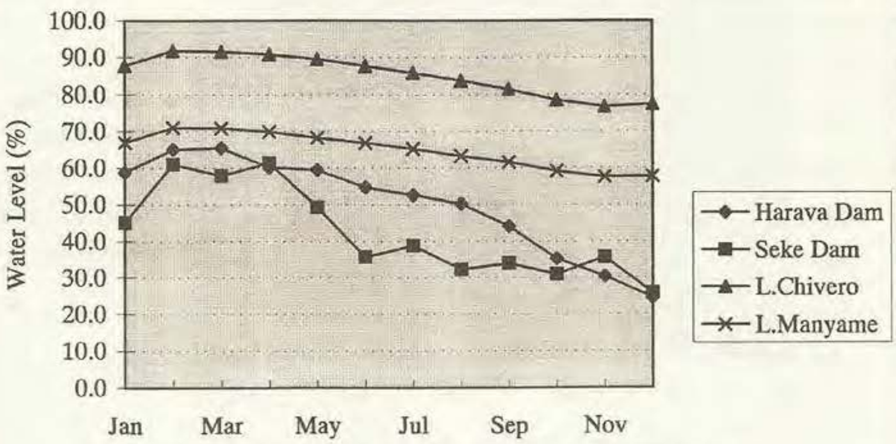


Figure 6.1.16 Monthly Average Water Level of Lakes/Dams*

*Source: NIPPON JOGESUIDO SEKKEI CO., LTD. & NIPPON KOEI CO., LTD., 1997, "The Study on Water Pollution Control in the Upper Manyame River Basin in The Republic of Zimbabwe", Volume 2 Main Report

Table 6.1.24 H-V Curve of Lakes and Dams*

Available Lavel (%)	Available capacity (%)			
	Harava Dam	Seke Dam	Lake Chivero	Lake Manyame
100	100.0	100.0	100.0	100.0
90	75.3	81.8	82.4	77.2
80	56.0	65.1	66.3	58.6
70	41.6	52.5	51.9	43.7
60	29.2	39.9	39.2	30.7
50	20.2	29.6	27.5	20.3
40	13.3	21.3	17.1	13.3

Available Lavel (%)	Available capacity (%)			
	Harava Dam	Seke Dam	Lake Chivero	Lake Manyame
30	8.1	15.3	8.5	8.3
20	5.2	9.2	1.0	4.5
10	1.7	3.7	n.a.	n.a.
0	0.0	0.0	0.0	0.0
Depth (m)	10.65	5.795	15.3	14.25
Max Capacity ($\times$1000 m^3)	9,026	3,380	247,181	480,236

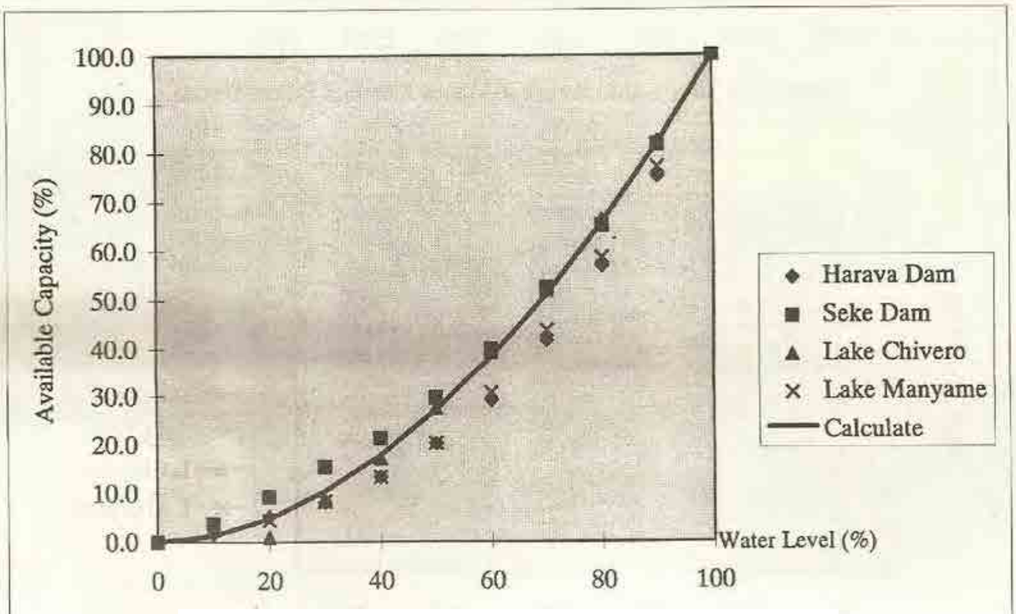


Figure 6.1.17 H-V Curve for Dam and Lake*

*Source: NIPPON JOGESUIDO SEKKEI CO., LTD. & NIPPON KOEI CO., LTD., 1997, T"he Study on Water Pollution Control in the Upper Manyame River Basin in the Republic of Zimbabwe", Volume 2 Main Report

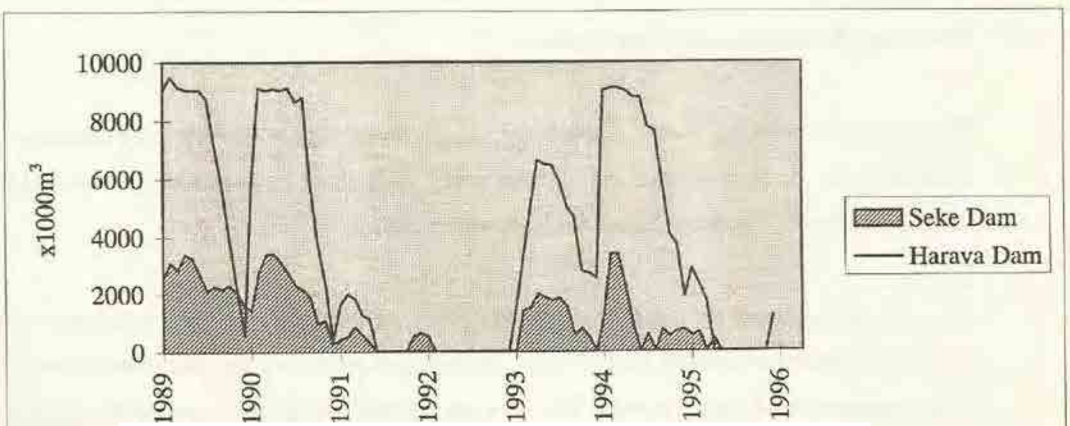


Figure 6.1.18 Water Reserve of Seke and Harava Dam*

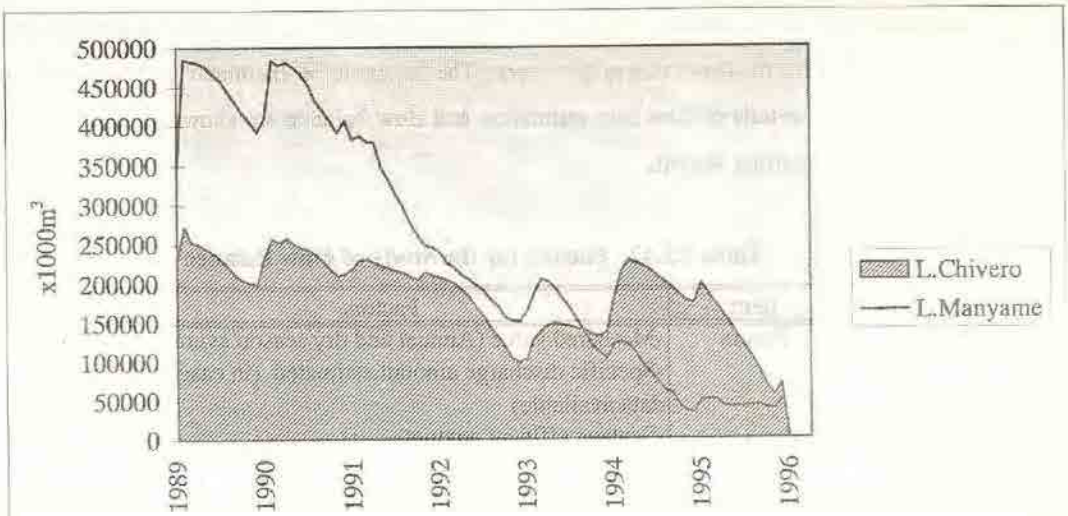


Figure 6.1.19 Water Reserve of Lake Chivero and Manyame*

*Source: NIPPON JOGESUIDO SEKKEI CO., LTD. & NIPPON KOEI CO., LTD., 1997, "The Study on Water Pollution Control in the Upper Manyame River Basin in the Republic of Zimbabwe", Volume 2 Main Report

(3) Flow rate estimation and flow balance

The flow pattern of the rivers, water level and discharge rate of the lakes are analysed to come up with the flow balance in the entire study basin. Based on such results, the control factors which affect water pollution analysis were clarified.

The average figures of the last 10 years (1992-2001) are utilised for the analysis, since a ten-year cycle pattern of rainfall is observed. Examination points are the lakes and the confluences before and after major rivers. The Seke and Harava Dams are regarded as one water body, because they are adjoined and their rated capacities and catchment areas are comparatively small. Figure 6.1.20 shows locations of the study points. The flow balance of the lake is studied with reference to annual average of the flow rates, while the annual and dry season averages were used for the flow rates of the rivers. The factors to be examined are shown in Table 6.1.25.

Table 6.1.25 Factors for the Study of Flow Balance

Flow	Item	Factors
inflow	Rivers	-Measured value Annual; 1992/2001 Dry season; 1985/94 from the Study 1996 -Specific discharge estimated (in case of no date available) -Sewage effluent amount (included in the river flow data)
	Direct Rainfall	-Full surface area of lake * Rainfall amount (2002/2011)
	Direct Area	-Specific discharge rate estimated; Runoff rate (1995)
Outflow	Evaporation	-Surface area of lake * Evaporation rate (2002/2011)
	Water Intake	-Records of Intake

Flow	Item	Factors
	Discharge	-Measured value, Specific discharge rate estimated and multiplying factor estimated
Balance	Water level of the lake	-Measured value (1995)
	Ground water recharge and others	-Assumed from other data

Source: JICA Project Team

1) River flow

The average flow rates at present were estimated using available annual data from 1992 to 2001. In this study, for the comparative result between previous and current available data, current river flow rate was estimated multiplying 1.7 times that of previous flow rate. Therefore in this study, in case no data is available 1.7 times of previous flow rate is adopted.

Influence of STP Effluent

Effluent discharged constantly from the STPs affects the flow rate of the river. Presently, the observation of simultaneous flow rates upstream and downstream of STPs is not conducted. Under these conditions, the flow rates at a certain point of the river are different between the measured date (flow implies discharged effluent) and that estimated using specific discharge rate in the subject basin. Additional flow to the rivers is calculated together with effluent discharge from the STPs. The following are condition/assumptions for the calculation of the flow rates for water pollution analysis.

- Flow rates in the river comprise base river water and effluent discharged directly from the STPs and through the irrigation area.
- The influences to river water by the discharged effluent were considered in the sub-river basin where the STPs and irrigation areas exist.
- Annual or dry season average figures are applied to the calculation.

2) Direct rainfall into the lake/dam

Direct inflow of rainfall into the lake/dam was assumed using the data of the Study 1997 where direct inflow of rainfall into the lake/dam was without any loss from the full surface area.

3) Direct area run-off

The direct area run-off into the lake/dam through small rivers/channels was referred from the Study 1997.

4) Evaporation

According to the study on Lake McLwaine (1982), the evaporation from Lake Chivero was estimated at 1291~ 2005 mm (Average 1541 mm). The amount of evaporation was estimated using surface area of the lake/dam at the average water level and average evaporation of 1541 mm. The surface area of the lake /dam was estimated using H-V curve.

Table 6.1.26 Monthly Evaporation of Lake McLwaine

Unit: mm/day

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	N/A	N/A	N/A	N/A	N/A	N/A	3.07	4.06	5.24	6.51	6.03	4.24
2002	4.77	5.48	4.57	4.26	3.69	2.83	N/A	3.87	5.28	6.07	5.61	4.71
2003	6.39	4.72	N/A	N/A	3.52	2.62	3.26	4.36	5.36	5.81	6.03	5.13
2004	0.31	N/A	4.06	3.76	N/A	N/A	3.19	4.30	5.39	5.08	5.89	4.20
2005	N/A	4.83	N/A	4.12	3.81	2.96	N/A	4.32	5.21	6.46	N/A	4.11
2006	4.13	4.21	3.37	3.56	3.08	2.92	3.48	4.26	N/A	6.63	5.93	5.17
2007	4.01	3.96	4.88	4.35	N/A	3.27	3.53	N/A	6.35	7.10	5.97	4.20
2008	N/A	4.69	4.40	4.33	N/A	3.35	3.42	4.65	6.44	7.20	5.84	7.13
2009	4.25	4.91	4.17	4.54	3.51	3.66	3.21	4.92	5.89	6.96	4.86	4.35
2010	4.28	4.26	4.13	N/A	3.62	3.04	3.26	4.58	5.99	7.14	5.48	3.71
2011	3.81	4.15	4.28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	3.99	4.58	4.23	4.13	3.54	3.08	3.30	4.37	5.68	6.50	5.74	4.70

Source: Metrological Department

Table 6.1.27 Annual Evaporation of Lake McLwaine

Months	Num. of Days	Average	
		mm/d	mm/month
Jan	31	3.99	123.7
Feb	28	4.58	128.2
Mar	31	4.23	131.2
Apr	30	4.13	123.9
May	31	3.54	109.7
Jun	30	3.08	92.4
Jul	31	3.30	102.4
Aug	31	4.37	135.5
Sep	30	5.68	170.5
Oct	31	6.50	201.4
Nov	30	5.74	172.1
Dec	31	4.70	145.6
		Total =	1636.7 mm/year

Source: Metrological Department

Table 6.1.28 Evaporation of Lakes and Dams

Lake/Dam	Surface Area (km^2)	Average Depth (%)	Surface Area at Ave. Depth (km^2)	Evaporation		
				(mm/y)	(×1000m^3/y)	(m^3/day)
Harava	2.2	50.02	1.17	1,637	1,915	5,246
Seke	1.1	42.27	0.51	1,637	835	2,287
Chivero	26.3	85.22	22.84	1,637	37,383	102,418
Manyame	81.0	64.83	55.27	1,637	90,461	247,839

Source: Metrological Department, JICA Project Team

5) WTPs water intake

The WTPs water intake flow at each lake/dam is estimated using the derived data in 2012.

Table 6.1.29 Balance between Inflow and Reduction Amount

Division	Item/month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WTP	Daily Intake(1000m^3/d)	60	60	60	60	60	60	60	60	45	45	45	45
	Daily Distribution(1000m^3/d)	55	55	55	55	55	55	55	55	40	40	40	40
DAM	Daily Flow(x1000m^3/d)	485	649	959	670	131	51	8	11	4	0	2	107
	Monthly Inflow(x1000m^3/d)	15,026	18,168	29,730	20,114	4,071	1,542	244	335	111	3	49	3,321
	Daily reduction(x1000m^3/d)	80	80	80	80	80	80	80	80	65	65	65	65
	Monthly Balance(x1000m^3/month)	12,546	15,928	27,250	17,714	1,591	-858	-2,236	-2,145	-1,839	-2,012	-1,901	1,264
	Storage Volume(x1000m^3)	12,500	12,500	12,500	12,500	12,500	11,642	9,406	7,261	5,422	3,410	1,509	2,773

Source: ZINWA, JICA Project Team

Table 6.1.30 Specifications of PE-WTP

Item		Prince Edward
Capacity (m^3/d)		90,000
Water Source		Seke Dam（Connecting with Harava Dam）
Process	Sedimentation	Upper flow sludge blanket type
	Filtration	Akazu Filter（Constant water level control by siphon）, Washing by air and water
	Sludge Treatment	After sedimentation, discharge to sludge lagoon
Treatment Facilities	Sedimentation Basin	Rectangular Tank 7
	Rapid Sand Filters	16 Filters
	Clear Water Tank	1 tank (under the filters)
	Sludge Treatment	Two series of sludge tanks, sludge transmission pumps and sludge lagoon
	Transmission facilities	A transmission P/S to southern east area of Harare and Chitungwiza Municipality from the clear water tank
Using Chemical		Powder activated carbon, Aluminum Sulfide, Soda ash, Chlorine (by one ton cylinder), Coagulation aid
Treated Quality		Based on WHO Standard

Source: Harare Water

Table 6.1.31 Production amount of MJ-WTP (unit:m^3/day)

Production /Month	2009		2010		2011	
	Monthly	Daily	Monthly	Daily	Monthly	Daily
Jan	13,459	434	18,011	581	18,182	587
Feb	10,968	392	15,526	555	15,513	554
Mar	11,913	384	17,173	554	18,576	599
Apr	11,452	369	15,923	514	17,792	574
May	11,228	362	18,151	586	17,985	580
Jun	14,667	489	15,147	505	17,981	599
Jul	11,891	384	16,822	543	18,804	607
Aug	15,930	514	18,207	587	17,794	574
Sep	17,887	596	17,535	585	17,683	589
Oct	16,944	547	17,816	575	17,559	566
Nov	15,976	533	17,248	575	17,573	586
Dec	16,362	528	17,581	567	18,029	582
Total	168,677	462	205,140	562	213,471	585

Source: Harare Water

6) Flow balance at the lakes/dams

The balance between annual average inflow and outflow at the respective lakes/dams is summarised in Table 6.1.29, and the flow model covering the basin is presented in Figure 6.1.20. The difference between inflow and outflow probably consists of groundwater influence and measurement/estimation errors. Seke and Harava receive a daily flow of around 300,000 m^3/day, while that of the Study 1997 the figure was 177,000 m^3/day. Lake Chivero receives a daily flow around 1,000,000 m^3/day and daily total discharge is 770,000 m^3/day, while that of the Study 1997 was around 558,000 m^3/day. Lake Manyame receives a daily flow around 930,000 m^3/day and daily total discharge is 870,000 m^3/day, while that of the Study 1997 was around 667,000 m^3/day. The result indicates that the rainfall during the years of the Study 1997 was considerably low.

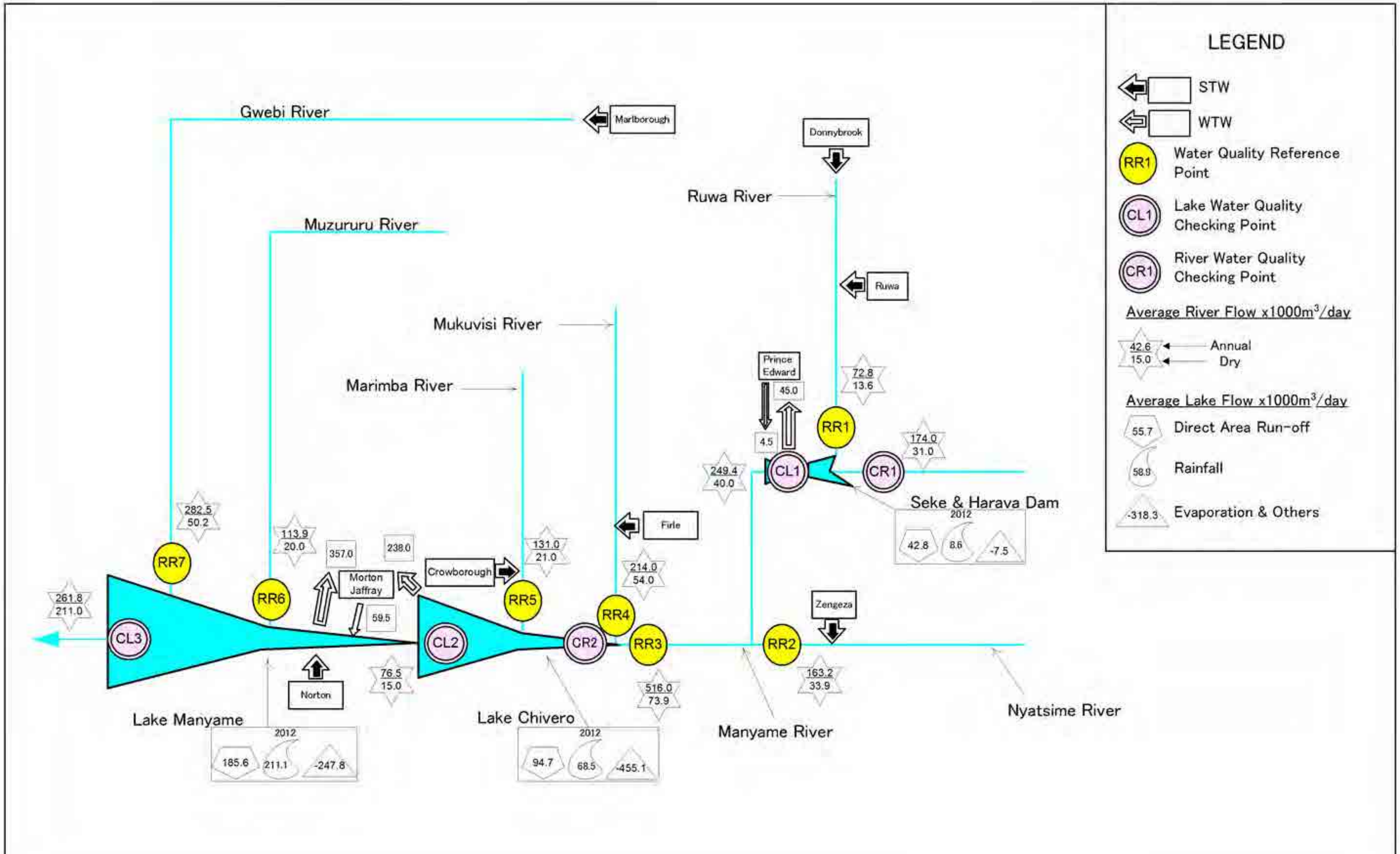
Table 6.1.32 Inflow and Outflow Water Balance at Lakes/Dams

Name	Inflow	Outflow
Seke & Harava Dam		
Manyame R.	174	
Ruwa R.	72.8	
Directi Rainfall	8.6	
Direct Area Run-off	42.8	
Evaporation & Others		7.5
Prince Edward		45
Discharge		245.7
Subtotal	298.2	298.2
Water Increase		
L.Chivero		
Manyame R.	516.0	
Mukuvisi R.	214.0	
Marimba R.	131.0	
Directi Rainfall	68.5	
Direct Area Run-off	94.7	
Evaporation & Others		455.1
Morton Jaffray		238.0
Discharge		76.5
Subtotal	1024.2	769.6
Water Increase	-254.6	
L.Manyame		
L.Chivero	76.5	
Muzururu R.	113.9	
Gwebi R.	282.5	
Directi Rainfall	211.1	
Direct Area Run-off	185.6	
Evaporation		247.8
Morton Jaffray	59.5	357.0
Discharge		261.8
Subtotal	929.1	866.6
Water Increase	-62.5	

Each catchment area is as follows:

Harava	2.2 km^2
Seke	1.1 km^2
Chivero	26.3 km^2
Manyame	81.0 km^2

Source: JICA Project Team



※Annual is flow for Lakes / Dry season is flow for Rivers

Figure 6.1.20 Flow Model of Rivers in Annual/Dry Season (Present, 2020, 2030)

(7) Flow balance in the future

The natural flow rates of the rivers are largely influenced by rainfall which fluctuates year by year. The future flow rates were set based on the average rainfall in the past ten-year period. On the other hand, human activities such as intake for water supply and discharge of treated effluent etc, also affect the flow rate in the river. In this study, flow balance was set for the present and future.

Figure 6.1.20 shows the flow balance of the rivers and lakes in the Upper Manyame Catchment. All the rivers, lakes, STP and WTP are included in the diagram. Direct Area Run-off, rainfall and evaporation and others are also considered. Annual average flow and that of dry season are also expressed in the diagram. When the water balance is negative, it shows that the water level in the lake is increasing according to the area of the lake and daily increase of the balance flow. The centre of the water recirculation is Lake Chivero with most active water inflow and discharge. Approximately 1,000,000 m^3/day has been inflowing to the Lake Chivero from the catchment including the effluent from the Firle STP, Crowborough STP, Zengeza STP, Ruwa STP and Norton STP. Around 640,000 m^3/day has been drawn for the water supply from the PW-WTP and MJ-WTP. Water loss by evaporation and others is assumed to be 450,000 m^3/day which is 60% of the total outflow from the Lake Chivero.

Since Mukuvisi and Marimba rivers do not have adequate flow and each river has Firle STP and Crowborough STP in their catchments, water quality is considered to be sensitive to pollution.

Lake Manyame has been supplying about 60% of raw water for the MJ-WTP (about 360,000 m^3/day). Inflow from the Lake Chivero averages about 80,000 m^3/day. Water loss by evaporation and others is assumed to be about 250,000 m^3/day. Approximately 930,000 m^3/day has been flowing into Lake Manyame from the catchment with less inflow from the STP. In August 2012, MJ-WTP was forced to limit water production due to the influence of raw sewage inflow from the Norton STP.

6.2 UNIT WASTEWATER FLOW AND QUALITY

6.2.1 General

Pollution sources are categorised into those related to human activities and those of natural origin, which are either point or non-point pollution sources. The former category includes human pollution, and pollution from business/institutional establishments, factories, livestock, farmland (fertiliser and agricultural chemicals), and rainwater run-off from urbanised areas. Undeveloped areas including grassland and rainfall on water bodies have a potential to discharge pollution load.

References were made to "The Study on Water Pollution Control in the Upper Manyame River Basin in the Republic of Zimbabwe" (the Study 1997) conducted by JICA for sewerage. The investigation results on the water quality of major pollution sources through this study were also utilised. Further, the experiences in Japan and other countries were referred to for some pollution sources. Unit wastewater flow investigation was also conducted in the field to get latest information regarding unit flow rate in Chitungwiza.

Future unit wastewater flow for various pollution sources was projected based on the study of present water consumption and effluent amount. With regard to water quality indices, Biochemical oxygen Demand (BOD_5) is used for water pollution analysis of rivers and the sewage treatment plan.

Water pollution analysis of lake is made using Total Nitrogen (T-N) and Total Phosphorus (T-P), which are usually applied to analyse eutrophication problems. Chemical Oxygen Demand (COD) is also used with reference to water pollution caused by organic substances. In this regard, interrelationship between BOD_5 and COD was analysed using available data of the water body.

6.2.2 Past Records of Domestic/Commercial Institutional Sewage

(1) Water consumption per capita per day

Per capita water consumption at present and in the future is discussed in the Study 1997 referring to existing plans by urban local authority as follows:

- City of Harare

City of Harare provides water supply service to its metropolitan area including Chitungwiza Municipality, Norton Town, Epworth Local/ Board and Ruwa Local Board. Investigated actual/ water supply and consumption amounts were reported in the Master Plan for Water Distribution in 1995. The data bases of water supply and water consumption are consumers' meters records (water sales) and pumping plant records (from bulk water meters on transmission mains). The five-year records from 1986-1991 are summarised in Table 6.2.1.

Table 6.2.1 Water Supply and Consumption Records (1986-1991)

Year	Pumped		Sales	
	Total Ml/annum	ADA(Ml/d)	Total Ml/annum	ADA(Ml/d)
1986/87	91,282	250	73,495	203
1987/88	102,785	279	89,516	243
1988/89	100,095	274	86,647	237
1989/90	113,742	319	96,806	265
1990/91	128,698	352	90,884	302

Note: ADA; Annual Daily Average, Source: Harare Water

Annual daily average consumption (sales) grew at a rate of 8.3% p.a. between 1986 and 1991. The mean difference between pumped volume and consumption amount was 18% mainly caused by losses in the transmission mains and reticulation system, and by under-measurement at consumers' meters.

Water consumption during 1986 to 1991 was further broken down by consumer category as shown in Table 6.2.2.

Table 6.2.2 Water Consumption by Category (1986-1991)

Unit: 1,000m^3

Year	Consumption (Annual Daily Average)						
	Residential (a)		Ind./Com. /Inst. (b)*	B/A (%)	Chitung-wiza	Minor Supplies	Total
	High	Low/Med.					
86/87	35	66	72	71	27	3	203
87/88	53	71	87	70	28	4	243
88/89	44	73	88	75	27	5	237
89/90	50	83	99	74	28	5	265
90/91	53	97	115	77	28	9	302
Growth Rate (% p.a.)	8.7	8.0	9.8	-	-	-	8.3

*: Ind./Com./Inst.; Industrial, Commercial and Institutional

Source: Harare Water

Water consumption rates by different density residential area were analysed as follows:

High-density 800 l stand/day (≒ 80* l/capita/day)
Medium-density 1, 800 l stand/day (≒ 80* l/capita/day)
Low-density 2, 500 l stand/day (≒ 80* l/capita/day)

The number of persons per stand of each category is assumed;

High density 11 p/s, Medium- 9 p/s, Low- 7 p/s

Applying above figures, per capita consumption is;

High- 78 l/cap/d, Medium- 200 l/cap./d, Low- 357 l/cap./d

- Chitungwiza Municipa1ity

The proposa1 for sewerage project in the Chitungwiza Municipality[1/] suggests an average daily water supply rate at 900 l/household/day based on the data obtained through bulk meter readings. It is also assumed that 20% of the total supply amount is not conveyed to the consumers due to leakage, wastage, etc. Under these conditions, water consumption rate is estimated to be 206 l/capita/day using an average household size of 4.37 (1992 Census).

(1) Sewage unit flow rate

1) Sanitation manual design procedure, Dec. 1990

This manual was prepared for infrastructure projects of Local Authorities in Zimbabwe by the Swedish Association of Local authorities (SALA) under financing by the Swedish International Development Agency (SIDA) at the request of the Ministry of Local Government Rural and Urban Development.

Annual average Daily Water Demand (AADWD) is recommended in the manual with a range from 600 l/stand/day to 2,000 l/stand/day depending on the difference of population density. It is assumed that about 85% of supply amount to a single high-density dwelling is discharged as sewage. In addition, 850 l/stand/day is suggested as a maximum figure for sewage planning because some water may be used for watering plants and others.

2) Plans of sewerage systems

- Harare City

The sewerage plan for Crowborough Sewage Treatment Works[1/] used following design criteria for the estimation of future sewage flow:

Category	Water Supply		Discharge Ratio		Sewage
High density	800 l/stand/day	x	0.85	=	680 l/stand/day
Medium density	1,800 l/stand/day	x	0.70	=	1,260 l/stand/day
Low density	2,800 l/stand/day	x	0.50/0.70[1/]	=	1,400 l/stand/day

The number of persons per stand (occupancy rate of single dwelling unit) was assumed to be 10 to 12. Applying the same number of persons per stand in the water supply master plan, following unit sewage flow by different density area (in the sewerage plan, 10 to 12 persons per single dwelling stand are assumed):

High density	680l/stand/day / 10	= 68 l/capita/day
Medium density	1, 260 l/stand/day / 6	= 210 l/capita/day
Low density	1, 400 l/stand/day/ 4	= 350 l/capita/day

- Chitungwiza Municipality

The following design criteria for the future sewage flow are used in the Proposal for Sewerage Project of Chitungwiza Municipality[1/].

Category	Water Supply		Discharge Ratio		Sewage
High density	800 l/stand/day	x	0.85	=	680 l/stand/day

The proposed unit sewage flow for high density is the same as Harare City. Applying number of persons per stand (nine persons/stand), unit sewage flow rate is 89l/capita/day and 761/capita/day, respectively. This unit water consumption is quite low in comparison with those in the water supply plans.

3) Unit sewage flow for water pollution control planning

Although the range of unit water consumption is different depending on population density, i.e. high density 70 - 110 l/capita/day, medium density 110 - 300 l/capita/day, and low density 150 - 625 1/capita/density, the figures used in the Harare Water Supply Master Plan was employed for the planning purpose.

The discharge ratio of consumed water applied in the sewerage master plan for Crowborough Sewage Treatment Works was referred to for this study. The following are the calculation results:

Category	Water Supply		Discharge Ratio		Sewage
High density	80 l/capita/day	x	0.85	=>	70 l/capita/day
Medium density	300 l/capita/day	x	0.70	=>	210 l/capita/day
Low density	625 l/capita/day	x	0.50	=>	315 l/capita/day

Unit water consumption quantities of low and medium density areas are assumed to be constant through the future, the same as in the previous studies, while increasing unit quantities are adopted for high density areas. The current figure of high density areas, 60 l/capita/day, is adopted based on the field study results at Zengeza STP, as shown in section 8.2.3. For the future projection, the following interpolated figures are applied:

Present 2012: 60 l/capita/day
2020: 65 l/capita/day
2030: 70 l/capita/day

These values are adopted for all urban Local Authorities, namely Harare, Chitungwiza, Norton, Ruwa and Epworth, because the lifestyle in these authorities are similar particularly in same density category. The discharge rate of domestic sewage in the rural area with no residential/ category is assumed to be the same as that in high-density area.

6.2.3 Study of Sewage Unit Flow Rate in Chitungwiza

(1) Outline

As shown in the former section, there are several unit sewage flows proposed. In order to confirm the unit sewage flow and flow fluctuation in Chitungwiza Municipality, a field survey was conducted. Flow measurement and sewage sampling were conducted during 13th September to 1st October (2012) at ZSTP at the old grit chamber to get the latest sewage unit flow information. The weather during the activity was fair. Measurements were taken hourly at the sewage intake (influent). The sewage flow to the ZSTP was estimated by using the Rectangular Flume structure of the old system. In this system, only the water depth in the fixed pit is needed to calculate the water flow. A flow rate computing program was developed for the purpose after confirming the configuration of the flume. Flow rate computation was checked by the flow rate derived by the surface velocity in the channel and water depth using a float for the length of the channel. Measures of depth were taken every hour, on the hour. Fifteen minutes prior to flow measurements, screenings were cleared to prevent water damming. Sand deposits were cleared during low water in the early morning.

(2) Estimate of population in the drainage area

Population in the drainage area of the Municipality was estimated from the total population derived from the survey described section 8.1.1 and the area temporarily unsewered. Table 6.2.3 shows the population and area to be excluded from the sewered area in Seke and Zengeza due to break down of the pipe lines. As a result of the survey, an area of 193.3 ha and a population of 64,256 shall be excluded from the sewered area in the Seke and Zengeza. Also, the population in the drainage area in St. Mary where three pump stations are located is 54,000. This was confirmed by the site survey with counterpart and verified by the study on the map/drawings. In total, a population of 211,744 out of 354,500, or about 64% of the area, is considered to be in the sewered area, as shown in Table 6.2.4.

Table 6.2.3 Population out of sewage inflow in Seke and Zengeza

Area	Population	Area (ha)
Seke North	21,294	78.9
Seke South	35,887	101.9
Zengeza	7,074	12.5
Total	64,256	193.3

Source: JICA Project Team

Table 6.2.4 Sewered Area in Chitungwiza

	Area (ha)	Population	Remarks
Sewered Area	1109.7	236,244	
St Mary's PS's Drainage Area	216.5	54,000	Breakdown of Pump Stations
Seke North, South & Zengeza Area	193.3	64,256	Refer to Table 6.2.3
Total	1519.5	354,500	

Source: JICA Project Team

(3) Water supply

Situation of water supply during the survey was made in parallel with the flow rate survey as shown below:

Table 6.2.5 Water Supply during 27th September and 1st October

Data of Water Supply from 27th September to 1st October							
date	flowrate(l/sec)	flowrate(m3/hr)	remarks	date	flowrate(l/sec)	flowrate(m3/hr)	remarks
2012/9/27 9:00	150	540		2012/9/30 9:00	460	1,656	↑
2012/9/27 10:00	150	540		2012/9/30 10:00	460	1,656	
2012/9/27 11:00	150	540		2012/9/30 11:00	460	1,656	
2012/9/27 12:00	540	1,944	↑	2012/9/30 12:00	500	1,800	
2012/9/27 13:00	520	1,872		2012/9/30 13:00	540	1,944	
2012/9/27 14:00	520	1,872		2012/9/30 14:00	540	1,944	
2012/9/27 15:00	520	1,872		2012/9/30 15:00	540	1,944	
2012/9/27 16:00	520	1,872		2012/9/30 16:00	540	1,944	
2012/9/27 17:00	520	1,872		2012/9/30 17:00	540	1,944	
2012/9/27 18:00	520	1,872		2012/9/30 18:00	540	1,944	
2012/9/27 19:00	520	1,872		2012/9/30 19:00	540	1,944	
2012/9/27 20:00	520	1,872		2012/9/30 20:00	540	1,944	
2012/9/27 21:00	530	1,908		2012/9/30 21:00	540	1,944	
2012/9/27 22:00	530	1,908		2012/9/30 22:00	540	1,944	
2012/9/27 23:00	530	1,908		2012/9/30 23:00	530	1,908	
2012/9/28 0:00	530	1,908		2012/10/1 0:00	520	1,872	
2012/9/28 1:00	520	1,872		2012/10/1 1:00	520	1,872	
2012/9/28 2:00	520	1,872		2012/10/1 2:00	520	1,872	
2012/9/28 3:00	520	1,872		2012/10/1 3:00	520	1,872	
2012/9/28 4:00	520	1,872		2012/10/1 4:00	520	1,872	
2012/9/28 5:00	520	1,872		2012/10/1 5:00	510	1,836	
2012/9/28 6:00	520	1,872		2012/10/1 6:00	520	1,872	
2012/9/28 7:00	530	1,908		2012/10/1 7:00	520	1,872	24hrs
2012/9/28 8:00	530	1,908		2012/10/1 8:00	520	1,872	↓ 44,928
2012/9/28 9:00	530	1,908					
2012/9/28 10:00	450	1,620	24hrs				
2012/9/28 11:00	460	1,656	↓ 44,784				
2012/9/28 12:00	460	1,656					
2012/9/28 13:00	460	1,656					
2012/9/28 14:00	460	1,656					
2012/9/28 15:00	440	1,584					
2012/9/28 16:00	440	1,584					
2012/9/28 17:00	450	1,620					

For three hours on the 27th of September (2012), there was low water supply in Chitungwiza and it was confirmed that all the water supply valves to the municipality were closed during that time. Approximately 45,000 m^3/day was supplied fairly constantly during the daytime except for the three hours mentioned. Under the flow rate condition the entire area is supposed to be supplied with water necessitating the examination of the unit flow rate.

(4) Sewage flow measurement

Flumes are generally used to measure flowrate (discharge) in open channels. These typically have widths from a few centimetres to 15 m or so. The water depth in the approach section of flumes typically can be between a few centimetres and about 2 m. Flumes, compared to weirs, have the advantage of less head loss through the device, yet are more complicated to construct and more difficult to analyse.

Head is measured in the flume upstream of the throat - in the so-called "approach channel". For Parshall flumes, head is measured upstream from the throat at a distance of 2/3 of the length of the approach channel (x=length of approach channel in the above diagram). For the other three flumes, head is measured upstream from the throat at a distance of three to four times the maximum expected head. This location is somewhat arbitrary because the head does not vary too much with position, so the exact location of the head measurement is not as important as for a Parshall flume. Since the rectangular, trapezoidal, and U flumes can have a raised throat (a hump), it is important to note that head is measured from the top of the hump rather than from the bottom of the approach channel.

Parshall flumes are the most common; however the flume in the ZSTP is the rectangular type. They were studied extensively in the mid1900s. Rectangular and trapezoidal flumes function by having a constriction at the throat and/or a raised invert (bottom) at the throat.
Either feature can cause critical flow at the throat in a properly operating flume.

Plan View

Section View

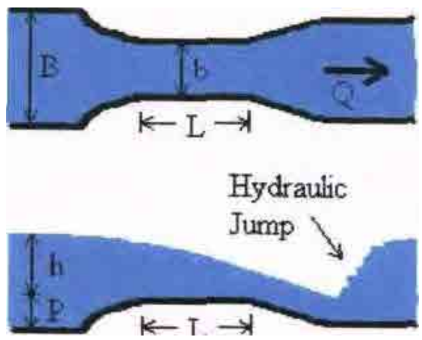


Figure 6.2.1 Flume type existing in the ZSTP-Rectangular Flume

These flumes are simpler to construct, can be more easily fit into an existing channel, and can trap less sediment than a Parshall flume. However, the methodology relating discharge to measured head is more complex. Critical flow is achieved by narrowing the throat or by raising the bottom of the flume at the throat. Analysis of U flumes is similar to that of the trapezoidal flume.

All flumes must be built with their dimensions in strict accordance with specifications in published documents such as the ISO and ASTM standards. Otherwise, discharge analysis must be conducted for the specific flume beginning with theory and proceeding to experimentation to modify the theory by physical observations. The flume in the ZSTP follows the fundamental configuration.

Regarding analysis of flumes, flumes (like weirs) are designed to force a transition from sub-critical to super-critical flow. In the case of flumes, the transition is caused by designing flumes to have a narrowing at the throat, raising of the channel bottom, or both. Such a transition causes flow to pass through critical depth at the flume throat. At the critical depth, energy is minimized and there is a direct relationship between water depth and velocity (and flowrate). However, it is physically very difficult to measure critical depth in a flume because its exact location is difficult to determine and may vary with flowrate. Through mass conservation, the upstream depth is related to the critical depth. Therefore, flowrate can be determined by measuring the upstream depth, which is a highly reliable measurement.

(5) Equations and methodology for rectangular flume

The methodology for the flume calculations follows that of ISO 4359 (1983, 1999) for the rectangular in this study. The ISO methodology for the flume was followed in this study. The calculation is most accurate when used within the ISO 4359 recommendations of $h<=2$ m, $0.1m<=b<=B$, $F<=0.5$, $h/b<=3$, $(b\times h)/[B\times(P+h)]<=0.7$, $h/L<=0.5$, and $h>=0.05$ or $h>=0.05$ L (whichever is greater). The conditions above in the ZSTP are confirmed to be within the range. The constants in the ZSTP are shown in the Table 6.2.6.

$$C_d = \left(1-\frac{0.006L}{b}\right)\left(1-\frac{0.003L}{h}\right)^{3/2}, \quad A = B(P+h)$$

Cv from numerical solution of

$$\sqrt{C_v^{2/3}-1} = \frac{2}{3\sqrt{3}}\frac{bhC_vC_d}{A} \quad \text{Then,}$$

$$Q = bC_dC_v\left(\frac{2h}{3}\right)^{3/2}\sqrt{g}, \quad V = \frac{Q}{A}, \quad F = \frac{V}{\sqrt{gh}}$$

Cv can only be computed if $b\times h\times Cd/A<0.93$.

Table 6.2.6 The Value of the Constant in the Formula

Variables	Actual Value	Unit	Remarks
P	0	m	Hump Height
B	0.91	m	Bottom width of approach channel
h	-	m	Measured Head
L	1.15	m	Length of Flume Throat
b	0.44	m	Bottom width of flume throat
g	9.81	m/s^2	Acceleration by gravity

Source: JICA Project Team

These procedure needs iteration in the calculation using personal computer to get the required accuracy. Re-computation for this was made until there are at least four significant digits of accuracy. Then, V and F are computed from the final Q. Sewage flow was surveyed as shown in Table 6.2.7. For the continuous 24 hours, observed flow was 12,667 m^3/day. As shown above, water supply for the days were 44,784m^3/day and 44,928 m^3/day indicating loss due to leakage from water supply, usage practices such as gardening, spill-out from manholes by blocked the sewers, discharge from broken pipelines. Spill-outs from manholes and discharge from broken pipelines were actually observed in the survey as shown in (3). About a population of 120,000 was confirmed to directly discharge raw sewage to the environment.

Table 6.2.7 Result of Field Sewage Flow Measurement

Hour	Sewage Flow			
	27th Sept, 2012	28th Sept 2012	30th Sept 2012	1st Oct, 2012 Monday
	Flow (m³/d)	Flow (m³/d)	Flow (m³/d)	Flow (m³/d)
0		8,563		10,136
1		9,120		12,366
2		11,147		13,030
3		9,991		15,277
4		10,925		14,766
5		11,024		13,751
6		11,598		15,676
7	5,618	16,104		16,114
8	5,618	22,945		16,020
9	5,618	13,575	13,929	
10	6,162	12,632	10,319	
11	5,322	9,381	10,166	
12	9,767	7,913	9,693	
13	12,056	7,752	10,556	
14	11,287	7,297	13,943	
15	16,500	6,004	16,070	
16	11,613	5,611	14,024	
17	10,172	5,112	14,710	
18	10,498		9,516	
19	10,791		10,973	
20	9,909		8,393	
21	10,145		13,007	
22	9,598		11,536	
23	8,694		10,030	

Remarks: Flowrate is expressed as m^3/day, Source: JICA Project Team

1) From 9a.m. on the 30th September (2012) to 8a.m. on the 1st October (2012), total flow observed

was 12,667 m^3/day

2) For the peak flow was observed at 1500 hours the on 27th September (2012).

3) Peak flow on 28th September (2012) was 800hours.

4) From 9 a.m. on the 30th September (2012) to 8 a.m. on 1st October (2012), there were two peaks in the morning and afternoon.

5) Although large fluctuations were found, there were trends of having two peaks, one in the morning and another in the afternoon.

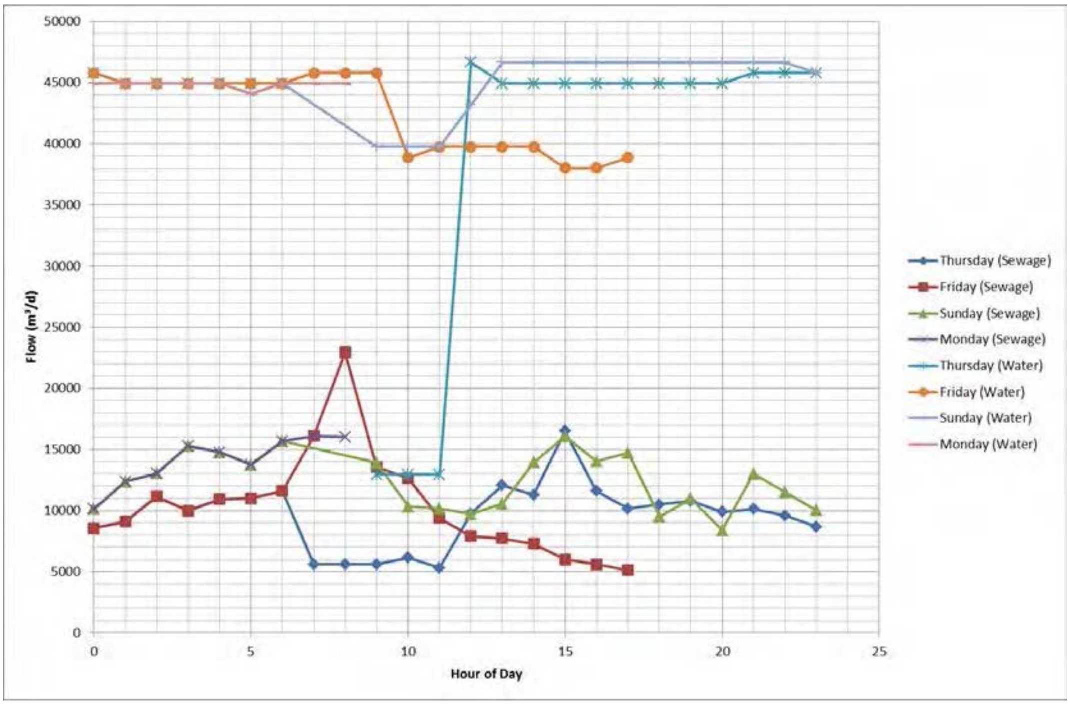


Figure 6.2.2 Flow Measurement Results (1)

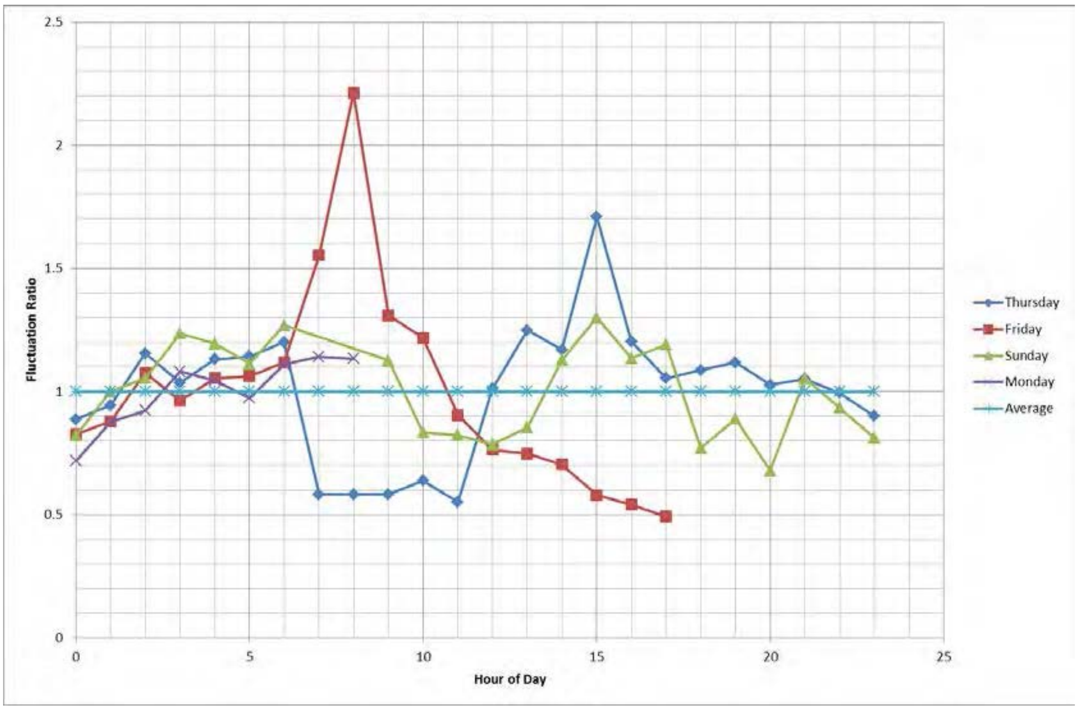


Figure 6.2.3 Flow Measurement Results (2)

(6) Sewage unit flow and peak ratio

1) Sewage unit flow

Sewage flow of 13,000 m^3/day on the 30th September (2012) was used for the examination. Population of 236,200 was confirmed in the area, excluding the pump station area and clogged/blocked area by sand deposit.

Then:

Sewage unit flow rate: 13,000 m^3/day /236,200 = 55 l/capita/day

2) Assumed unit water supply flow based on sewage unit flow

Water supply unit rate was computed as 64.7 l/day/capita using the conversion rate of 0.85.

55/0.85 = 64.7 l /capita/day

3) Peak flow rate

Peak rate was observed as 1.7 on the 27th September and 2.2 on the 30th September (2012). It is evident that the entire Chitungwiza is high density area from the data derived. The unit flow rate and peak factor will be used in planning of sewerage system in Chitungwiza.

6.2.4 Commercial Wastewater

(1) City of Harare

The water supply authority in the study area does not have statistics on the share of commercial /

institutional water consumption. However, as presented in Table 6.2.8, the total water consumption of commercial / institutional and industrial was computed to be about 75% of domestic water consumption in City of Harare. This assumption is also supported by recent available data presented in Table 6.2.8 which shows the trend of the ratio of commercial / industrial and institutional water sales volume to domestic volume in City of Harare to be about 75% in 1995 to 1996. Thus, the total amount of commercial / industrial and institutional water consumption at present may be assumed at 75% of domestic water consumption. Discharge ratio may also be assumed to be equal to that of domestic sewage. Therefore, unit wastewater discharge is also set at 75% of domestic sewage flow. The net commercial and institutional wastewater is derived from the total amount by deducting the industrial wastewater. The data imply that the ratio of commercial and institutional consumption to domestic consumption has been increasing.

Table 6.2.8 Water Sales Volume

Month - Year	Total Sales (m3/month)	Sales in Harare City					Sales to Chitungwiza	Sales to Norton	Sales to Others
		High-dens. Residential	Other Residential	Others* (C./ I. / I.)	Others/Res. %	Total			
Jan-90	6,865,275	1,416,887	2,026,572	2,273,959	66%	5,717,418	580,126	131,990	435,741
Feb-90	6,870,157	1,255,125	2,144,908	2,257,185	66%	5,657,218	744,082	90,090	378,767
Mar-90	6,684,058	1,247,952	1,928,914	2,292,405	72%	5,469,271	762,216	105,636	346,935
Apr-90	7,001,899	1,440,528	2,042,535	2,257,504	65%	5,740,567	752,670	135,720	372,942
May-90	7,104,209	1,506,601	1,796,746	2,367,513	72%	5,670,860	826,297	135,800	471,252
Jun-90	9,054,938	1,444,867	2,966,622	3,255,116	74%	7,711,246	684,785	165,984	492,923
Jul-90	9,003,703	1,287,027	3,007,597	3,476,633	81%	7,771,257	664,218	79,651	488,577
Aug-90	10,464,114	1,507,247	4,023,768	3,486,415	63%	9,017,430	941,776	79,719	425,189
Sep-90	8,685,296	1,657,672	3,442,710	2,779,368	54%	7,879,750	239,857	116,190	449,499
Oct-90	9,845,991	1,692,379	3,275,752	3,449,020	69%	8,417,151	956,147	4,000	468,693
Nov-90	10,228,822	1,760,497	3,713,992	2,927,563	53%	8,402,052	1,256,130	35,865	534,775
Dec-90	8,928,586	1,764,368	2,822,268	2,905,194	63%	7,491,830	806,821	52,018	577,917
90 Daily Avg.	275,992	49,263	90,938	92,405	66%	232,729	25,247	3,103	14,913
Jan-91	8,694,434	1,582,121	2,516,670	2,973,324	73%	7,072,115	722,919	394,100	505,300
Feb-91	8,633,746	1,486,553	2,127,135	2,763,024	76%	6,376,712	788,448	394,100	1,074,486
Mar-91	.7,945,872	1,461,035	2,184,738	2,713,352	74%	6,359,125	806,162	394,100	386,485
Apr-91	8,281,005	1,755,297	2,200,829	2,766,972	70%	6,723,098	721,628	394,100	442,179
May-91	9,224,381	1,674,916	3,017,302	2,883,523	61%	7,575,741	765,009	394,100	489,531
Jun-91	9,609,357	1,712,952	3,139,943	2,986,629	62%	7,839,524	874,515	394,100	501,218
Jul-91	-	-	-	-	-	-	-	-	-
Aug-91	9,833,413	1,750,410	3,300,320	3,065,948	61%	8,189,835	1,121,907	14,923	506,748
Sep-91	9,176,004	1,797,469	2,684,203	3,006,039	67%	7,487,711	1,171,224	12,999	504,070
Oct-91	8,461,546	1,657,966	2,567,024	2,952,027	70%	7,177,017	801,414	12,999	470,116
Nov-91	8,500,070	1,842,963	2,568,561	2,760,477	63%	7,172,001	840,911	11,971	475,187
Dec-91	8,555,536	1,806,828	2,146,572	3,019,718	76%	6,973,118	1,072,169	11,770	498,479
91 Daily Avg.	265,522	50,763	77,954	87,373	68%	216,290	26,538	6,656	16,038
Jan-92	7,964,238	1,569,026	2,044,098	2,547,111	70%	6,160,235	1,316,996	8,976	478,031
Feb-92	7,721,962	1,587,010	2,195,027	2,504,384	66%	6,286,421	947,126	16,691	471,724
Mar-92	7,737,063	1,644,624	2,006,899	2,747,870	75%	6,399,393	869,464	11,538	456,668
Apr-92	7,517,527	1,568,271	2,016,786	2,669,466	74%	6,254,523	865,091	8,447	389,466
May-92	8,180,371	1,767,178	2,218,845	2,718,038	68%	6,704,061	1,133,264	16,094	326,952
Jun-92	7,840,943	1,616,864	2,411,813	2,550,581	63%	6,579,258	811,427	13,352	436,906
Jul-92	7,728,548	1,407,633	2,204,538	2,722,691	75%	6,334,862	957,041	14,077	422,568
Aug-92	8,057,252	1,753,933	2,214,570	2,725,952	69%	6,694,455	915,980	20,033	426,784
Sep-92	7,961,477	1,706,062	2,227,971	2,554,031	65%	6,488,064	878,301	24,055	571,057
Oct-92	7,211,638	1,646,740	1,905,747	2,383,107	67%	5,935,594	870,283	26,803	378,958
Nov-92	7,952,266	1,859,877	1,892,290	2,889,333	77%	6,641,500	879,826	27,864	403,076
Dec-92	7,309,890	1,658,996	1,708,961	2,446,597	73%	5,814,554	1,059,056	35,155	401,125
92 Daily Avg.	255,296	54,209	68,623	86,189	70%	209,022	31,517	611	14,146
Jan-93	6,380,212	1,650,498	1,600,246	2,175,235	67%	5,425,979	595,956	13,515	344,762
Feb-93	7,310,328	1,439,866	1,686,085	2,918,736	93%	6,044,687	943,202	20,256	302,183
Mar-93	6,724,801	1,436,671	1,840,848	2,320,597	71%	5,598,116	710,432	13,478	402,775
Apr-93	6,852,606	1,624,088	1,708,008	2,316,405	70%	5,648,501	791,263	11,316	401,526
May-93	6,889,375	1,612,291	1,727,805	2,259,406	68%	5,599,502	841,043	15,017	433,813
Jun-93	7,713,583	1,685,113	2,110,357	2,450,729	65%	6,246,199	1,002,882	23,629	440,873
93 Daily Avg.	231,331	52,202	58,969	79,785	72%	190,956	26,988	537	12,850

*: commercial, industrial and institutional water consumption

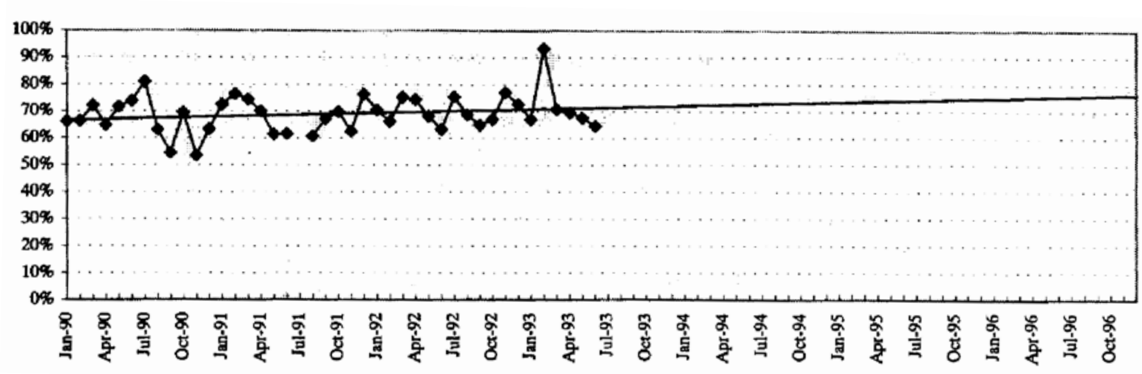


Figure 6.2.4 Ratio of Com./ Ind./ Inst. Water Sales Volume against Domestic Volume in Harare City

The commercial water consumers in the Harare city are unevenly distributed. Many shopping centres are dispersed, but their water consumption and discharge may be regarded as negligible compared to the total domestic consumption and discharge. Most of the commercial water consumers are located in the central business district in the service area of Firle STP (Mukuvisi sub-basin), while many institutional/ water consumers are in the service area of Crowborough STP (Marimba sub-basin). Taking account the influent quantities at both STPs, it is assumed that 80% of total commercial/institutional wastewater is discharged in the Mukuvisi sub-basin, and 20% in the Marimba sub-basin.

(2) Chitungwiza Municipality

According to the investigation results of the bulk meter reading the Chitungwiza in 1992, water consumption is categorised as shown in Table 6.2.9.

Table 6.2.9 Water Consumption in Chitungwiza

Area	Monthly Consumption (m^3)	Daily Consumption (m^3/day)	Share in Total
TILCOR Industrial Area	603,759	2,537	8.9%
Shopping Centre	107,095	450	1.6%
Hospital	234,552	986	3.5%
Others	5,844,651	24, 557	86.1%
Total	6,790,057	28, 530	

Based on the figures in Table 6.2.14, the ratio of water consumption of the shopping centre and the hospital to others is calculated as 5.0%. Other commercial and institutional water consumption may be regarded as minimal in comparison with total water consumption. Discharge rate to supplied water may be regarded as the same with that of domestic water consumption. Thus, the present ratio of commercial/institutional wastewater to domestic sewage is planned at 5% and will be constant in the future.

6.2.5 Unit Pollution Load

(1) Domestic sewage

Quality of the sewage is a requisite for water pollution analysis and designing of sewage treatment works. Generally, water quality indices to be used for those purposes are BOD_5, COD, T-N, T P and Suspended Solid (SS).

1) Sanitation manual

Sanitation manual recommends only following the design values of BOD_5 load:

For high-density areas: 40 g- BOD_5 /capita/day

For low-density areas: 50 g- BOD_5 /capita/day

The manual also presented following reference data:

Daily Per Capita BOD_5:		
	Zambia	36g/capita/day
	Kenya	23g /capita/day
	S.E. Asia	43g/capita/day
	India	30-45g/capita/day
	Rural/ France	24-34g/capita/day
	USA	45-78g/capita/day

3) JICA Study conducted in 1997

JICA Study on “Water Pollution Control in The Upper Manyame River Basin” (1997), presented the surveyed data as shown in Table 6.2.10. “Cal/c. Results” in the table shows the analysed data in Zimbabwe in 1997. The column “Exp. in Japan” shows the value indicated in the guideline for modelling and planning in Japan. The results show that the values for BOD_5 and COD_{Mn} in Zimbabwe were a bit lower than that of Japan. On the other hand, T-P was slightly higher than that of Japan.

Table 6.2.10 Estimated Unit Pollution Load and Comparison with Experience in Japan

Unit Load	Cal/c. Results (a)	Exp. in Japan (b)	(a/b) %
Sewage (Dry Season)	55.3- 63.0 l/pcd	-	-
BOD_5	44.1- 50.2 gpcd	57 gpcd	77 - 88 %
COD_{Mn}	-	28 gpcd	-
T-N	10.8 - 12.3 gpcd	12 gpcd	90 -103 %
T-P	1.3 - 1.4 gpd	1.2 gpcd	108-117 %

Note: lpcd; litre per capita per day, gpcd; gram per capita per day

This high T-P value may be due to the use of detergent containing phosphate. Giving consideration to above discussions, the following figures are used for planning purposes as the unit generated pollution loads for domestic sewage:

Table 6.2.11 Unit Generated Pollution Load of Domestic Sewage

Unit Pollution load	High-density	Medium-density	Low-density
BOD_5	44 gpcd	47 gpcd	50 gpcd
CODcr*	88 gpcd	94 gpcd	100 gpcd
T-N	11 gpcd	12 gpcd	13 gpcd
T-P	1.2gpcd	1.3 gpcd	1.4 gpcd

Note: gpcd; gram per capita per day
*: COD values are assumed to be two times of BOD values.

Generally, generated sewage consisting of night soil and grey water in the unsewered area is treated by septic tanks with seepage pit. Thus, any pollution load does not flow into public water bodies. Most of the septic tanks are generally maintained properly. However, in the rural area, it may be assumed that considerable amount of pollution load reaches the environment from septic tanks and seepage pit overflows, direct discharge of grey water, and washing at rivers, etc.

Although it is difficult to quantify such pollution loads, 8% of generated pollution loads of unsewered area in high density areas is assumed to reach the water bodies. This ratio is assumed to be nil for low and medium density areas in the unsewered areas based on field observation. The ratio of 8% for the reached load was determined by the experience and result of research which was made in Japan. ("Guide Line for the Modelling of Sewerage in a Catchment" etc.) The values in Table 6.2.12 are assumed to be constant through the future.

Table 6.2.12 Unit Reached Pollution Load of Domestic Sewage in Unsewered Area

Unit Pollution Load	High-density
BOD_5	3.52 gpcd
COD_{Cr}	7.04 gpcd
T-N	0.88 gpcd
T-P	0.096 gpcd

Source: JICA Project Team, Note: gpcd; gram per capita per day.

(2) Commercial/institutional wastewater

No data is available for commercial and institutional wastewater quality. This is assumed to be the same as that of domestic sewage, as suggested in Japanese guidelines. In the calculation for the pollution analysis, it is assumed that the concentration of commercial industrial wastewater is the same as that of domestic sewage in the respective rural local authorities.

(3) Industrial wastewater

1) Unit wastewater flow

Study on unit flow of industrial wastewater by industrial type was conducted based on the data collected in the field survey at 24 factories in the four urban Local Authorities.

Six types of industries were selected from six major industrial types which consider the type of industry in each industrial area and the type of industrial discharge as it relates to the organic pollution load:

- Processed Foodstuffs
- Chemicals
- Plastic Products
- Ceramics, Stone and Clay Products
- Transportation Equipment
- Other Manufacturing Industry Products

The ratio of employees collected in the Study 1997 was used and is shown in Table 6.2.13. Table 6.2.14 shows current detailed data about the existing factories in the study area. According to current data, the total number of employees is 0.628 times the previous study (current: 12,096, previous: 19,274, 12,096/19,274= 0.628). Therefore, the value of 0.628 is adopted to revise the frame.

Unit wastewater flow is shown in Table 6.2.15. Current data is adopted. Unit pollution load of each industry is shown in Table 6.2.16. In the analysis, unit flow of industrial wastewater is assumed to be constant for the four urban Local Authorities in the study area from present through the future, considering that no remarkable change is anticipated on the composition and operating scale of major industries.

Table 6.2.13 Composition Ratio of Employee by Industrial Type

Local Authority	STW Service Area	Type No.	Type of Industry	Number of Factories	Number of Employees	Ratio of Employees (%)
Harare City	Firle Crowborough	1	Processed Foodstuffs	-	23,676	41.6
		4	Pulp, Paper & Related Products	-	753	1.3
		6	Chemicals	-	7,668	13.4
		7	Plastic Products	-	2,839	5.0
		11	Ceramics, Stone & Clay Products	-	4,692	8.2
		14	Metal Products	-	11,425	20.0
		17	Transportation Equipment	-	4,652	8.2
		19	Other Industry Products	-	1,340	2.3
			Subtotal	-	57,045	100.0
Chitungwiza Municipality	Zengeza	1	Processed Foodstuffs	5	836	42.0
		7	Plastic Products	1	25	1.3
		11	Ceramics, Stone & Clay Products	1	30	1.5
		14	Metal Products	2	93	4.7
		17	Transportation Equipment	3	875	43.9
		19	Other Industry Products	1	131	6.6
			Subtotal	13	1,990	100.0
Norton Town Council	Norton	1	Processed Foodstuffs	3	245	10.1
		4	Pulp, Paper & Related Products	1	650	26.7
		6	Chemicals	1	30	1.2
		11	Ceramics, Stone & Clay Products	1	61	2.5
		14	Metal Products	3	545	22.4
		17	Transportation Equipment	2	178	7.3
		19	Other Industry Products	3	723	29.8
			Subtotal	14	2,432	100.0
Ruwa Local Board	Ruwa	1	Processed Foodstuffs	1	125	5.3
		6	Chemicals	1	60	2.6
		7	Plastic Products	5	448	19.1
		11	Ceramics, Stone & Clay Products	1	35	1.5
		14	Metal Products	4	267	11.4
		19	Other Industry Products	5	1,411	60.1
			Subtotal	17	2,346	100.0

Table 6.2.14 Unit Flow Rate of Wastewater of Industry

Type of Industry	Company Name	Number of Employees	Wastewater Quantity (m^3/d)	Unit Wastewater Quantity ($m^3/d/person$)
Processed Foodstuffs	Chibuku Brew	250	75.0	0.300
	United Bottle	942	1,258.1	1.336
	Olivine Ind.	1500	759.1	0.506
	D.M.B.	600	900.0	1.500
	National Foods	516	256.5	0.497
	Aroma Bakeries LTD	145	18.7	0.129
	Dairboard	70	22.0	0.314
	Food & Industrial	168	22.0	0.131
	NBC	103	3.3	0.032
	Zim Freeze	200	64.8	0.324
	Sub Total	4,494	3,380.0	0.507
Pulp Paper	Hunyani	650	2,800.0	4.308
	Sub Total	650	2,800.0	4.308
Chemicals	Caps	400	65.0	0.163
	Windmill (Pvt) Ltd	450	12.0	0.027
	Sub Total	850	77.0	0.095
Plastics	Pyramid Products	34	6.0	0.176
	Sub Total	34	6.0	0.176
Transportation	W/Vale M.M. ind.	600	200.0	0.333
	Zupco	3,226	70.0	0.022
	Zupco	400	300.0	0.750
	GDC Hauliers	400	33.0	0.083
	Sub Total	4,626	603.0	0.297
Other	Abercom Dry Co.	35	80	2.286
	Norton Hospital	46	17	0.362
	NAT. REH. Centre	200	115	0.576
	Aurex	1,000	63	0.063
	Grand-Alert	131	3	0.025
	Sub Total	1,412	278	0.662
Total		12,096	7,561.0	19.934

Source: JICA Project Team

Table 6.2.15 Unit Pollution Load of Industrial Wastewater by Industrial Type

Number of Industrial Type	Type of Industry	Number of Factories	Number of Employees	Wastewater Quantity (m^3/day)	Wastewater Quality (mg/l)					Pollution Load (kg/day)					Unit Pollution Load (g/day person)				
					BOD	COD	SS	T-N	T-P	BOD	COD	SS	T-N	T-P	BOD	COD	SS	T-N	T-P
1	Processed Foodstuffs	18	8,056	5,453.8	2,262	3,916	637	66.2	23.75	12,336.5	21,357.1	3,472.0	361.15	129.51	966	2,002	301	25.06	9.61
4	Pulp, Paper & Related Products	1	650	2,800.0	2,275	9,720	498	38.0	6.20	6,370.0	27,216.0	1,394.4	106.40	17.36	9,800	41,871	2,145	163.69	26.71
6	Chemicals	6	2,495	718.9	392	2,569	795	29.8	8.19	281.6	1,846.8	571.2	21.45	5.89	106	840	306	6.30	1.73
7	Plastic Products	2	74	6.2	240	2,160	11,280	37.0	3.20	1.5	13.3	69.6	0.20	0.02	23	242	1,954	0.27	0.08
11	Ceramics, Stone & Clay Products	2	580	483.3	66	206	287	7.0	0.91	31.9	99.3	138.7	3.36	0.44	91	66	682	13.89	2.26
14	Metal Products	4	786	171.1	148	488	138	19.5	2.00	25.2	83.4	23.5	3.34	0.34	61	208	93	6.92	0.66
17	Transportation Equipment	6	5,049	718.9	262	1,802	363	16.6	20.93	180.6	1,243.3	250.1	11.45	14.44	70	392	81	3.54	4.90
19	Other Industry Products	6	1,584	498.2	213	1,324	359	53.9	5.78	106.3	659.7	178.7	26.87	2.88	230	887	397	56.04	6.51

2) Unit pollution load

The unit pollution load of industrial wastewater was calculated in the same manner as what was adopted in the unit flow calculation. The result is shown in Table 6.2.15.

6.2.6 Unit Pollution Load of Other Pollution on Sources

Aside from domestic and industrial pollution loads, the ones generated by livestock, slaughterhouse, farmland and natural land are studied as major pollution sources.

(1) Livestock

Unit pollution load of livestock was established by species. Major livestock raised in the study area are cattle, sheep, goat, pig and poultry. However, data on the pollution load from these livestock are not currently available. Thus, the standard figure for generated and reached load used in Japan for pollution control are employed as shown in Table 6.2.16.

Table 6.2.16 Unit Pollution Load of Livestock

Item	Generated *1				Concentrated *2			
	Cattle	Sheep/ Goats	Pigs	Horses	Cattle	Sheep/ Goats	Pigs	Horses
Wastewater Q (l/head/day)	90	9	13.5	N/A	-	-	-	-
BOD_5 (g/head/day)	640	64	200	220	51.20	5.12	16.0	17.6
CODcr (g/head/day)[3]	1,280	128	400	440	102.40	10.24	32.0	35.2
COD_{Mn} (g/head/day)	530	53	130	700	-	-	-	-
T-N (g/head/day)	378	38	40	170	30.24	3.04	3.2	13.6
T-P (g/head/day)	56	6	25	40	4.48	0.48	2.0	3.2

Note:
1: **Guidelines for Basin-wide Water Pollution Control Master Plan, Japan Sewage Works Association, 1993, p40**
2: **Concentrated pollution load is assumed to be 8 % of generated load according to the guidelines in Japan (less than 10%).**
3: **The standard COD in Japan (italics) is presented as COD_{Mn}, while COD_{Cr} is used in Zimbabwe. Thus the COD values for the study are assumed to be two times of BOD_5 values.**

Reduction of reached pollution load for open defecation of livestock is assumed to be 8% in the pollution analysis of rivers for dry season based on field confirmation.

Pollution loads of poultry were regarded to be negligible, because most of poultry are raised in pens and their excreta is not discharged. Table 6.2.17 shows unit reached BOD_5 load for livestock in dry season.

Table 6.2.17 Unit Reached Pollution Load of Livestock (Dry Season) Pollutant

Pollutant	Cattle	Sheep/ Goats	Pigs	Horses
BOD_5 (g/head/day)	4.096	0.4096	1.28	1.408

(2) Slaughterhouse

Data on pollution load discharged from slaughterhouses in Zimbabwe were not available. Most of slaughtering in the study area is carried out for cattle, swine, poultry and ostrich, and wastewater from these are discharged into the public sewerage system.

(3) Natural land/farm land

1) Natural land

Natural pollution load is defined as that generated without effects from human activities. The land use in the study area is characterised as a combination of natural land, farmland and developed land as shown in Table 6.2.18.

Table 6.2.18 Land Use in the Manyame River Basin (Upstream of Chivero Lake)

Land Use	Area	%
Woodlands (including plantations)	644	30.2
Scrubland	283	13.2
Grassland and wet land	517	24.2
Cultivation and commercial farming	231	10.8
Cultivation and rural subsistence farming	261	12.2
Residential areas	146	6.8
CBD (Central Business District) and avenues	5	0.2
Industrial area	12	0.6
Hospitals	1	0.1
Lakes, dams, sewage farms	32	1.5
Other	4	0.2
Total	2,136	100.0

Source: Lake Mclwaine, Dr. W. Junk Publishers, 1982, p17

There is no available data on natural pollution load in Zimbabwe. References were made to the results of investigations conducted in Japan for woodlands as follows:

Table 6.2.19 Unit Pollution Load of Woodlands in Japan

Pollution load	BOD_5	COD_{Mn}	T-N	T-P
Number of investigations	3	11	23	21
Minimum (kg/km^2/yr)	250	390	30	1
Maximum (kg/km^2/yr)	330	6,600	880	127
Average (kg/km^2/yr)	290	2,150	360	30

Source: JICA Project Team

In Japan, the figure of 0.5-1.0 kg-BOD/km^2/day (182.5-365 kg-BOD/km^2/year) is commonly used for water pollution study of rivers. Although pollution loads fluctuate according to types of vegetation, rainfall intensity, specific flow discharge of river, etc., the average figures in the above table were used for the planning purpose, as summarised in 6.2.20.

Table 6.2.20 Unit Natural Pollution Load

Pollutant	Unit Pollution Load	
	(kg/km^2/year)	(kg/km^2/day)
BOD_5	290	0.795
CODcr*	4,300	11.781
T-N	360	0.986
T-P	30	0.082

*: The COD investigated in Japan(italics) are presented as COD_{Mn} while CODcr is used in Zimbabwe. Thus CODcr Value for the study are assumed to be two times of COD $_{Mn}$ values.

Source: JICA Project Team

Most pollution loads are discharged during the rainy season, however, for the pollution analysis of the river during the dry season, 8% of BOD load, 0.064 kg/km^2/day, was assumed to be discharged. The pollution loads shown in the table were used for the entire study area, not only for natural land but also for other land use areas.

2) Farmland

Farmlands are a potential non-point pollution source due to agricultural activity. Unit run-off pollution load from farmlands are generally larger than that of natural land because of surface run-off ratio and the provision of fertiliser use. However, there is currently no data available on such pollution load in Zimbabwe. The following are the references in Japan, although characteristics of cultivation and climatic condition are different from Zimbabwe:

Table 6.2.21 Unit Pollutant Load of Farmland in Japan

Pollution load	BOD_5	COD_{MN}	T-N	T-P
Number of Investigation	2	5	24	17
Minimum (km^2/yr)	29	399	820	0
Maximum (kg/km^2/year)	471	2,190	23,800	243
Average (kg/km^2/year)	250	1,030	7,600	68

Source: JICA Project Team

The Department of Research and Specialists, Ministry of Agriculture investigated the quantity of fertiliser provided to farmlands by seven farmers in the study area (refer to Chapter 2, Supporting Report, The Study on Water Pollution Control in The Upper Manyame River Basin in The Republic of Zimbabwe, 1997). The results of the investigation are as follows:

Table 6.2.22 Investigation on Fertilizer Quantity

Pollution load	Nitrogen Fertiliser	Phosphate Fertiliser
Crops (including Horticulture)		
Total area of Farmland (ha)	3,413	3,413
Total/ Fertilised Quantity (kg/yr)	117,411	6,520
Average Fertilised Quantity (kg/km^2/yr)	3,440	191

Pollution load	Nitrogen Fertiliser	Phosphate Fertiliser
Pastures		
Total area of Farmland (ha)	1387	1387
Total/ Fertilised Quantity (kg/yr)	824	2160
Average Fertilised Quantity (kg/km^2/yr)	59	156

Source: JICA Project Team

Because of insufficient data, the pollution load provided to farmlands was assumed by taking into consideration the above-mentioned information. Those of BOD_5 and COD are based on the experience in Japan; while T-N and T-P are based on the investigation results in the study area. Part of the fertilisers will be absorbed by crops/, plants and soil, and volatilise to the air. If 10% of the fertiliser is assumed to potentially run off, then unit pollution load in the discharged level is calculated as shown in Table 6.2.23.

Table 6.2.23 Unit Pollution Load of Farmland

Pollutant	Unit Pollution Load	
	(kg/km^2/year)	(kg/km^2/day)
BOD_5	250	0.685
CODcr*	2,060	5.644
COD_{Mn} *	1,030	2.822
T-N (Crops)	350	0.959
T-P (Crops)	20	0.055
T-N (Pastures)	6	0.016
T-P (Pastures)	16	0.044

*: the COD investigated in Japan (italics) is presented as COD_{Mn} while COD_{Cr} is used in Zimbabwe. Thus the COD_{Cr} va1ues for the study are assumed to be two times of COD_{Mn} values.
Source: Guidelines for Basin-wide Water Pollution Control Master Plan, Japan Sewage Works Association

Farmland area by sub-basin in the study area is not available. Since the pollution loads of farmlands and natural land are on the same magnitude /level, the pollution load discharged from farmlands will be calculated in the same manner as that of natural land.

(4) Other pollution sources

In addition to the pollution loads discussed in the previous sub-sections, that caused by rainfall (air pollution) and urban rainwater run-off are sometimes considered in similar studies. The former may be negligible in the country, while the latter may have to be included in the assumed natural pollution load. Although the pollution load carried by rainwater run-off from urbanised areas cannot be neglected, the amount in dry season for river is minimal. In addition to aforementioned pollution sources, the Morton Jaffray and the Prince Edward water treatment plants (WTPs) are considered as pollution sources. Presently, wastewater generated at the Morton Jaffray WTP through backwashing process is discharged to a nearby river without any treatment. Sludge in a sedimentation tank is led to a sedimentation pond, and supernatant liquid is discharged to an open area.

At the Prince Edward WTP, sludge from the sedimentation pond is discharged to an open area and supernatant liquid is led to the Seke Dam, while backwashed wastewater returns to water treatment process. Pollution load of the wastewater originates from intake water. Therefore, pollution load may be calculated by the pollution load concentration of the water sources and the intake water amount. For the water pollution analysis, pollution loads from WTWs were assumed as follows:

1) Morton Jaffray WTP
a. Sludge (assumed to be 75% of total/ pollution load)
-8% of pollution load reaches Lake Manyame
During dry season, 8% of BOD_5 load reaches Lake Manyame
Backwashing sludge (assumed to be 25% of total/ pollution load)
100% of pollution load reaches Lake Manyame.
Pollution load does not reach Lake Manyame after introduction of sludge treatment plant.

2) Prince Edward WTP
a. Sludge (assumed to be 100% of total/ pollution load)
8% of pollution load reaches Manyame River (downstream).
During dry season, 8% of BOD_5 load reaches Manyame River
b. Backwashing sludge (assumed to be 0% of total/ pollution load)
Constant pollution load is circulating in the processes.

6.3 CURRENT WATER POLLUTION ANALYSIS

6.3.1 General

Current water pollution analysis was conducted to establish the simulation model and major factors to be applied to projecting water quality in the future and to identify the impact of countermeasures for water pollution. Schematic flow diagrams of present water pollution analysis for rivers and lakes are presented in Figures 6.3.1 and 6.3.2 respectively.

Water pollution analysis conducted considered human-related pollution and natural pollution loads as non-point sources. Modelling of the entire study basin for water pollution analysis was made using the result of studies made in the last 10 years as discussed in the section Appendix 6.

The quantitative analysis was made for Seke and Harava Dams, Lake Chivero and Lake Manyame for T-N, T-P and COD. The relationships between pollution loads discharged from pollution sources and the pollution load reached at the water quality checking points along the main river were derived through the analysis. Water quality indices used in the analysis for rivers was BOD, representing water pollution by organic substances mainly caused by human activities. Run-off modelling for the dry season was applied for the pollution analysis of rivers.

6.3.2 Methodology

(1) Rivers

The water pollution study was conducted through the analysis of existing data, water quality examination results obtained through the study, and previous pollution study reports. The major water quality index used in the study was BOD. BOD is converted to COD, and vice versa, if necessary, using a conversion formula derived from the regression analysis on the results of water quality examination both for BOD and COD.

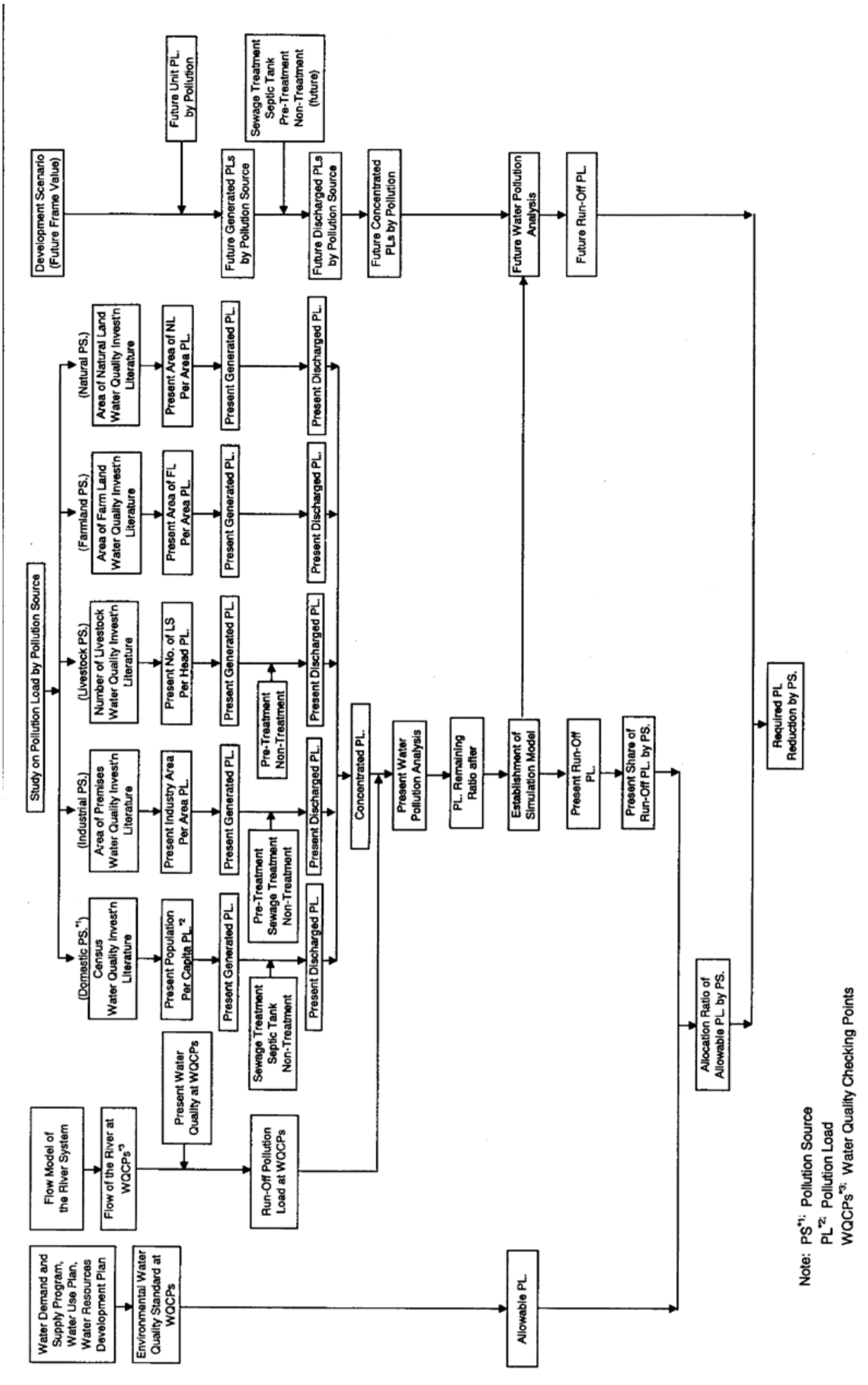
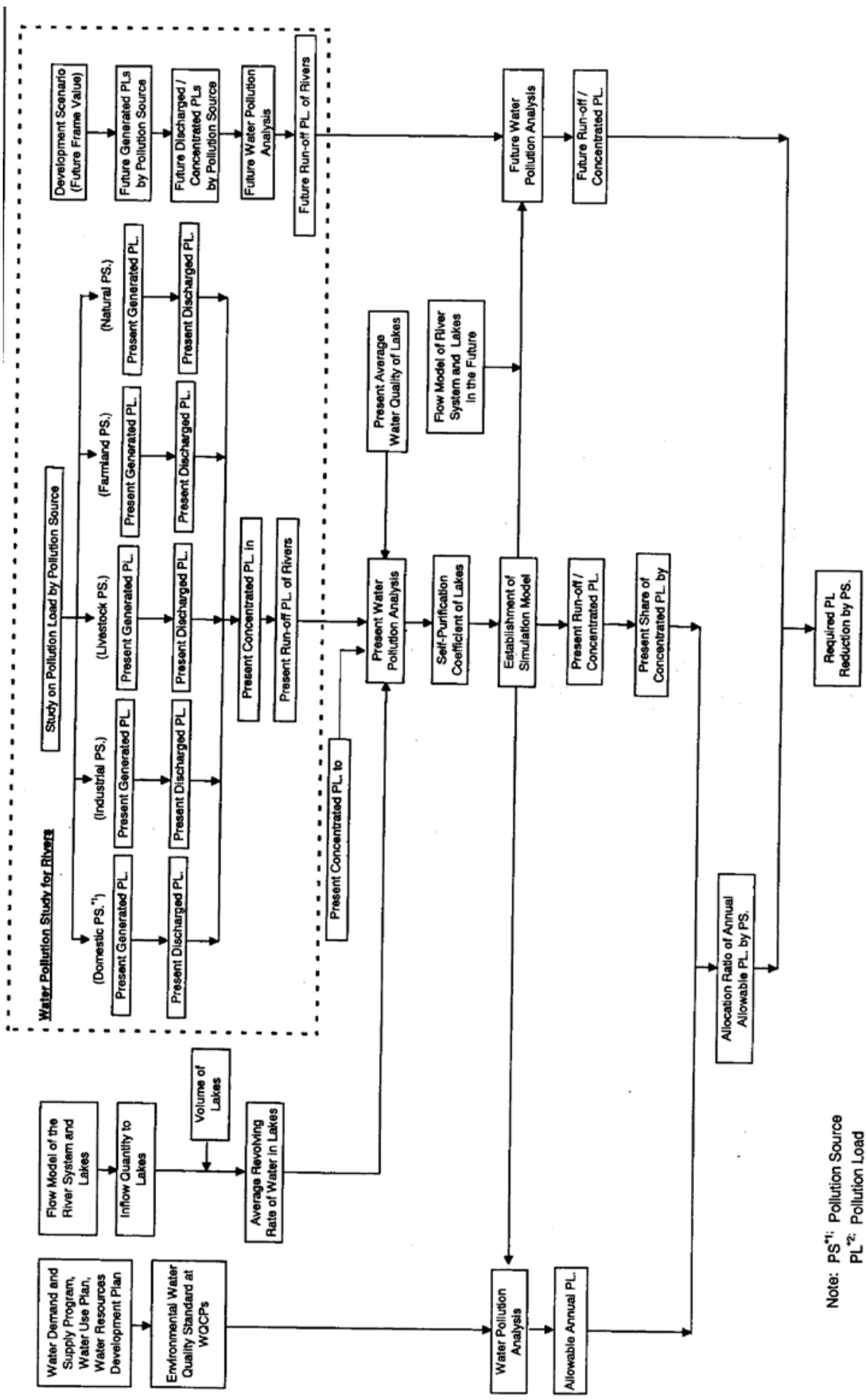


Figure 6.3.1 Flow Diagram of Water Pollution Study (River)



Note: PS*1: Pollution Source
PL*2: Pollution Load
WQCPs*3: Water Quality Checking Points

Figure 6.3.2 Flow Diagram of Water Pollution Study (Lakes)

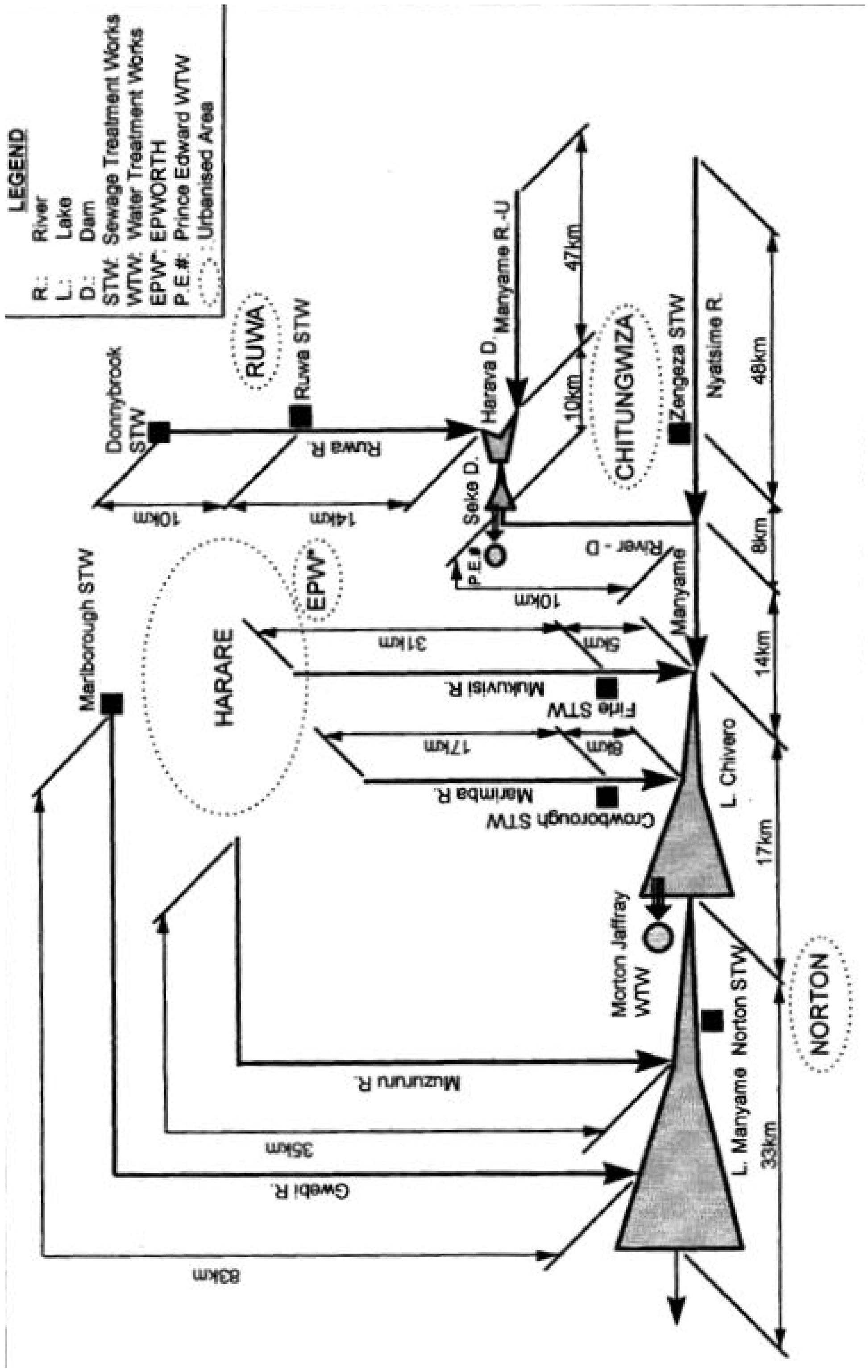
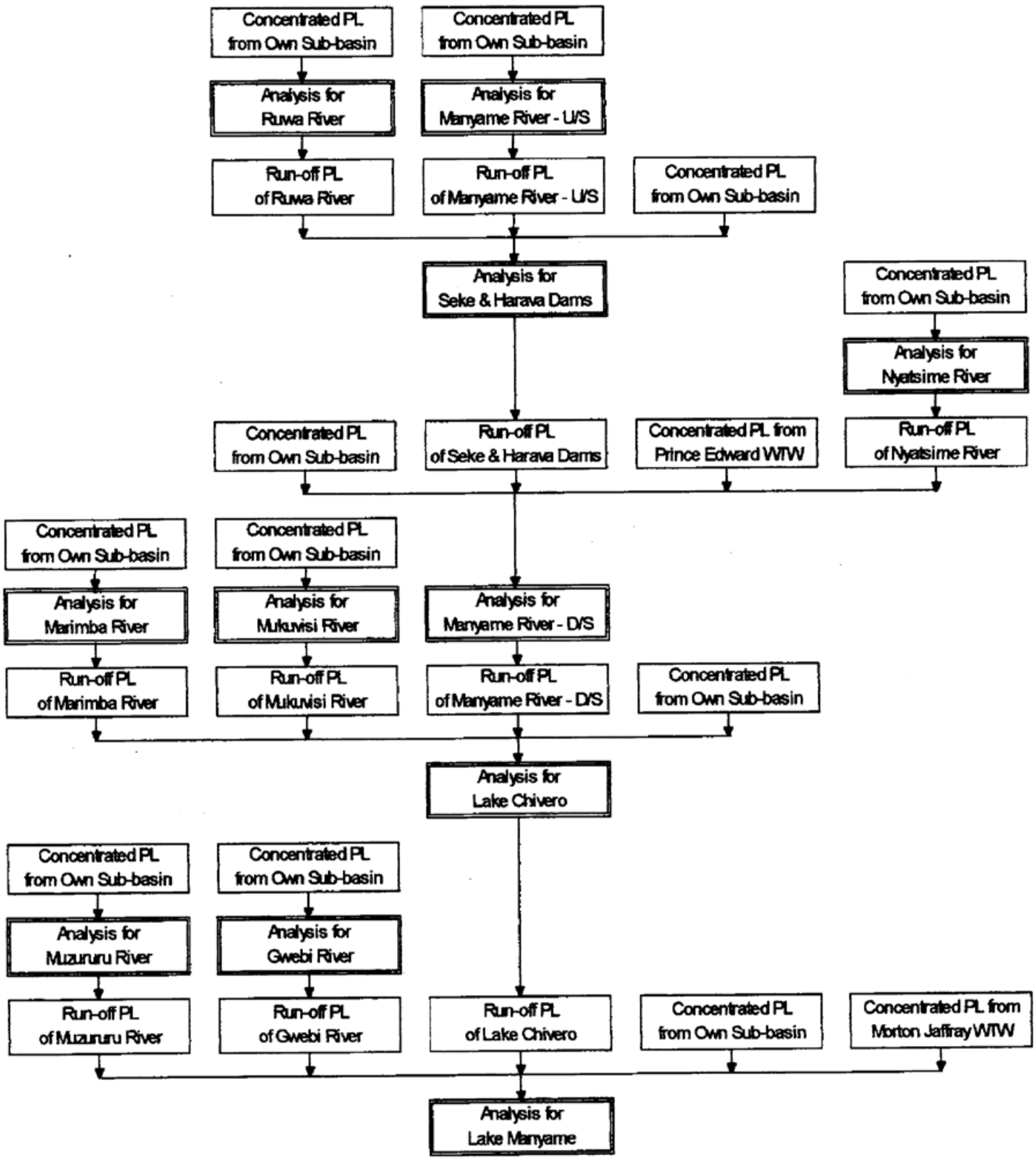
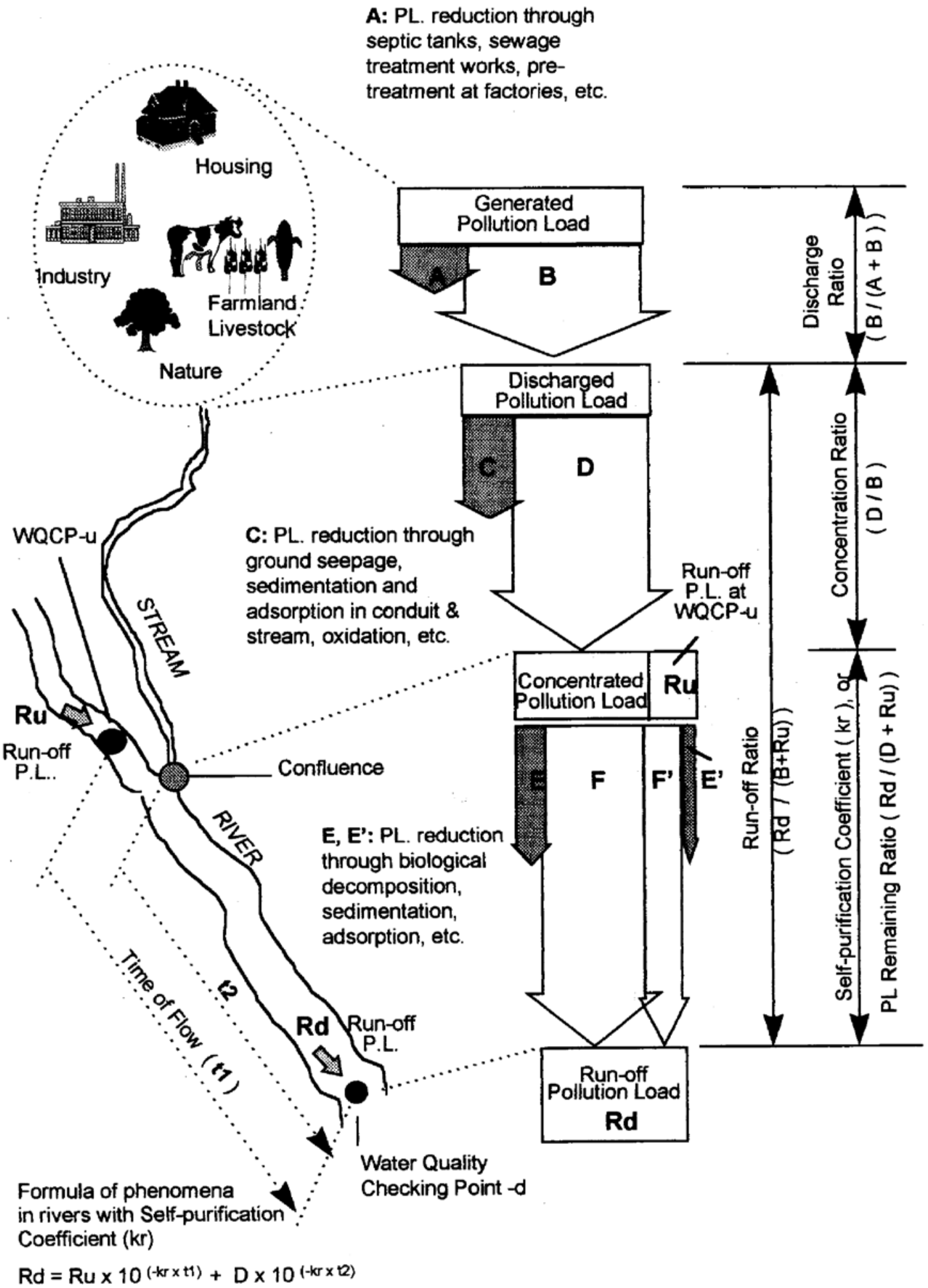


Figure 6.3.3 Location of Rivers, Lakes and STPs



Source: JICA Project Team

Figure 6.3.4 Flow Diagram of Analysis for Rivers and Lakes



Source: JICA Project Team

Figure 6.3.5 Concept of Pollution Load Flow System of Rivers

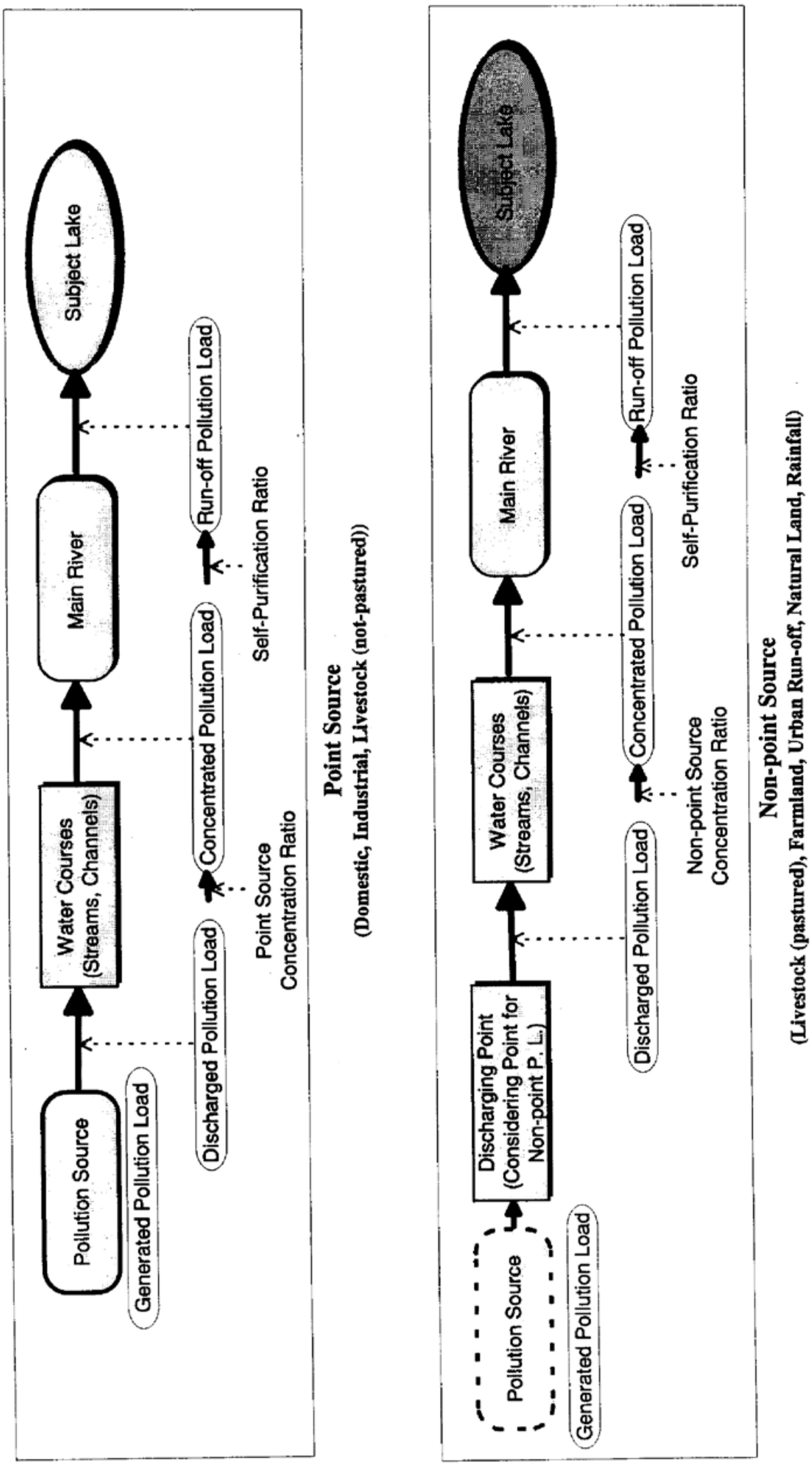


Figure 6.3.6 Concept of Pollution Load Run-off

In the study, the residual ratio of the pollution load of each river was derived through the analysis of self-purification. Reached pollution load was estimated using frame values, unit pollution load and assumed reaching ratio. Run-off load was estimated based on the existing data on flow rate and water quality of rives.

(2) Lakes/dams

The water pollution study for the lakes was also conducted in the same way. Water quality indices used in the study were T-N, T-P and COD. COD was uti1ised to eliminate the influence of algae in the examination of BOD. In the study, COD was made as a reference. The Vollenweider Model was adopted for the water pollution simulation model in terms of T-N, T-P and COD, and the increase of COD caused by elution from sediment in the lake is considered in this concept.

6.3.3 Fundamentals for the Analysis

(1) Domestic/commercial/institutional/ sewage

The pollution load collected from the sewered area will flow into the sewage treatment plant. The pollution load was calculated using existing data at the STPs. Results of the analysis are presented in Table 6.3.2. BOD load was adopted for the water pollution analysis of rivers; while COD, T-N and T-P load were selected for the pollution analysis of lakes. It was also assumed that 8% of the pollution load for irrigation reuse reaches the subject water bodies.

(2) Industrial wastewater

1) Industrial wastewater flow

Industrial wastewater flow was examined using the data of industrial wastewater flow per employee and the number of employees. The result is shown in Table 6.3.7

2) Pollution load

Pollution load was calculated by multiplying the unit pollution load of industrial wastewater per employee and the number of employee at present. The result is presented in Table 6.3.9

3) Sewered/Unsewered wastewater

Wastewater flow and pollution load were calculated for sewered/unsewered by public sewerage system based on the present conditions. The results are shown in Table 6.3.1.

Table 6.3.1 Population by Sewered/Unsewered by Sub-basin (Present)

Sub-basin/District	Total Population		Estimated	Sewered Area				Unsewered Area			
	Sewered	Unsewered	Sewered %	Low	Medium	High	Total	Low	Medium	High	Total
1. Manyame River (U.stream) S/B											
Goromonzi Rural	-	2,255	0%	-	-	-	-	-	-	2,255	2,255
Harare Rural	-	568	0%	-	-	-	-	-	-	568	568
Manyame Rural	-	1,498	0%	-	-	-	-	-	-	1,498	1,498
Total	-	4,321		-	-	-	-	-	-	4,321	4,321
2. Ruwa River S/B											
Harare City	95,381	-	100%	-	-	95,381	95,381	-	-	-	-
Ruwa Local Board	55,766	534	99%	4,556	1,152	50,058	55,766	534	-	-	534
Epworth Local Board	-	103,578	0%	-	-	-	-	-	-	103,578	103,578
Goromonzi Rural	-	535	0%	-	-	-	-	-	-	535	535
Harare Rural	-	19,482	0%	-	-	-	-	-	-	19,482	19,482
Total	151,147	124,129		4,556	1,152	145,439	151,147	534	-	123,595	124,129
3. Seke & Harava Dams S/B											
Epworth Local Board	-	11,651	0%	-	-	-	-	-	-	11,651	11,651
Goromonzi Rural	-	10	0%	-	-	-	-	-	-	10	10
Harare Rural	-	10,592	0%	-	-	-	-	-	-	10,592	10,592
Manyame Rural	-	623	0%	-	-	-	-	-	-	623	623
Total	-	22,876		-	-	-	-	-	-	22,876	22,876
4. Nyatsime River S/B											
Chitungwiza Municipality	279,379	-	100%	-	-	279,379	279,379	-	-	-	-
Manyame Rural	-	6,519	0%	-	-	-	-	-	-	6,519	6,519
Marondera Rural	-	60,000	0%	-	-	-	-	-	-	60,000	60,000
Total	279,379	66,519		-	-	279,379	279,379	-	-	66,519	66,519
5. Mukuvisi River S/B											
Harare City	680,857	30,755	96%	42,843	69,158	568,857	680,857	30,755	-	-	30,755
Epworth Local Board	-	273	0%	-	-	-	-	-	-	273	273
Harare Rural	-	8,679	0%	-	-	-	-	-	-	8,679	8,679
Zvimba Rural	-	142	0%	-	-	-	-	-	-	142	142
Total	680,857	39,849		42,843	69,158	568,857	680,857	30,755	-	9,094	39,849
6. Manyame River (D.stream) S/B											
Chitungwiza Municipality	75,121	-	100%	-	-	75,121	75,121	-	-	-	-
Harare Rural	-	46,674	0%	-	-	-	-	-	-	46,674	46,674
Manyame Rural	-	939	0%	-	-	-	-	-	-	939	939
Total	75,121	47,613		-	-	75,121	75,121	-	-	47,613	47,613
7. Marimba River S/B											
Harare City	573,685	-	100%	65,025	31,301	477,359	573,685	-	-	-	-
Zvimba Rural	-	882	0%	-	-	-	-	-	-	882	882
Total	573,685	882		65,025	31,301	477,359	573,685	-	-	882	882
8. Lake Chivero S/B											
Harare City	-	-	-	-	-	-	-	-	-	-	-
Chegutu Rural	-	672	0%	-	-	-	-	-	-	672	672
Manyame Rural	-	1,292	0%	-	-	-	-	-	-	1,292	1,292
Zvimba Rural	-	1,563	0%	-	-	-	-	-	-	1,563	1,563
Total	-	3,527		-	-	-	-	-	-	3,527	3,527
9. Muzururu River S/B											
Zvimba Rural	-	4,606	0%	-	-	-	-	-	-	4,606	4,606
Total	-	4,606		-	-	-	-	-	-	4,606	4,606
10. Gwebi River S/B											
Harare City	11,057	50,097	18%	11,057	-	-	11,057	50,097	-	-	50,097
Mazowe Rural	-	5,100	0%	-	-	-	-	-	-	5,100	5,100
Zvimba Rural	-	6,688	0%	-	-	-	-	-	-	6,688	6,688
Total	11,057	61,885		11,057	-	-	11,057	50,097	-	11,788	61,885
11. Lake Manyame S/B											
Norton Town	55,016	3,384	94%	692	742	53,582	55,016	3,384	-	-	3,384
Chegutu Rural	-	2,928	0%	-	-	-	-	-	-	2,928	2,928
Zvimba Rural	-	4,119	0%	-	-	-	-	-	-	4,119	4,119
Total	55,016	10,431		692	742	53,582	55,016	3,384	-	7,047	10,431
Grand Total	1,826,263	386,637	83%	124,173	102,353	1,599,737	1,826,263	84,769	-	301,868	386,637

Source: JICA Project Team

Table 6.3.2 Discharged Pollution Load at Sewage Treatment Works (Present)

Sub-basin	Sewage Treatment Works	Eff. Flow (m^3/day)		Irrigation	Average Effluent Water Quality (mg/l)				Pollution Load of Effluent (kg/day)				Reached Pollution Load [f] (kg/day)			
		Annual	Dry	Reuse (%)	BOD	COD	T-N	T-P [a]	BOD	COD	T-N	T-P	BOD (dry)	COD	T-N	T-P
Marimba R.	Crowborough (TF)	39,400	32,300	100%	98.1	282.0	37.9	8.4	3,169	11,111	1,493	331	253	889	119	26
do	Crowborough (BNR)	16,000	15,700	0%	18.9	91.3	9.3	2.7	297	1,461	149	43	297	1,461	149	43
do	Crowborough Total	55,400	48,000						3,465	12,572	1,642	374	550	2,350	268	70
L. Chivero	Firle Units 1&2 (TF)	83,900	81,300	100% [c]	137.8	268.0	38.7	7.2	11,203	22,485	3,247	604	896	1,799	260	48
Mukuvisi R.	Firle Unit 3 (BNR)	12,400	12,700	0%	13.8	107.6	13.7	4.7	175	1,334	170	58	175	1,334	170	58
do	Firle Unit 4 (BNR)	15,300	15,400	0%	18.2	94.7	13.0	3.7	280	1,449	199	57	280	1,449	199	57
do	Firle Total (Mukuvisi)	27,700	28,100						456	2,783	369	115	456	2,783	369	115
Gwebi R.	Marlborough (WSP)[b]	2,000	2,000	100%	51.4	161.9	36.4	6.5	103	324	73	13	8	26	6	1
Ruwa R.	Donnybrook-1 (WSP)[b]	400	400	-	-	-	-	-	-	-	-	-	-	-	-	-
do	Donnybrook-2 (WSP)[b]	1,400	1,400	100%	40.6	162.1	99.6	17.3	73	292	179	20	6	23	14	2
do	Donnybrook-3 (WSP)[b]	1,400	1,400	100%	89.6	264.3	69.3	15.2	340	1,004	263	37	27	80	21	3
do	Donnybrook-4 (WSP)[b]	2,400	2,400	-	-	-	-	-	-	-	-	-	-	-	-	-
do	Donnybrook Total [h]	5,600	5,600						414	1,296	443	56	33	104	35	5
Nyatsime R.	Zengeza (TF)[b]	36,400	33,100	100, 50%[d]	130.0	540.0	119.0	16.6	4,303	19,656	4,332	266	-	9,828	2,166	133
L. Manyame	Norton (TF)	2,700	2,700	100%	520.0	1,191.9	65.8	12.0	1,404	3,218	178	32	112	257	14	3
Ruwa R.	Ruwa (WSP)[b]	2,900	2,000	100%	123.0	278.0	6.1	4.0	246	806	18	12	20	64	1	1
Total		216,600	202,800						21,593	63,140	10,300	1,472	2,075	17,211	3,119	375

Note: a) T-P is calculated from P-P values using following correlation formula which is derived from measurement results by the Study Team.
T-P = P-P x 1.5482 + 0.2682   P-P; Phosphate Phosphorus (refer to Section 9.3, Chapter 2, Supporting Report)

b) COD values of STWs with " b " are calculated from BOD values using following correlation formula which is derived from measurement results of other STWs with trickling filter method.
COD = BOD (annual average) x 2.08 (refer to Section 9.3, Chapter 2, Supporting Report)

c) The irrigation farm of the Firle STW is located in the Lake Chivero sub-basin.

d) The irrigation farm of the Zengeza STW is located outside of the Upper Manyame river basin. 100% of effluent is reused at present. Previously, 50% of it was discharged to Nyatsime River (conditions for calculation of COD, T-N and T-P).

e) Water quality of Zengeza STW is from measurement results surveyed by JICA team.

f) Concentration ratios of pollution loads are; for direct discharge; 100% for irrigation reuse; 8% (for BOD during dry season ; 8%)

g) Values for dry season are adopted for calculation regarding BOD.

h) Treated effluent of Donnybrook Nos. 1 and 4 are flowing into Nos. 2 and 3 respectively.

i) T-N for Ruwa STW is calculated from Anmonia-N values using following correlation formula which is derived from measurement results of same WSP effluent of Donnybrook STW.
T-N = A-N x 1.58

Table 6.3.3 Estimated Domestic/Commercial/institutional Pollution Load by Sewered/unsewered Area by Sub-basin-BOD (Present) (1/2)

Sub-basin/District	Generated BOD (kg/day)											Reaching BOD (kg/day)										
	Sewered Area						Unsewered Area					Sewered Area						Unsewered Area				
	50	47	44				50	47	44			100%	100%	100%	100%	100%		0	0	3.52	8%	
	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total
1. Manyame River (Upstream) S/B																						
Goromonzi Rural	-	-	-	-	-	-	-	-	99	-	99	-	-	-	-	-	-	-	-	8	-	8
Harare Rural	-	-	-	-	-	-	-	-	25	-	25	-	-	-	-	-	-	-	-	2.0	-	2.0
Manyame Rural	-	-	-	-	-	-	-	-	66	-	66	-	-	-	-	-	-	-	-	5	-	5
Total	-	-	-	-	-	-	-	-	190	-	190	-	-	-	-	-	-	-	-	15	-	15
2. Ruwa River S/B																						
Harare City	-	-	4,197	-	-	4,197	-	-	-	-	-	-	-	4,197	-	-	4,197	-	-	-	-	-
Ruwa Local Board	228	54	2,203	126	323	2,933	27	-	-	-	27	228	54	2,203	126	323	2,934	-	-	-	-	-
Epworth Local Board	-	-	-	-	-	-	-	-	4,557	228	4,785	-	-	-	-	-	-	-	-	365	18	383
Goromonzi Rural	-	-	-	-	-	-	-	-	24	-	24	-	-	-	-	-	-	-	-	2	-	2
Harare Rural	-	-	-	-	-	-	-	-	857	-	857	-	-	-	-	-	-	-	-	69	-	69
Total	228	54	6,399	126	323	7,130	27	-	5,438	228	5,693	228	54	6,400	126	323	7,131	-	-	435	18	453
3. Seke & Harava Dams S/B																						
Epworth Local Board	-	-	-	-	-	-	-	-	513	26	538	-	-	-	-	-	-	-	-	41	2	43
Goromonzi Rural	-	-	-	-	-	-	-	-	0.4	-	0.4	-	-	-	-	-	-	-	-	0.04	-	0.04
Harare Rural	-	-	-	-	-	-	-	-	466	-	466	-	-	-	-	-	-	-	-	37	-	37
Manyame Rural	-	-	-	-	-	-	-	-	27	-	27	-	-	-	-	-	-	-	-	2	-	2
Total	-	-	-	-	-	-	-	-	1,007	26	1,032	-	-	-	-	-	-	-	-	81	2	83
4. Nyatsime River S/B																						
Chitungwiza Municipality	-	-	12,293	780	728	13,801	-	-	-	-	-	-	-	12,293	780	728	13,801	-	-	-	-	-
Manyame Rural	-	-	-	-	-	-	-	-	287	-	287	-	-	-	-	-	-	-	-	23	-	23
Marondera Rural	-	-	-	-	-	-	-	-	2,640	-	2,640	-	-	-	-	-	-	-	-	211	-	211
Total	-	-	12,293	780	728	13,801	-	-	2,927	-	2,927	-	-	12,293	780	728	13,801	-	-	234	-	234
5. Mukuvisi River S/B																						
Harare City	2,142	3,250	25,030	10,417	17,449	58,289	1,538	-	-	-	1,538	2,142	3,250	25,030	10,417	17,449	58,288	-	-	-	-	-
Epworth Local Board	-	-	-	-	-	-	-	-	12	1	13	-	-	-	-	-	-	-	-	1	0	1
Harare Rural	-	-	-	-	-	-	-	-	382	-	382	-	-	-	-	-	-	-	-	31	-	31
Zvimba Rural	-	-	-	-	-	-	-	-	6	-	6	-	-	-	-	-	-	-	-	0.5	-	0.5
Total	2,142	3,250	25,030	10,417	17,449	58,289	1,538	-	400	1	1,938	2,142	3,250	25,030	10,417	17,449	58,288	-	-	32	0	32
6. Manyame River (D.stream) S/B																						
Chitungwiza Municipality	-	-	3,305	-	-	3,305	-	-	-	-	-	-	-	3,305	-	-	3,305	-	-	-	-	-
Harare Rural	-	-	-	-	-	-	-	-	2,054	-	2,054	-	-	-	-	-	-	-	-	164	-	164
Manyame Rural	-	-	-	-	-	-	-	-	41	-	41	-	-	-	-	-	-	-	-	3	-	3
Total	-	-	3,305	-	-	3,305	-	-	2,095	-	2,095	-	-	3,305	-	-	3,305	-	-	168	-	168

Table 6.3.3 Estimated Domestic/Commercial/institutional Pollution Load by Sewered/unsewered Area by Sub-basin-BOD (Present) (2/2)

Sub-basin/District	Generated BOD (kg/day)											Reaching BOD (kg/day)										
	Sewered Area						Unsewered Area					Sewered Area						Unsewered Area				
	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total
7. Marimba River S/B																						
Harare City	3,251	1,471	21,004	2,604	6,787	35,118	-	-	-	-	-	3,251	1,471	21,004	2,604	6,787	35,117	-	-	-	-	-
Zvimba Rural	-	-	-	-	-	-	-	-	39	-	39	-	-	-	-	-	-	-	-	3	-	3
Total	3,251	1,471	21,004	2,604	6,787	35,118	-	-	39	-	39	3,251	1,471	21,004	2,604	6,787	35,117	-	-	3	-	3
8. Lake Chivero S/B																						
Harare City	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chegutu Rural	-	-	-	-	-	-	-	-	30	-	30	-	-	-	-	-	-	-	-	2	-	2
Manyame Rural	-	-	-	-	-	-	-	-	57	-	57	-	-	-	-	-	-	-	-	5	-	5
Zvimba Rural	-	-	-	-	-	-	-	-	69	-	69	-	-	-	-	-	-	-	-	6	-	6
Total	-	-	-	-	-	-	-	-	155	-	155	-	-	-	-	-	-	-	-	12	-	12
9. Muzururu River S/B																						
Zvimba Rural	-	-	-	-	-	-	-	-	203	-	203	-	-	-	-	-	-	-	-	16	-	16
Total	-	-	-	-	-	-	-	-	203	-	203	-	-	-	-	-	-	-	-	16	-	16
10. Gwebi River S/B																						
Harare City	553	-	-	-	-	553	2,505	-	-	-	2,505	553	-	-	-	-	553	-	-	-	-	-
Mazowe Rural	-	-	-	-	-	-	-	-	224	-	224	-	-	-	-	-	-	-	-	18	-	18
Zvimba Rural	-	-	-	-	-	-	-	-	294	-	294	-	-	-	-	-	-	-	-	24	-	24
Total	553	-	-	-	-	553	2,505	-	519	-	3,024	553	-	-	-	-	553	-	-	41	-	41
11. Lake Manyame S/B																						
Norton Town	35	35	2,358	130	75	2,632	169	-	-	-	169	35	35	2,358	130	75	2,633	-	-	-	-	-
Chegutu Rural	-	-	-	-	-	-	-	-	129	-	129	-	-	-	-	-	-	-	-	10	-	10
Zvimba Rural	-	-	-	-	-	-	-	-	181	-	181	-	-	-	-	-	-	-	-	14	-	14
Total	35	35	2,358	130	75	2,632	169	-	310	-	479	35	35	2,358	130	75	2,633	-	-	25	-	25
Grand Total	6,234	4,834	70,410	14,057	25,362	120,827	4,263	24	13,304	254	17,775	6,210	4,811	70,391	14,058	25,363	120,828	-	-	1,063	20	1,083

Note: 1. Estimated population for year 2012

2. Residential density is based on those shown in 12.2.3., Section 12.2, Chapter 2, Supporting Report

3. Population in rural districts is categorised to high-density area.

4. Concentration ratios are; for direct discharge (ST 100% for irrigation reuse (ST' 8% for unsewered area: High; 8% Low & Medium; 0%

Table 6.3.4 Estimated Domestic/Commercial/institutional Pollution Load by Sewered/Unsewered Area by Sub-basin COD (Present) (1/2)

Sub-basin/District	Generated COD (kg/day)											Reaching COD (kg/day)										
	Sewered Area						Unsewered Area					Sewered Area						Unsewered Area				
	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total
1. Manyame River (Upstream) S/B																						
Goromonzi Rural	-	-	-	-	-	-	-	-	198	-	198	-	-	-	-	-	-	-	-	16	-	16
Harare Rural	-	-	-	-	-	-	-	-	50	-	50	-	-	-	-	-	-	-	-	4	-	4
Manyame Rural	-	-	-	-	-	-	-	-	132	-	132	-	-	-	-	-	-	-	-	11	-	11
Total	-	-	-	-	-	-	-	-	380	-	380	-	-	-	-	-	-	-	-	30	-	30
2. Ruwa River S/B																						
Harare City	-	-	8,394	-	0	8,394	-	-	-	-	-	-	-	8,394	-	-	8,394	-	-	-	-	-
Ruwa Local Board	456	108	4,405	251	1,168	6,388	53	-	-	-	53	456	108	4,405	251	1,168	6,388	-	-	-	-	-
Epworth Local Board	-	-	-	-	-	-	-	-	9,115	456	9,571	-	-	-	-	-	-	-	-	729	36	766
Goromonzi Rural	-	-	-	-	-	-	-	-	47	-	47	-	-	-	-	-	-	-	-	4	-	4
Harare Rural	-	-	-	-	-	-	-	-	1,714	-	1,714	-	-	-	-	-	-	-	-	137	-	137
Total	456	108	12,799	251	1,168	14,782	53	-	10,876	456	11,385	456	108	12,799	251	1,168	14,782	-	-	870	36	907
3. Seke & Harava Dams S/B																						
Epworth Local Board	-	-	-	-	-	-	-	-	1,025	51	1,077	-	-	-	-	-	-	-	-	82	4	86
Goromonzi Rural	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	0.1	-	0.1
Harare Rural	-	-	-	-	-	-	-	-	932	-	932	-	-	-	-	-	-	-	-	75	-	75
Manyame Rural	-	-	-	-	-	-	-	-	55	-	55	-	-	-	-	-	-	-	-	4	-	4
Total	-	-	-	-	-	-	-	-	2,013	51	2,064	-	-	-	-	-	-	-	-	161	4	165
4. Nyatsime River S/B																						
Chitungwiza Municipality	-	-	24,585	1,560	1,754	27,899	-	-	-	-	-	-	-	24,585	1,560	1,754	27,899	-	-	-	-	-
Manyame Rural	-	-	-	-	-	-	-	-	574	-	574	-	-	-	-	-	-	-	-	46	-	46
Marondera Rural	-	-	-	-	-	-	-	-	5,280	-	5,280	-	-	-	-	-	-	-	-	422	-	422
Total	-	-	24,585	1,560	1,754	27,899	-	-	5,854	-	5,854	-	-	24,585	1,560	1,754	27,899	-	-	468	-	468
5. Mukuvisi River S/B																						
Harare City	4,284	6,501	50,059	20,835	43,360	125,039	3,075	-	-	-	3,075	4,284	6,501	50,059	20,835	43,360	125,039	-	-	-	-	-
Epworth Local Board	-	-	-	-	-	-	-	-	24	1	25	-	-	-	-	-	-	-	-	2	0	2
Harare Rural	-	-	-	-	-	-	-	-	764	-	764	-	-	-	-	-	-	-	-	61	-	61
Zvimba Rural	-	-	-	-	-	-	-	-	12	-	12	-	-	-	-	-	-	-	-	1	-	1
Total	4,284	6,501	50,059	20,835	43,360	125,039	3,075	-	800	1	3,877	4,284	6,501	50,059	20,835	43,360	125,039	-	-	64	0	64
6. Manyame River (D.stream) S/B																						
Chitungwiza Municipality	-	-	6,611	-	-	6,611	-	-	-	-	-	-	-	6,611	-	-	6,611	-	-	-	-	-
Harare Rural	-	-	-	-	-	-	-	-	4,107	-	4,107	-	-	-	-	-	-	-	-	329	-	329
Manyame Rural	-	-	-	-	-	-	-	-	83	-	83	-	-	-	-	-	-	-	-	7	-	7
Total	-	-	6,611	-	-	6,611	-	-	4,190	-	4,190	-	-	6,611	-	-	6,611	-	-	335	-	335

Table 6.3.4 Estimated Domestic/Commercial/institutional Pollution Load by Sewered/Unsewered Area by Sub-basin COD (Present) (2/2)

Sub-basin/District	Generated COD (kg/day)											Reaching COD (kg/day)									
	Sewered Area						Unsewered Area					Sewered Area						Unsewered Area			
	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total
7. Marimba River S/B																					
Harare City	6,502	2,942	42,008	5,209	16,868	73,529	-	-	-	-	-	6,502	2,942	42,008	5,209	16,868	73,529	-	-	-	-	-
Zvimba Rural	-	-	-	-	-	-	-	-	78	-	78	-	-	-	-	-	-	-	-	6	-	6
Total	6,502	2,942	42,008	5,209	16,868	73,529	-	-	78	-	78	6,502	2,942	42,008	5,209	16,868	73,529	-	-	6	-	6
8. Lake Chivero S/B	-	-	-				-	-	-													
Harare City	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chegutu Rural	-	-	-	-	-	-	-	-	59	-	59	-	-	-	-	-	-	-	-	5	-	5
Manyame Rural	-	-	-	-	-	-	-	-	114	-	114	-	-	-	-	-	-	-	-	9	-	9
Zvimba Rural	-	-	-	-	-	-	-	-	138	-	138	-	-	-	-	-	-	-	-	11	-	11
Total	-	-	-	-	-	-	-	-	310	-	310	-	-	-	-	-	-	-	-	25	-	25
9. Muzururu River S/B																					
Zvimba Rural	-	-	-	-	-	-	-	-	405	-	405	-	-	-	-	-	-	-	-	32	-	32
Total	-	-	-	-	-	-	-	-	405	-	405	-	-	-	-	-	-	-	-	32	-	32
10. Gwebi River S/B																					
Harare City	1,106	-	-	-	-	1,106	5,010	-	-	-	5,010	1,106	-	-	-	-	1,106	-	-	-	-	-
Mazowe Rural	-	-	-	-	-	-	-	-	449	-	449	-	-	-	-	-	-	-	-	36	-	36
Zvimba Rural	-	-	-	-	-	-	-	-	589	-	589	-	-	-	-	-	-	-	-	47	-	47
Total	1,106	-	-	-	-	1,106	5,010	-	1,037	-	6,047	1,106	-	-	-	-	1,106	-	-	83	-	83
11. Lake Manyame S/B																					
Norton Town	69	70	4,715	260	230	5,344	338	-	-	-	338	69	70	4,715	260	230	5,344	-	-	-	-	-
Chegutu Rural	-	-	-	-	-	-	-	-	258	-	258	-	-	-	-	-	-	-	-	21	-	21
Zvimba Rural	-	-	-	-	-	-	-	-	362	-	362	-	-	-	-	-	-	-	-	29	-	29
Total	69	70	4,715	260	230	5,344	338	-	620	-	959	69	70	4,715	260	230	5,344	-	-	50	-	50
Grand Total	12,467	9,668	140,821	28,114	63,380	254,309	8,527	47	26,608	508	35,550	12,418	9,622	140,778	28,116	63,381	254,310	-	-	2,125	41	2,166

Note: 1. Estimated population for year 2012

2. Residential density is based on those shown in 12.2.3., Section 12.2, Chapter 2, Supporting Report

3. Population in rural districts is categorised to high-density area.

4. Concentration ratios are; for direct discharge (STW): 100% for irrigation reuse (STW): 8% for unsewered area: High; 8% Low & Medium; 0%

Table 6.3.5 Estimated Domestic/Commercial/institutional Pollution Load by Sewered/Unsewered Area by Sub-basin T-N (Present) (1/2)

Sub-basin/District	Generated T-N (kg/day)											Concentrated T-N (kg/day)										
	Sewered Area						Unsewered Area					Sewered Area						Unsewered Area				
	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total
1. Manyame River (Upstream) S/B																						
Goromonzi Rural	-	-	-	-	-	-	-	-	25	-	25	-	-	-	-	-	-	-	-	2	-	2
Harare Rural	-	-	-	-	-	-	-	-	6.2	-	6.2	-	-	-	-	-	-	-	-	0.5	-	0.5
Manyame Rural	-	-	-	-	-	-	-	-	16	-	16	-	-	-	-	-	-	-	-	1.3	-	1.3
Total	-	-	-	-	-	-	-	-	48	-	48	-	-	-	-	-	-	-	-	4	-	4
2. Ruwa River S/B																						
Harare City	-	-	1,049	-	-	1,049	-	-	-	-	-	-	-	1,049	-	-	1,049	-	-	-	-	-
Ruwa Local Board	59	14	551	32	60	715	7	-	-	-	7	59	14	551	32	60	716	-	-	-	-	-
Epworth Local Board	-	-	-	-	-	-	-	-	1,139	57	1,196	-	-	-	-	-	-	-	-	91	5	96
Goromonzi Rural	-	-	-	-	-	-	-	-	6	-	6	-	-	-	-	-	-	-	-	0.5	-	0.5
Harare Rural	-	-	-	-	-	-	-	-	214	-	214	-	-	-	-	-	-	-	-	17	-	17
Total	59	14	1,600	32	60	1,764	7	-	1,360	57	1,423	59	14	1,600	32	60	1,765	-	-	109	5	113
3. Seke & Harava Dams S/B																						
Epworth Local Board	-	-	-	-	-	-	-	-	128	6	135	-	-	-	-	-	-	-	-	10	0.5	11
Goromonzi Rural	-	-	-	-	-	-	-	-	0.1	-	0.1	-	-	-	-	-	-	-	-	0.01	-	0.01
Harare Rural	-	-	-	-	-	-	-	-	117	-	117	-	-	-	-	-	-	-	-	9	-	9
Manyame Rural	-	-	-	-	-	-	-	-	7	-	7	-	-	-	-	-	-	-	-	0.5	-	0.5
Total	-	-	-	-	-	-	-	-	252	6	258	-	-	-	-	-	-	-	-	20	0.5	21
4. Nyatsime River S/B																						
Chitungwiza Municipality	-	-	3,073	195	29	3,297	-	-	-	-	-	-	-	3,073	195	29	3,297	-	-	-	-	-
Manyame Rural	-	-	-	-	-	-	-	-	72	-	72	-	-	-	-	-	-	-	-	6	-	6
Marondera Rural	-	-	-	-	-	-	-	-	660	-	660	-	-	-	-	-	-	-	-	53	-	53
Total	-	-	3,073	195	29	3,297	-	-	732	-	732	-	-	3,073	195	29	3,297	-	-	59	-	59
5. Mukuvisi River S/B																						
Harare City	557	830	6,257	2,624	935	11,204	400	-	-	-	400	557	830	6,257	2,624	935	11,203	-	-	-	-	-
Epworth Local Board	-	-	-	-	-	-	-	-	3	0	3	-	-	-	-	-	-	-	-	0	0	0
Harare Rural	-	-	-	-	-	-	-	-	95	-	95	-	-	-	-	-	-	-	-	7.6	-	7.6
Zvimba Rural	-	-	-	-	-	-	-	-	2	-	2	-	-	-	-	-	-	-	-	0.1	-	0.1
Total	557	830	6,257	2,624	935	11,204	400	-	100	0	500	557	830	6,257	2,624	935	11,203	-	-	8	0	8
6. Manyame River (D.stream) S/B																						
Chitungwiza Municipality	-	-	826	-	-	826	-	-	-	-	-	-	-	826	-	-	826	-	-	-	-	-
Harare Rural	-	-	-	-	-	-	-	-	513	-	513	-	-	-	-	-	-	-	-	41	-	41
Manyame Rural	-	-	-	-	-	-	-	-	10	-	10	-	-	-	-	-	-	-	-	0.8	-	0.8
Total	-	-	826	-	-	826	-	-	524	-	524	-	-	826	-	-	826	-	-	42	-	42

Table 6.3.5 Estimated Domestic/Commercial/institutional Pollution Load by Sewered/Unsewered Area by Sub-basin T-N (Present) (2/2)

Sub-basin/District	Generated T-N (kg/day)											Concentrated T-N (kg/day)										
	Sewered Area						Unsewered Area					Sewered Area						Unsewered Area				
	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total
7. Marimba River S/B																						
Harare City	845	376	5,251	656	363	7,491	-	-	-	-	-	845	376	5,251	656	363	7,491	-	-	-	-	-
Zvimba Rural	-	-	-	-	-	-	-	-	10	-	10	-	-	-	-	-	-	-	-	0.8	-	0.8
Total	845	376	5,251	656	363	7,491	-	-	10	-	10	845	376	5,251	656	363	7,491	-	-	0.8	-	0.8
8. Lake Chivero S/B	-	-	-				-	-	-													
Harare City	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chegutu Rural	-	-	-	-	-	-	-	-	7	-	7	-	-	-	-	-	-	-	-	0.6	-	0.6
Manyame Rural	-	-	-	-	-	-	-	-	14	-	14	-	-	-	-	-	-	-	-	1.1	-	1.1
Zvimba Rural	-	-	-	-	-	-	-	-	17	-	17	-	-	-	-	-	-	-	-	1.4	-	1.4
Total	-	-	-	-	-	-	-	-	39	-	39	-	-	-	-	-	-	-	-	3	-	3
9. Muzururu River S/B																						
Zvimba Rural	-	-	-	-	-	-	-	-	51	-	51	-	-	-	-	-	-	-	-	4	-	4
Total	-	-	-	-	-	-	-	-	51	-	51	-	-	-	-	-	-	-	-	4	-	4
10. Gwebi River S/B																						
Harare City	144	-	-	-	-	144	651	-	-	-	651	144	-	-	-	-	144	-	-	-	-	-
Mazowe Rural	-	-	-	-	-	-	-	-	56	-	56	-	-	-	-	-	-	-	-	4	-	4
Zvimba Rural	-	-	-	-	-	-	-	-	74	-	74	-	-	-	-	-	-	-	-	6	-	6
Total	144	-	-	-	-	144	651	-	130	-	781	144	-	-	-	-	144	-	-	10	-	10
11. Lake Manyame S/B																						
Norton Town	9	9	589	33	11	651	44	-	-	-	44	9	9	589	33	11	651	-	-	-	-	-
Chegutu Rural	-	-	-	-	-	-	-	-	32	-	32	-	-	-	-	-	-	-	-	3	-	3
Zvimba Rural	-	-	-	-	-	-	-	-	45	-	45	-	-	-	-	-	-	-	-	4	-	4
Total	9	9	589	33	11	651	44	-	78	-	122	9	9	589	33	11	651	-	-	6	-	6
Grand Total	1,621	1,234	17,603	3,540	1,398	25,377	1,108	6	3,326	64	4,486	1,615	1,230	17,597	3,541	1,399	25,377	-	-	266	5	271

Note: 1. Estimated population for year 2012
2. Residential density is based on those shown in 12.2.3., Section 12.2, Chapter 2, Supporting Report
3. Population in rural districts is categorised to high-density area.
4. Concentration ratios are; for direct discharge (ST 100% for irrigation reuse (ST\ 8% for unsewered area: High; 8% Low & Medium; 0%

Table 6.3.6 Estimated Domestic/Commercial/institutional Pollution Load by Sewered/Unsewered Area by Sub-basin T-P (Present) (1/2)

Sub-basin/District	Generated T-P (kg/day)											Concentrated T-P (kg/day)										
	Sewered Area						Unsewered Area					Sewered Area						Unsewered Area				
	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total
1. Manyame River (Upstream) S/B																						
Goromonzi Rural	-	-	-	-	-	-	-	-	3	-	3	-	-	-	-	-	-	-	-	0.2	-	0.2
Harare Rural	-	-	-	-	-	-	-	-	0.7	-	0.7	-	-	-	-	-	-	-	-	0.05	-	0.05
Manyame Rural	-	-	-	-	-	-	-	-	2	-	2	-	-	-	-	-	-	-	-	0.1	-	0.1
Total	-	-	-	-	-	-	-	-	5	-	5	-	-	-	-	-	-	-	-	0.4	-	0.4
2. Ruwa River S/B																						
Harare City	-	-	114	-	-	114	-	-	-	-	-	-	-	114	-	-	114	-	-	-	-	-
Ruwa Local Board	6	1.5	60	3	8	79	0.7	-	-	-	1	6	1.0	60	3	8	78	-	-	-	-	-
Epworth Local Board	-	-	-	-	-	-	-	-	124	6	131	-	-	-	-	-	-	-	-	10	0.5	10
Goromonzi Rural	-	-	-	-	-	-	-	-	0.6	-	1	-	-	-	-	-	-	-	-	0.1	-	0.1
Harare Rural	-	-	-	-	-	-	-	-	23	-	23	-	-	-	-	-	-	-	-	1.9	-	1.9
Total	6	1.5	175	3	8	194	0.7	-	148	6	155	6	1.0	174	3	8	192	-	-	12	0.5	12
3. Seke & Harava Dams S/B																						
Epworth Local Board	-	-	-	-	-	-	-	-	14	0.7	15	-	-	-	-	-	-	-	-	1.1	0.06	1.2
Goromonzi Rural	-	-	-	-	-	-	-	-	0.01	-	0.01	-	-	-	-	-	-	-	-	0.001	-	0.001
Harare Rural	-	-	-	-	-	-	-	-	13	-	13	-	-	-	-	-	-	-	-	1.0	-	1.0
Manyame Rural	-	-	-	-	-	-	-	-	0.7	-	0.7	-	-	-	-	-	-	-	-	0.06	-	0.06
Total	-	-	-	-	-	-	-	-	27	0.7	28	-	-	-	-	-	-	-	-	2.2	0.06	2.3
4. Nyatsime River S/B																						
Chitungwiza Municipality	-	-	335	21	10	367	-	-	-	-	-	-	-	335	21	10	366	-	-	-	-	-
Manyame Rural	-	-	-	-	-	-	-	-	8	-	8	-	-	-	-	-	-	-	-	0.6	-	0.6
Marondera Rural	-	-	-	-	-	-	-	-	72	-	72	-	-	-	-	-	-	-	-	6	-	6
Total	-	-	335	21	10	367	-	-	80	-	80	-	-	335	21	10	366	-	-	6	-	6
5. Mukuvisi River S/B																						
Harare City	60	90	683	286	227	1,345	43	-	-	-	43	60	90	683	286	227	1,346	-	-	-	-	-
Epworth Local Board	-	-	-	-	-	-	-	-	0	0	0	-	-	-	-	-	-	-	-	0	0.0	0.0
Harare Rural	-	-	-	-	-	-	-	-	10.4	-	10.4	-	-	-	-	-	-	-	-	0.8	-	0.8
Zvimba Rural	-	-	-	-	-	-	-	-	0.2	-	0.2	-	-	-	-	-	-	-	-	0.01	-	0.01
Total	60	90	683	286	227	1,345	43	-	11	0	54	60	90	683	286	227	1,346	-	-	1	0.0	0.9
6. Manyame River (D.stream) S/B																						
Chitungwiza Municipality	-	-	90	-	-	90	-	-	-	-	-	-	-	90	-	-	90	-	-	-	-	-
Harare Rural	-	-	-	-	-	-	-	-	56	-	56	-	-	-	-	-	-	-	-	4.5	-	4.5
Manyame Rural	-	-	-	-	-	-	-	-	1.1	-	1.1	-	-	-	-	-	-	-	-	0.1	-	0.1
Total	-	-	90	-	-	90	-	-	57	-	57	-	-	90	-	-	90	-	-	4.6	-	4.6

Table 6.3.6 Estimated Domestic/Commercial/institutional Pollution Load by Sewered/Unsewered Area by Sub-basin T-P (Present) (2/2)

Sub-basin/District	Generated T-P (kg/day)											Concentrated T-P (kg/day)										
	Sewered Area						Unsewered Area					Sewered Area						Unsewered Area				
	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total	Low	Med.	High	C & I	Ind.	Total	Low	Med.	High	C & I	Total
7. Marimba River S/B																						
Harare City	91	41	573	71	90	866	-	-	-	-	-	91	41	573	71	90	866	-	-	-	-	-
Zvimba Rural	-	-	-	-	-	-	-	-	1.1	-	1.1	-	-	-	-	-	-	-	-	0.1	-	0.1
Total	91	41	573	71	90	866	-	-	1.1	-	1.1	91	41	573	71	90	866	-	-	0.1	-	0.1
8. Lake Chivero S/B	-	-	-				-	-	-													
Harare City	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chegutu Rural	-	-	-	-	-	-	-	-	0.8	-	0.8	-	-	-	-	-	-	-	-	0.1	-	0.1
Manyame Rural	-	-	-	-	-	-	-	-	2	-	2	-	-	-	-	-	-	-	-	0.1	-	0.1
Zvimba Rural	-	-	-	-	-	-	-	-	2	-	2	-	-	-	-	-	-	-	-	0.2	-	0.2
Total	-	-	-	-	-	-	-	-	4	-	4	-	-	-	-	-	-	-	-	0.3	-	0.3
9. Muzururu River S/B																						
Zvimba Rural	-	-	-	-	-	-	-	-	6	-	6	-	-	-	-	-	-	-	-	0.4	-	0.4
Total	-	-	-	-	-	-	-	-	6	-	6	-	-	-	-	-	-	-	-	0.4	-	0.4
10. Gwebi River S/B																						
Harare City	15	-	-	-	-	15	70	-	-	-	70	15	-	-	-	-	15	-	-	-	-	-
Mazowe Rural	-	-	-	-	-	-	-	-	6	-	6	-	-	-	-	-	-	-	-	0.5	-	0.5
Zvimba Rural	-	-	-	-	-	-	-	-	8	-	8	-	-	-	-	-	-	-	-	0.6	-	0.6
Total	15	-	-	-	-	15	70	-	14	-	84	15	-	-	-	-	15	-	-	1.1	-	1.1
11. Lake Manyame S/B																						
Norton Town	1.0	1.0	64	4	1.0	71	5	-	-	-	5	1.0	1.0	64	4	1.0	71	-	-	-	-	-
Chegutu Rural	-	-	-	-	-	-	-	-	4	-	4	-	-	-	-	-	-	-	-	0.3	-	0.3
Zvimba Rural	-	-	-	-	-	-	-	-	5	-	5	-	-	-	-	-	-	-	-	0.4	-	0.4
Total	1.0	1.0	64	4	1.0	71	5	-	8	-	13	1.0	1.0	64	4	1.0	71	-	-	0.7	-	0.7
Grand Total	175	134	1,920	385	336	2,948	119	1	363	7	488	174	134	1,920	386	337	2,946	-	-	29	0.55	30

Note: 1. Estimated population for year 2012
2. Residential density is based on those shown in 12.2.3., Section 12.2, Chapter 2, Supporting Report
3. Population in rural districts is categorised to high-density area.
4. Concentration ratios are; for direct discharge (STW): 100% for irrigation reuse (STW): 8% for unsewered area: High; 8% Low & Medium; 0%

Table 6.3.7 Present and Future Industrial Wastewater Flow

Local Authority	Sub-Basin	Present		2020 Year		2030 Year	
		Number of Employee	Wastewater Flow (m^3/day)	Number of Employee	Wastewater Flow (m^3/day)	Number of Employee	Wastewater Flow (m^3/day)
Harare City	Marimba River	14,004	21,729	22,300	34,612	22,300	34,612
	Mukuvisi River	40,004	62,079	74,900	116,242	82,400	127,881
	Ruwa River	—	—	—	—	50,200	77,901
	Manyame River	—	—	77,400	120,120	77,400	120,120
	Total	54,008	83,808	174,600	270,974	232,300	360,514
Chitungwiza Municipality	Nyatsime River	1,570	994	2,261	1,423	17,333	10,899
	Manyame River	—	—	—	—	3,266	2,054
	Total	1,570	994	2,261	1,423	20,598	12,953
Norton Town Council	Lake Manyame	1,381	1,444	3,592	3,750	11,288	11,795
Ruwa Local Board	Ruwa River	1,444	1,081	12,400	9,234	16,200	12,064
Total		58,403	87,327	192,853	285,381	280,386	397,326

Source: JICA Project Team

(3) Other wastewater

1) Livestock

Table 6.3.8 shows the result of the comparison between current total number with the previous study's total number of Cattle, Pigs, Sheep, and Horses and shows the ratio of change. In this study, the number of each livestock in each sub-basin is determined by multiplying the previous number by calculated ratio.

Table 6.3.8 Comparison of Total Livestock Number

Livestock	Previous Number	Current Number	Ratio
Cattle	26,964	24,268	0.90
Pigs	4,175	11,481	2.75
Sheep/Goats	17,189	5,672	0.33
Horses	2,190	88	0.04

Source: JICA Project Team

The computed results are shown in Table 6.3.10. Generated and reached pollution loads from major livestock, i.e. cattle, sheep/goats, pigs and horses, were calculated for each sub-basin using the number of livestock and unit pollution load discussed in sub-section 6.3.2. The summary of calculation is shown in Table 6.3.12.

Table 6.3.9 Present and Future Industrial Wastewater Flow

Local Authority	Sub-Basin	Present Industrial Wastewater Pollution Load (kg/day)					
		Number of Employees	BOD	COD	SS	T-N	T-P
Harare City	Marimba River	14,004	6,787	16,868	5,884	363	90
	Mukuvisi River	40,004	19,389	48,179	16,809	1,039	253
	Ruwa River	0	0	0	0	0	0
	Manyame River	0	0	0	0	0	0
	Total	54,008	26,176	65,047	22,693	1,402	343
Chitungwiza Municipality	Nyatsime River	1,570	728	1,754	380	29	10
	Manyame River	0	0	0	0	0	0
	Total	1,570	728	1,754	380	29	10
Norton Town Council	Lake Manyame	1,381	427	1,329	497	61	9
Ruwa Local Board	Ruwa River	1,444	323	1,168	998	60	8
Total		58,403	27,654	69,298	24,568	1,552	370

Local Authority	Sub-Basin	Year 2020 Industrial Wastewater Pollution Load (kg/day)						Year 2030 Industrial Wastewater Pollution Load (kg/day)					
		Number of Employees	BOD	COD	SS	T-N	T-P	Number of Employees	BOD	COD	SS	T-N	T-P
Harare City	Marimba River	22,300	10,809	26,858	9,369	577	141	22,300	10,809	26,858	9,369	577	141
	Mukuvisi River	74,900	36,303	90,207	31,472	1,943	475	82,400	39,939	99,241	34,622	2,138	523
	Ruwa River	0	0	0	0	0	0	50,200	24,332	60,460	21,093	1,302	319
	Manyame River	77,400	37,514	93,218	32,523	2,007	491	77,400	37,514	93,218	32,523	2,007	491
	Total	174,600	84,626	210,283	73,364	4,527	1,107	232,300	112,594	279,777	97,607	6,024	1,474
Chitungwiza Municipality	Nyatsime River	2,261	1,050	2,527	548	42	16	17,333	8,045	19,367	4,202	323	121
	Manyame River	0	0	0	0	0	0	3,266	1,515	3,649	790	61	22
	Total	2,261	1,050	2,527	548	42	16	20,598	9,560	23,016	4,992	384	143
Norton Town Council	Lake Manyame	3,592	1,109	3,459	1,294	158	24	11,288	3,486	10,867	4,067	499	74
Ruwa Local Board	Ruwa River	12,400	2,779	10,035	8,571	519	65	16,200	3,632	13,113	11,198	678	85
Total		192,853	89,564	226,304	83,777	5,246	1,212	280,386	129,272	326,773	117,864	7,585	1,776

Table 6.3.10 Present and Future Industrial Wastewater Pollution Load

	Sub-Basin	Industrial Wastewater Quantity (m³/day)			Industrial Wastewater Pollution Load (kg/day)														
					Total					Sewered					Un-Sewered				
		Total	Sewered	Un-sewered	BOD	COD	SS	T-N	T-P	BOD	COD	SS	T-N	T-P	BOD	COD	SS	T-N	T-P
Present	Manyame R. (Upstream)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Marimba River	21,729	21,729	–	6,787	16,868	5,884	363	90	6,787	16,868	5,884	363	90	–	–	–	–	–
	Mukuvisi River	62,079	55,871	6,208	19,389	48,179	16,809	1,039	253	17,450	43,361	15,128	935	228	1,939	4,818	1,681	104	25
	Ruwa River	1,081	1,081	–	323	1,168	998	60	8	323	1,168	998	60	8	–	–	–	–	–
	Manyame R. (Downstream)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Nyatsime River	994	994	–	728	1,754	380	29	10	728	1,754	380	29	10	–	–	–	–	–
	Lake Manyame	1,444	253	1,191	427	1,329	497	61	9	75	233	87	11	2	352	1,096	410	50	7
	Lake Chivero	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Muzururu River	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Gwebi River	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Sake & Harava Dam	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Total	87,327	79,928	7,399	27,654	69,298	24,568	1,552	370	25,363	63,384	22,477	1,398	338	2,291	5,914	2,091	154	32
Year 2020	Manyame R. (Upstream)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Marimba River	34,612	34,612	–	10,809	26,858	9,369	577	141	10,809	26,858	9,369	577	141	–	–	–	–	–
	Mukuvisi River	116,242	110,034	6,208	36,303	90,207	31,472	1,943	475	34,364	85,389	29,791	1,839	450	1,939	4,818	1,681	104	25
	Ruwa River	9,234	9,234	–	2,779	10,035	8,571	519	65	2,779	10,035	8,571	519	65	–	–	–	–	–
	Manyame R. (Downstream)	120,120	120,120	–	37,514	93,218	32,523	2,007	491	37,514	93,218	32,523	2,007	491	–	–	–	–	–
	Nyatsime River	1,423	1,423	–	1,050	2,527	548	42	16	1,050	2,527	548	42	16	–	–	–	–	–
	Lake Manyame	3,750	1,856	1,894	1,109	3,459	1,294	158	24	549	1,712	640	78	12	560	1,747	654	80	12
	Lake Chivero	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Muzururu River	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Gwebi River	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Sake & Harava Dam	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Total	285,381	277,279	8,102	89,564	226,304	83,777	5,246	1,212	87,065	219,739	81,442	5,062	1,175	2,499	6,565	2,335	184	37
Year 2030	Manyame R. (Upstream)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Marimba River	34,612	34,612	–	10,809	26,858	9,369	577	141	10,809	26,858	9,369	577	141	–	–	–	–	–
	Mukuvisi River	127,881	121,673	6,208	39,939	99,241	34,622	2,138	523	38,000	94,423	32,941	2,034	498	1,939	4,818	1,681	104	25
	Ruwa River	89,965	89,965	–	27,964	73,573	32,291	1,980	404	27,964	73,573	32,291	1,980	404	–	–	–	–	–
	Manyame R. (Downstream)	122,174	122,174	–	39,029	96,867	33,313	2,068	513	39,029	96,867	33,313	2,068	513	–	–	–	–	–
	Nyatsime River	10,899	10,899	–	8,045	19,367	4,202	323	121	8,045	19,367	4,202	323	121	–	–	–	–	–
	Lake Manyame	11,795	9,901	1,894	3,486	10,867	4,067	499	74	2,926	9,122	3,414	419	62	560	1,745	653	80	12
	Lake Chivero	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Muzururu River	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Gwebi River	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Sake & Harava Dam	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Total	397,326	389,224	8,102	129,272	326,773	117,864	7,585	1,776	126,773	320,210	115,530	7,401	1,739	2,499	6,563	2,334	184	37

Table 6.3.11 Number of Major Livestock by Sub-basin

Cattle

Sub-basin	Total	Nyabira	Marondera	Mel./Ruwa	Harare C.	Manyame	Chegutu
Manyame R. (U/S)	2,186	-	859	725	-	602	-
Ruwa River	1,072	-	-	443	629	-	-
Seke & harava D.	910	-	-	-	310	596	5
Nyatsime River	3,695	-	1,611	-	-	2,084	-
Manyame R. (D/S)	302	-	-	-	302	-	-
Mukuvisi River	719	-	-	-	207	364	149
Marimba River	282	-	-	-	282	-	-
Lake Chivero	1,172	-	-	-	882	-	290
Muzururu River	4,033	3,148	-	-	856	-	29
Gwebi River	8,050	7,764	-	-	239	-	46
Lake Manyame	1,848	822	-	-	235	-	791
Study Area Total	24,268	11,734	2,470	1,168	3,941	3,646	1,309

Pigs

Sub-basin	Total	Nyabira	Marondera	Mel./Ruwa	Harare C.	Manyame	Chegutu
Manyame R. (U/S)	704	-	201	465	-	39	-
Ruwa River	503	-	-	283	220	-	-
Seke & harava D.	146	-	-	-	107	39	-
Nyatsime River	512	-	380	-	-	132	-
Manyame R. (D/S)	105	-	-	-	105	-	-
Mukuvisi River	102	-	-	-	72	22	8
Marimba River	99	-	-	-	99	-	-
Lake Chivero	325	-	-	-	308	-	17
Muzururu River	2,574	2,272	-	-	300	-	3
Gwebi River	5,690	5,605	-	-	83	-	3
Lake Manyame	723	594	-	-	83	-	47
Study Area Total	11,481	8,470	580	748	1,375	231	77

Sheep / Goats

Sub-basin	Total	Nyabira	Marondera	Mel./Ruwa	Harare C.	Manyame	Chegutu
Manyame R. (U/S)	1,025	-	622	258	-	145	-
Ruwa River	342	-	-	158	184	-	-
Seke & harava D.	234	-	-	-	91	143	0
Nyatsime River	1,669	-	1,169	-	-	500	-
Manyame R. (D/S)	88	-	-	-	88	-	-
Mukuvisi River	156	-	-	-	61	87	8
Marimba River	83	-	-	-	83	-	-
Lake Chivero	274	-	-	-	258	-	15
Muzururu River	619	367	-	-	251	-	2
Gwebi River	977	905	-	-	70	-	2
Lake Manyame	206	96	-	-	69	-	41
Study Area Total	5,672	1,367	1,791	416	1,155	875	68

Horses

Sub-basin	Total	Nyabira	Marondera	Mel./Ruwa	Harare C.	Manyame	Chegutu
Manyame R. (U/S)	4	-	1	3	-	-	-
Ruwa River	9	-	-	2	8	-	-
Seke & harava D.	4	-	-	-	4	-	-
Nyatsime River	1	-	1	-	-	-	-
Manyame R. (D/S)	4	-	-	-	4	-	-
Mukuvisi River	3	-	-	-	3	-	0
Marimba River	3	-	-	-	3	-	-
Lake Chivero	11	-	-	-	11	-	0
Muzururu River	19	8	-	-	10	-	0
Gwebi River	24	21	-	-	3	-	0
Lake Manyame	6	2	-	-	3	-	1
Study Area Total	88	31	2	5	48	-	1

Note: Area for livestock raising in Gwebi, Marimba and Mukuvisi of harare Central is assumed to be 10 % of each area because of urbanizarion.

Table 6.3.12 Pollution Load of Sub-basin

(unit: kg/day)

Sub-basin	BOD			COD		T-N		T-P	
	Generated	Reached	Reached (dry)	Generated	Reached	Generated	Reached	Generated	Reached
Manyame R. (U/S)	1,607	128	10	3,213	257	894	71	146	11
Ruwa River	811	65	5	1,621	130	440	35	75	6
Seke & harava D.	627	50	4	1,255	100	360	29	56	4
Nyatsime River	2,574	206	17	5,150	411	1,480	119	229	19
Manyame R. (D/S)	221	17	1	441	35	122	9	20	1
Mukuvisi River	491	40	3	982	79	282	22	44	3
Marimba River	206	16	1	414	33	114	9	18	1
Lake Chivero	835	66	5	1,670	133	468	37	76	6
Muzururu River	3,140	250	20	6,279	502	1,653	132	294	23
Gwebi River	6,358	508	40	12,714	1,017	3,312	264	599	47
Lake Manyame	1,342	108	9	2,683	214	736	59	122	9
Study Area Total	18,212	1,454	115	36,422	2,911	9,861	786	1,679	130

Source: JICA Project Team

2) Farmland / natural land

The pollution loads derived from farmland and natural land were calculated for each sub-basin as shown in Table 6.3.12 using the area of each sub-basin and unit pollution load presented in Tables 6.3.13.

3) Water treatment plant (WTP)

Pollution load from WTPs is shown in Figure 6.3.8, 6.3.10, 6.3.12 and 6.3.14. Pollution load from Prince Edward WTP is calculated for the available concentration data for each component (BOD, COD, T-N, T-P). Pollution load from Morton Jeffry is assumed that amount of pollution load coming from Lake Chivero all goes to Lake Manyame through Morton Jaffray WTP.

6.3.4 Modelling of Pollution Load Run-off

(1) Rivers

1) Flow run-off model

The pollution analysis of the rivers was conducted for BOD_5 under the dry season condition. The river flow adopted in the analysis was derived from the average figures during the dry season in the last 10 years. The river flow run-off model was established as illustrated in Figure 6.3.7 with pollution load discharging points and water quality checking points.

Table 6.3.13 Pollution Load of Farmland / Natural Land

(unit: kg/km²/day, kg/day)

Sub-basin	Area	BOD	BOD(dry)	COD	COD(dry)	T-N	T-P
	(km²)	0.795	0.0636	11.781	0.94248	0.986	0.082
Manyame R. (U/S)	574	456	37	6,762	541	566	47
Ruwa River	245	195	16	2,886	231	242	20
Seke & harava D.	115	91	7	1,355	108	113	9
Nyatsime River	780	620	50	9,189	735	769	64
Manyame R. (D/S)	230	183	15	2,710	217	227	19
Mukuvisi River	166	132	11	1,956	156	164	14
Marimba River	315	250	20	3,711	297	311	26
Lake Chivero	255	203	16	3,004	240	251	21
Muzururu River	310	246	20	3,652	292	306	25
Gwebi River	970	771	62	11,428	914	956	80
Lake Manyame	590	469	38	6,951	556	582	48
Study Area Total	4,550	3,616	292	53,604	4,287	4,487	373

Source: JICA Project Team

2) Pollution load run-off model

The reached BOD load calculated in the previous section is summarized in Table 6.3.14. Most of the reached load were discharged from the sewage treatment works because of high sewerage service coverage ratio and low river flow (little rainfall during dry season).

(2) Lakes/dams

1) Pollution load run-off model

The reached pollution loads calculated in the previous chapter are summarised in Tables 6.3.14, 6.3.15, 6.3.16 and 6.3.17 for BOD, COD, T-N and T-P, respectively. The reached loads coming from livestock and natural pollution occupy large share of the total loads. These pollution loads were assumed to reach the subject lakes with reduction (purification) when flowing in the main rivers.

Pollution load reduction ratio is calculated before reaching the rivers. Using the pollution load and the water balance, the pollution load run-off model/s for present pollution analysis of the lakes were established as presented in Figures 6.3.11, 6.3.13 and 6.3.15 for COD, T-N and T-P, respectively.

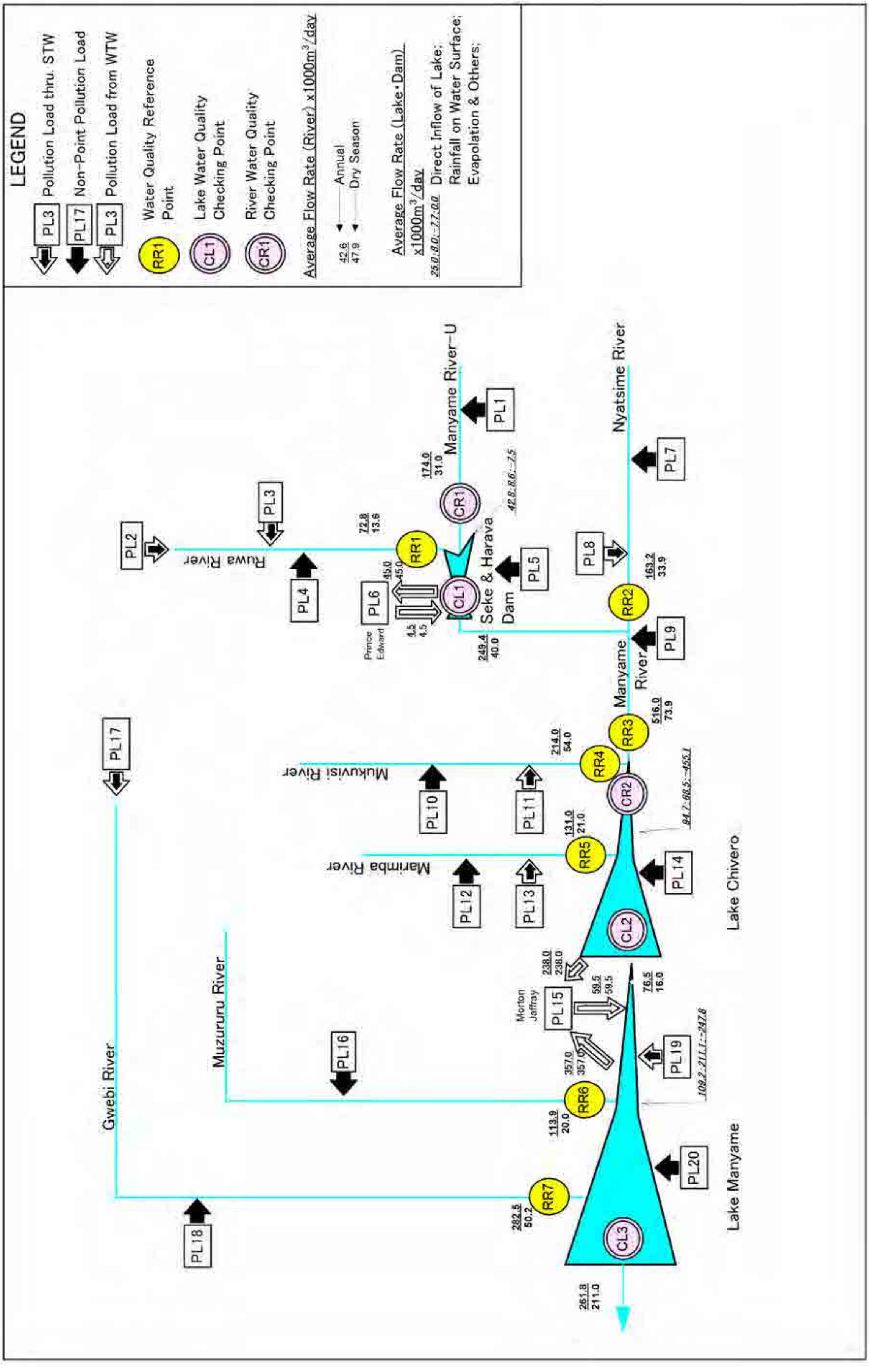


Figure 6.3.7 Flow Model for Present Water Pollution Analysis

Table 6.3.14 Reached Pollution Load by Sub-basin by Pollution Source (Present, BOD, Dry Season)

(kg/day)

Water Quality Checking Points		No.	Sub-basin	Dom./Com./Ins.Sewage			Industrial	Livestock	Natural Pollution	Water Treatment Works***	Total
				Sewered	Unsewered	Total	Unsewered**				
C_{R1}		1	Manyame R (Upstream)	-	15	15	—	10	36	-	61
	R_{R1}	2	Ruwa River	7,131	453	7,584	-	5	16	-	7,605
C_{L1}		3	Seke & Harava Dams	-	83	83	—	4	7	-	94
	R_{R2}	4	Nyatsime River	13,801	234	14,035	-	17	50	-	14,102
	R_{R4}	5	Mukuvisi River	58,288	32	58,320	155	1	15	-	58,491
C_{R2}	R_{R3}*	6	Manyame R. (Downstream)	3,305	168	3,473	-	3	11	2	3,488
	R_{R5}	7	Marimba River	35,117	3	35,120	-	1	20		35,141
C_{L2}		8	Lake Chivero	-	12	12	—	5	16	-	33
	R_{R6}	9	Muzururu River	-	16	16	—	20	20	-	56
	R_{R7}	10	Gwebi River	553	41	594	—	40	62	-	696
C_{L3}		11	Lake Manyame	2,633	25	2,658	28	9	38	219	2,952
			Grand Total	120,828	1,083	121,911	183	115	291	221	122,721

*: Before confluence of Mukuvisi River
**: Pollution load of industries in sewared area is counted as a part of domestic pollution load sewered area.
***: Pollution load of Water Treatment Works;

Prince Edward WTW;

Amount of water intake;	45,000 m^3/day		
BOD concentration of intake water;	1.2 mg/l	(Seke Dam, Av	20.63)
Concentrated BOD load;	1.9 kg/day	(to Manyame River (Downstream))	

Morton Jaffray WTW;

Water Quality from MJ WTW to Lake Manyame is assumed that pollution loads come from only Lake Chivero.
※According to "9-4-2Ff", Pollution Load reached to C_{L2} is 288 kg/day
And according to "9-5-4Ff", flow rate from Lake Chivero to MJ WTW is 238,000(76% of total flow rate).
Therefore pollution load of Water Treatment Works reach to Manayme river is 288 *0.76 = 218.88

		Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Dry Season (1000*m^3/d)	Conc. (mg/L)
C_{R1}	1	Manyame R (Upstream)	PL1	Non point Pollution Loading (Unsewered, Livestock)	25		
			PL1'	Non point Pollution Loading (Natural Pollution)	36		
			C_{R1}	C_{R1}' + NP_{CR1}	41	31.0	1.3
			C_{R1}'	PL1*0.2	5		
			NP_{CR1}	PL1'	36		
R_{R1}	2	Ruwa River	PL2	Pollution Loading through STP	4,440		
			PL3	Pollution Loading through STP	2,691		
			PL4	Non point Pollution Loading (Unsewered, Livestock)	458		
			PL4'	Non point Pollution Loading (Natural Pollution)	16		
			R_{R1}	R_{R1}' + NP_{RR1}	1,534	13.6	112.8
			R_{R1}'	(PL2 + PL3 + PL4)*0.2	1,518		
			NP_{RR1}	PL4'	16		
C_{L1} (C_{R1}+R_{R1}+α)	3	Seke & Harava Dams	PL5	Non point Pollution Loading (Unsewered, Livestock)	87		
			PL5'	Non point Pollution Loading (Natural Pollution)	7		
			C_{L1}	C_{L1}' + NP_{CR1}+ NP_{CL1}	67	40.0	1.7
			C_{L1}'	(C_{R1}'+R_{R1}'+PL5)*Self-Purification Coefficient	8		
			NP_{CL1}	NP_{CR1}+ NP_{RR1}+PL5'	59		
R_{R2}	4	Nyatsime River	PL7	Non point Pollution Loading (Unsewered, Livestock)	251		
			PL7'	Non point Pollution Loading (Natural Pollution)	50		
			PL8	Pollution Loading through STP	13,801		
			R_{R2}	R_{R2}' + NP_{RR2}	4,266	33.9	125.8
			R_{R2}'	(PL7 + PL8)*0.3	4,216		
			NP_{RR2}	PL7'	50		
R_{R4}	5	Mukuvisi River	PL10	Non point Pollution Loading (Unsewered, Livestock)	188		
			PL10'	Non point Pollution Loading (Natural Pollution)	15		
			PL11	Pollution Loading through STP	58,288		
			R_{R4}	R_{R4}' + NP_{RR4}	11,710	54.0	216.9
			R_{R4}'	(PL10 + PL11)*0.2	11,695		
			NP_{RR4}	PL10'	15		
R_{R3} (C_{L1}+R_{R2}+α)	6	Manyame R. (Downstream)	PL6	Pollution Loading from Prince Edward WTP	2		
			PL9	Non point Pollution Loading (Unsewered, Livestock)	3,476		
			PL9'	Non point Pollution Loading (Natural Pollution)	11		
			R_{R3}*	R_{R3}'*+ NP_{RR3}	3,202	73.9	43.3
			R_{R3}'*	(C_{L1}` + $R_{R2}$` + PL9) * 0.4	3,080		
			NP_{RR3}	NP_{CL1}+ NP_{RR2}+ PL6 + PL9'	122		

※Purification coefficient of rivers and lakes affects the pollution quantity of "Unsewere", "Livestock", “Pollution though STW”
※Purification coefficient of rivers and lakes doesn't affect the pollution quantity of "Natural Pollution"Figure

Figure 6.3.8 Reached Pollution Load by Sub-basin (Present, BOD, Dry Season) (1/2)

	No.	Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Dry Season (1000*m^3/d)	Conc. (mg/L)
C_{R2} (R_{R3}+R_{R4})			C_{R2}	C_{R2}' + NP_{CL2}	14,912	21.0	6.5
			C_{R2}'	R_{R3}'+R_{R4}'	14,775		
			NP_{CR2}	NP_{RR3}+ NP_{RR4}	137		
R_{R5}	7	Marimba River	PL12	Non point Pollution Loading (Unsewered, Livestock)	4		
			PL12'	Non point Pollution Loading (Natural Pollution)	20		
			PL13	Pollution Loading through STP	35,117		
			R_{R5}	R_{R5}' + PL13	14,068	21.0	669.9
			R_{R5}'*	PL12 + PL13	14,048		
			NP_{RR5}	PL12'	20		
C_{L2} (C_{R2}+R_{R5}+α)	8	Lake Chivero	PL14	Non point Pollution Loading (Unsewered, Livestock)	17		
			PL14'	Non point Pollution Loading (Natural Pollution)	16		
			C_{L2}	C_{L2}' + NP_{CL2}	70	16.0	4.4
			C_{L2}'	(C_{R2}'+R_{R5}'+PL14)*Self-Purification Coefficient*0.243	28		
			NP_{CL2}	NP_{CR2}+ NP_{RR5} + PL14' * 0.243	42		

※"0.243" is the ratio of volum to Lake Manyame River from Lake Chivero (Rest of volum heads to WTP).

	No.	Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Dry Season (1000*m^3/d)	Conc. (mg/L)
R_{R6}	9	Muzururu River	PL16	Non point Pollution Loading (Unsewered, Livestock)	36		
			PL16'	Non point Pollution Loading (Natural Pollution)	20		
			R_{R6}	R_{R6}' + NP_{RR6}	24	20.0	1.2
			R_{R6}'	PL16*0.1	4		
			NP_{RR6}	PL16'	20		
R_{R7}	10	Gwebi River	PL17	Pollution Loading through STP	553		
			PL18	Non point Pollution Loading (Unsewered, Livestock)	81		
			PL18'	Non point Pollution Loading (Natural Pollution)	62		
			R_{R7}	R_{R7}'+ NP_{RR7}	252	50.2	5.0
			R_{R7}'	(PL17 + PL18)*0.3	190		
			NP_{RR7}	PL18'	62		
C_{L3} (C_{L2}+R_{R6} +R_{R7}+α)	11	Lake Manyame	PL15	Pollution Loading from Morton JaffrayWTP	219		
			PL19	Pollution Loading through STP	2,633		
			PL20	Non point Pollution Loading (Unsewered, Livestock)	62		
			PL20'	Non point Pollution Loading (Natural Pollution)	38		
			C_{L3}	C_{L7}'+ NP_{RR7}	382	211.0	1.8
			C_{L3}'	(C_{L2}' + R_{R6}' + R_{R7}' + PL19 + PL20)*Self-Purification Coefficient	1		
			NP_{CL3}	NP_{CL2} + NP_{RR6} + NP_{RR7} + PL15 + PL20'	381		

※Purification coefficient of rivers and lakes affects the pollution quantity of "Unsewered", "Livestock", “Pollution though STW”
※Purification coefficient of rivers and lakes doesn't affect the pollution quantity of "Natural Pollution"Figure

Figure 6.3.8 Reached Pollution Load by Sub-basin (Present, BOD, Dry Season) (2/2)

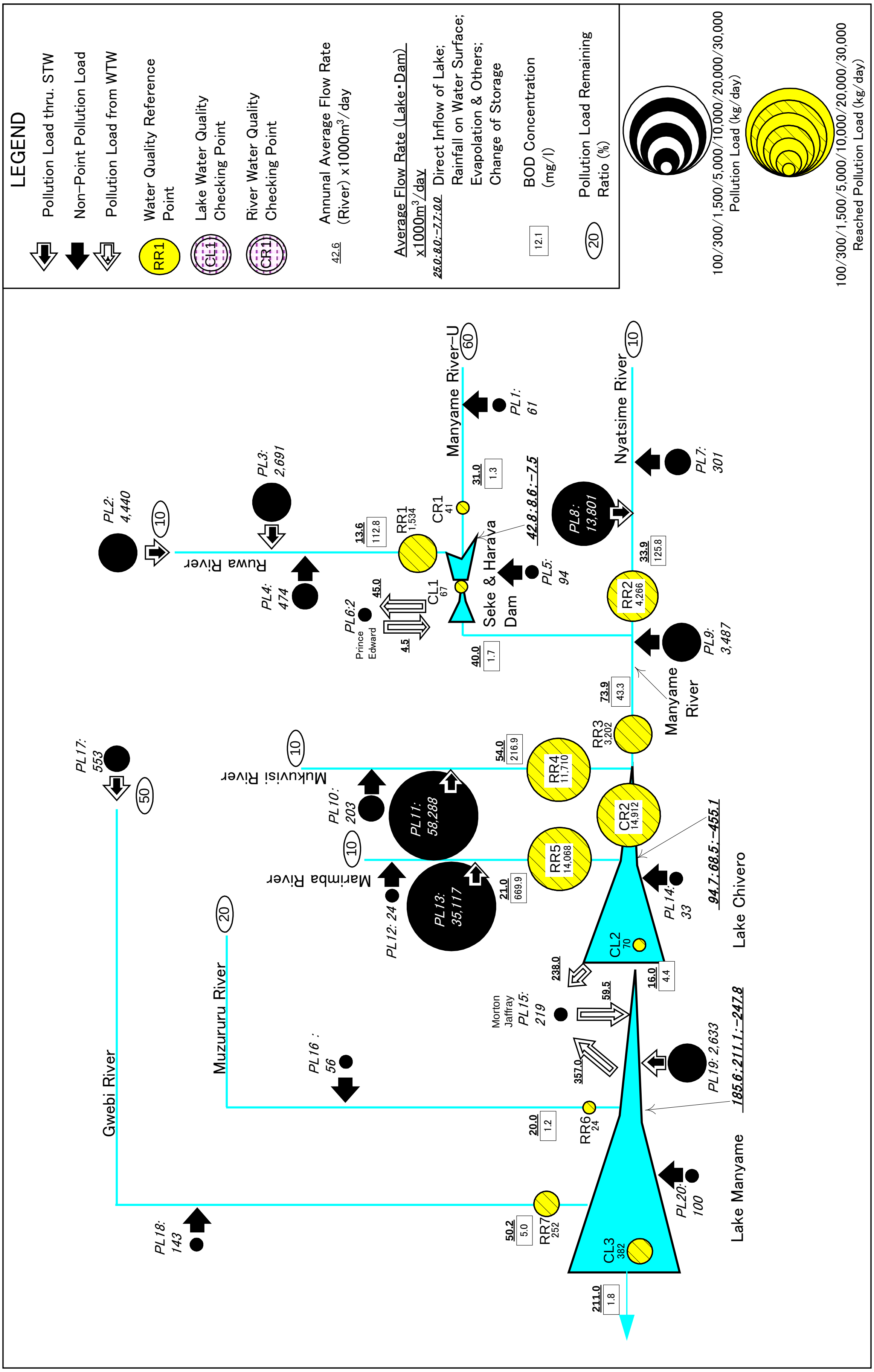


Figure 6.3.9 Pollution Load Run-off Model for Present Water Pollution Analysis (BOD, Dry Season)

Table 6.3.15 Reached Pollution Load by Sub-basin by Pollution Source (Present, COD, Annual)

(kg/day)

Water Quality Checking Points	Sub-basin	Domestic Sewage			Industrial	Livestock	Natural Pollution	Water Treatment Works***	Total
		Sewered	Unsewered	Total	Unsewered**				
C_{R1}	1 Manyame R (Upstream)	-	30	30	—	257	541	-	828
R_{R1}	2 Ruwa River	14,782	907	15,689	-	130	231	-	16,049
C_{L1}	3 Seke & Harava Dams	-	165	165	—	100	108	-	374
R_{R2}	4 Nyatsime River	27,899	468	28,367	-	411	735	-	29,513
R_{R4}	5 Mukuvisi River	125,039	64	125,103	385	35	217	-	125,740
C_{R2} R_{R3}*	6 Manyame R. (Downstream)	6,611	335	6,946	-	79	156	34	7,216
R_{R5}	7 Marimba River	73,529	6	73,535	-	33	297	-	73,865
C_{L2}	8 Lake Chivero	-	25	25	—	133	240	-	398
R_{R6}	9 Muzururu River	-	32	32	—	502	292	-	827
R_{R7}	10 Gwebi River	1,106	83	1,189	—	1,017	914	-	3,120
C_{L3}	11 Lake Manyame	5,344	50	5,394	88	214	556	2,131	8,382
Grand Total		254,310	2,166	256,476	473	2,911	4,288	2,165	266,313

*: Before confluence of Mukuvisi River

**: Pollution load of industries in sewared area is counted as a part of domestic pollution load sewered area.

***: Pollution load of Water Treatment Works;

Prince Edward WTW;

Amount of water intake;	45,000 m^3/day	
COD concentration of intake water;	20.63 mg/l	(Seke Dam)
Reaced COD load;	34 kg/day	(to Manyame River (Downstream))

Morton Jaffray WTW;

Water Quality from MJ WTW to Lake Manyame is assumed that pollution loads come from only Lake Chivero.

※According to "9-4-2Ff", Pollution Load reached to C_{L2} is 2,804 kg/day

And according to "9-5-4Ff", flow rate from Lake Chivero to MJ WTW is 238,000(76% of total flow rate).

Therefore pollution load of Water Treatment Works reach to Manayme river is 2,804 *0.76 = 2,131kg/day

		Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Annual (1000*m³/d)	Conc. (mg/L)
C_{R1}	1	Manyame R (Upstream)	PL1	Non point Pollution Loading (Unsewered, Livestock)	287		
			PL1'	Non point Pollution Loading (Natural Pollution)	541		
			C_{R1}	C_{R1}' + NP_{CR1}	598	174.0	3.4
			C_{R1}'	PL1*0.2	57		
			NP_{CR1}	PL1'	541		
R_{R1}	2	Ruwa River	PL2	Pollution Loading through STP	9,204		
			PL3	Pollution Loading through STP	5,578		
			PL4	Non point Pollution Loading (Unsewered, Livestock)	1,037		
			PL4'	Non point Pollution Loading (Natural Pollution)	231		
			R_{R1}	R_{R1}' + NP_{RR1}	3,395	72.8	46.6
			R_{R1}'	(PL2 + PL3 + PL4)*0.2	3,164		
			NP_{RR1}	PL4'	231		
C_{L1} (C_{R1}+R_{R1}+α)	3	Seke & Harava Dams	PL5	Non point Pollution Loading (Unsewered, Livestock)	265		
			PL5'	Non point Pollution Loading (Natural Pollution)	108		
			C_{L1}	C_{L1}' + NP_{CR1}+ NP_{CL1}	897	249.4	3.6
			C_{L1}'	(C_{R1}'+R_{R1}'+PL5)*Self-Purification Coefficient	17		
			NP_{CL1}	NP_{CR1}+ NP_{RR1}+PL5'	880		
R_{R2}	4	Nyatsime River	PL7	Non point Pollution Loading (Unsewered, Livestock)	879		
			PL7'	Non point Pollution Loading (Natural Pollution)	735		
			PL8	Pollution Loading through STP	27,899		
			R_{R2}	R_{R2}' + NP_{RR2}	9,369	163.2	57.4
			R_{R2}'	(PL7 + PL8)*0.3	8,633		
			NP_{RR2}	PL7'	735		
R_{R4}	5	Mukuvisi River	PL10	Non point Pollution Loading (Unsewered, Livestock)	485		
			PL10'	Non point Pollution Loading (Natural Pollution)	217		
			PL11	Pollution Loading through STP	125,039		
			R_{R4}	R_{R4}' + NP_{RR4}	25,322	214.0	118.3
			R_{R4}'	(PL10 + PL11)*0.2	25,105		
			NP_{RR4}	PL10'	217		
R_{R3} (C_{L1}+R_{R2}+α)	6	Manyame R. (Downstream)	PL6	Pollution Loading from Prince Edward WTP	34		
			PL9	Non point Pollution Loading (Unsewered, Livestock)	7,025		
			PL9'	Non point Pollution Loading (Natural Pollution)	156		
			R_{R3}*	R_{R3}'*+ NP_{RR3}	8,076	516.0	15.7
			R_{R3}'*	(C_{L1}` + $R_{R2}$` + PL9) * 0.4	6,270		
			NP_{RR3}	NP_{CL1}+ NP_{RR2}+ PL6 + PL9'	1,806		

※Purification coefficient of rivers and lakes affects the pollution quantity of "Unsewered", "Livestock", “Pollution though STW”
※Purification coefficient of rivers and lakes doesn't affect the pollution quantity of "Natural Pollution"Figure

Figure 6.3.10 Reached Pollution Load by Sub-basin (Present, COD, Annual) (1/2)

	No.	Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Annual ($1000*m^3/d$)	Conc. (mg/L)
C_{R2} ($R_{R3}+R_{R4}$)			C_{R2}	$C_{R2}' + NP_{CL2}$	33,398	730.0	45.8
			C_{R2}'	$R_{R3}'+R_{R4}'$	31,375		
			NP_{CR2}	$NP_{RR3}+ NP_{RR4}$	2,023		
R_{R5}	7	Marimba River	PL12	Non point Pollution Loading (Unsewered, Livestock)	39		
			PL12'	Non point Pollution Loading (Natural Pollution)	297		
			PL13	Pollution Loading through STP	73,529		
			R_{R5}	R_{R5}' + PL13	29,724	131.0	226.9
			R_{R5}'*	PL12 + PL13	29,427		
			NP_{RR5}	PL12'	297		
C_{L2} ($C_{R2}+R_{R5}+\alpha$)	8	Lake Chivero	PL14	Non point Pollution Loading (Unsewered, Livestock)	158		
			PL14'	Non point Pollution Loading (Natural Pollution)	240		
			C_{L2}	$C_{L2}' + NP_{CL2}$	681	76.5	8.9
			C_{L2}'	($C_{R2}'+R_{R5}'$+PL14)*Self-Purification Coefficient*0.243	59		
			NP_{CL2}	$NP_{CR2}+ NP_{RR5}$ + PL14' * 0.243	622		

※"0.243" is the ratio of volum to Lake Manyame River from Lake Chivero (Rest of volum heads to WTP).

	No.	Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Annual ($1000*m^3/d$)	Conc. (mg/L)
R_{R6}	9	Muzururu River	PL16	Non point Pollution Loading (Unsewered, Livestock)	534		
			PL16'	Non point Pollution Loading (Natural Pollution)	292		
			R_{R6}	$R_{R6}' + NP_{RR6}$	346	113.9	3.0
			R_{R6}'	PL16*0.1	53		
			NP_{RR6}	PL16'	292		
R_{R7}	10	Gwebi River	PL17	Pollution Loading through STP	1,106		
			PL18	Non point Pollution Loading (Unsewered, Livestock)	1,100		
			PL18'	Non point Pollution Loading (Natural Pollution)	914		
			R_{R7}	$R_{R7}'+ NP_{RR7}$	1,576	282.5	5.6
			R_{R7}'	(PL17 + PL18)*0.3	662		
			NP_{RR7}	PL18'	914		
C_{L3} ($C_{L2}+R_{R6}+R_{R7}+\alpha$)	11	Lake Manyame	PL15	Pollution Loading from Morton JaffrayWTP	2,131		
			PL19	Pollution Loading through STP	5,344		
			PL20	Non point Pollution Loading (Unsewered, Livestock)	351		
			PL20'	Non point Pollution Loading (Natural Pollution)	556		
			C_{L3}	$C_{L7}'+ NP_{RR7}$	4,518	261.8	17.3
			C_{L3}'	($C_{L2}' + R_{R6}' + R_{R7}'$ + PL19 + PL20)*Self-Purification Coefficient	3		
			NP_{CL3}	$NP_{CL2} + NP_{RR6} + NP_{RR7}$ + PL15 + PL20'	4,516		

※Purification coefficient of rivers and lakes affects the pollution quantity of "Unsewered", "Livestock", “Pollution though STW”
※Purification coefficient of rivers and lakes doesn't affect the pollution quantity of "Natural Pollution"Figure

Figure 6.3.10 Reached Pollution Load by Sub-basin (Present, COD, Annual) (2/2)

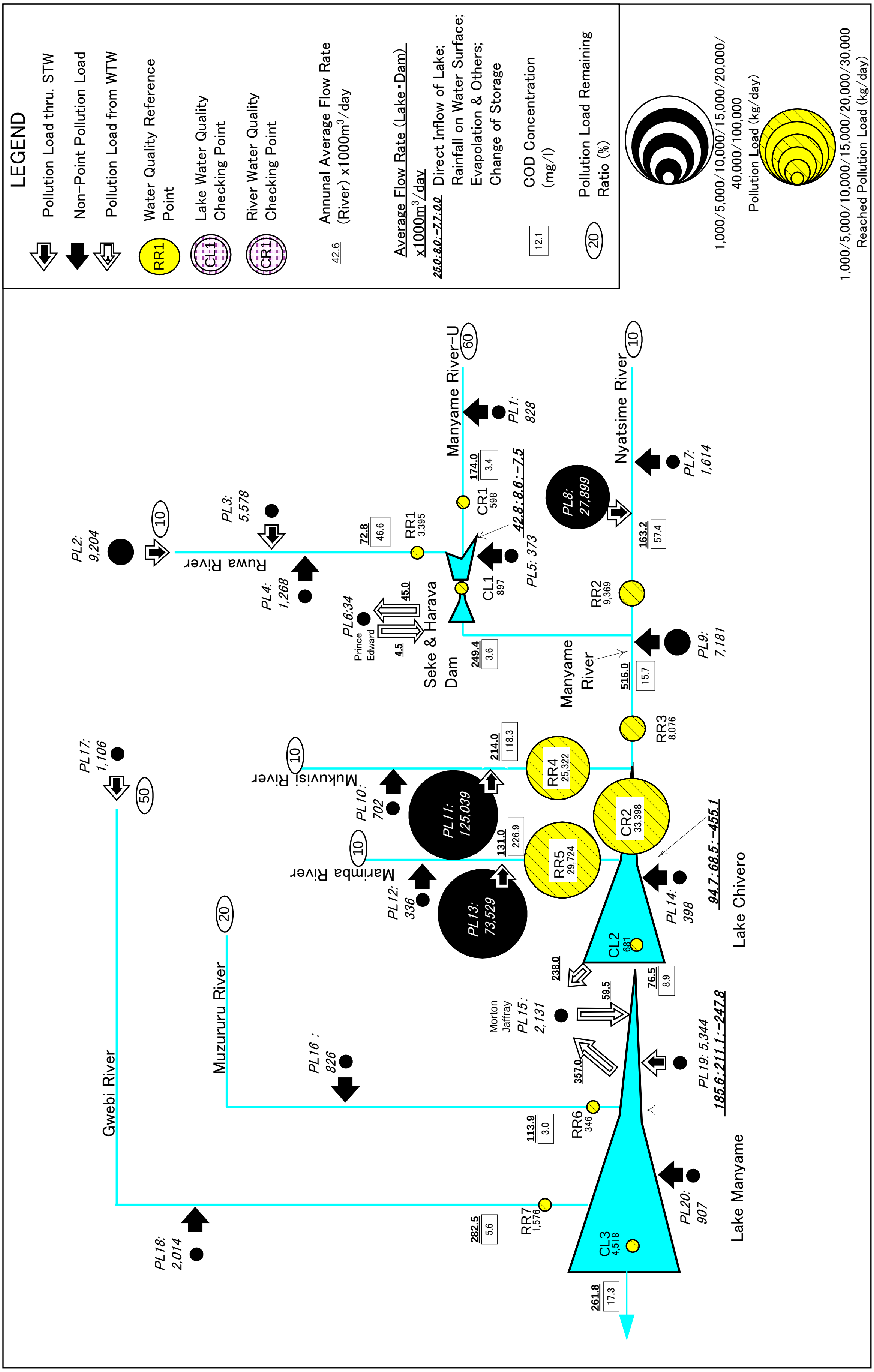


Figure 6.3.11 Pollution Load Run-off Model for Present Water Pollution Analysis (COD, Annual)

Table 6.3.16 Reached Pollution Load by Sub-basin by Pollution Source (Present, T-N, Annual)

(kg/day)

Water Quality Checking Points		Sub-basin	Domestic Sewage			Industrial	Livestock	Natural Pollution	Water Treatment Works***	Total
			Sewered	Unsewered	Total	Unsewered**				
C_{R1}		1 Manyame R (Upstream)	-	4	4	—	71	566	-	641
	R_{R1}	2 Ruwa River	1,765	113	1,878	-	35	242	-	2,155
C_{L1}		3 Seke & Harava Dams	-	21	21	—	29	113	-	163
	R_{R2}	4 Nyatsime River	3,297	59	3,356	-	119	769	-	4,244
	R_{R4}	5 Mukuvisi River	11,203	8	11,211	8	9	227	-	11,455
C_{R2}	R_{R3}*	6 Manyame R. (Downstream)	826	42	868	-	22	164	1	1,055
	R_{R5}	7 Marimba River	7,491	1	7,492	-	9	311	-	7,812
C_{L2}		8 Lake Chivero	-	3	3	—	37	251	-	291
	R_{R6}	9 Muzururu River	-	4	4	—	132	306	-	442
	R_{R7}	10 Gwebi River	144	10	154	—	264	956	-	1,374
C_{L3}		11 Lake Manyame	651	6	657	4	59	582	2,111	3,413
Grand Total			25,377	271	25,648	12	786	4,487	2,112	33,045

*: Before confluence of Mukuvisi River

**: Pollution load of industries in sewared area is counted as a part of domestic pollution load sewered area.

***: Pollution load of Water Treatment Works;

Prince Edward WTW;
Amount of water intake; 45,000 m^3/day
T-N concentration of intake water; 0.645 mg/l (Seke Dam)
Concentrated T-N load; 1 kg/day (to Manyame River (Downstream))

Morton Jaffray WTW;
Water Quality from MJ WTW to Lake Manyame is assumed that pollution loads come from only Lake Chivero.
※According to "9-4-2Ff", Pollution Load reached to C_{L2} is 2,778 kg/day
And according to "9-5-4Ff", flow rate from Lake Chivero to MJ WTW is 238,000(76% of total flow rate).
Therefore pollution load of Water Treatment Works reach to Manayme river is 2,778 *0.76 = 2,111kg/day

		Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Annual (1000*m^3/d)	Conc. (mg/L)
C_{R1}	1	Manyame R (Upstream)	PL1	Non point Pollution Loading (Unsewered, Livestock)	75		
			PL1'	Non point Pollution Loading (Natural Pollution)	566		
			C_{R1}	C_{R1}' + NP_{CR1}	581	174.0	3.3
			C_{R1}'	PL1*0.2	15		
			NP_{CR1}	PL1'	566		
R_{R1}	2	Ruwa River	PL2	Pollution Loading through STP	1,099		
			PL3	Pollution Loading through STP	666		
			PL4	Non point Pollution Loading (Unsewered, Livestock)	148		
			PL4'	Non point Pollution Loading (Natural Pollution)	242		
			R_{R1}	R_{R1}' + NP_{RR1}	625	72.8	8.6
			R_{R1}'	(PL2 + PL3 + PL4)*0.2	383		
			NP_{RR1}	PL4'	242		
C_{L1} (C_{R1}+R_{R1}+α)	3	Seke & Harava Dams	PL5	Non point Pollution Loading (Unsewered, Livestock)	50		
			PL5'	Non point Pollution Loading (Natural Pollution)	113		
			C_{L1}	C_{L1}' + NP_{CR1}+ NP_{CL1}	1,025	249.4	4.1
			C_{L1}'	(C_{R1}'+R_{R1}'+PL5)*Self-Purification Coefficient	104		
			NP_{CL1}	NP_{CR1}+ NP_{RR1}+PL5'	921		
R_{R2}	4	Nyatsime River	PL7	Non point Pollution Loading (Unsewered, Livestock)	178		
			PL7'	Non point Pollution Loading (Natural Pollution)	769		
			PL8	Pollution Loading through STP	3,297		
			R_{R2}	R_{R2}' + NP_{RR2}	1,811	163.2	11.1
			R_{R2}'	(PL7 + PL8)*0.3	1,042		
			NP_{RR2}	PL7'	769		
R_{R4}	5	Mukuvisi River	PL10	Non point Pollution Loading (Unsewered, Livestock)	25		
			PL10'	Non point Pollution Loading (Natural Pollution)	227		
			PL11	Pollution Loading through STP	11,203		
			R_{R4}	R_{R4}' + NP_{RR4}	2,473	214.0	11.6
			R_{R4}'	(PL10 + PL11)*0.2	2,246		
			NP_{RR4}	PL10'	227		
R_{R3} (C_{L1}+R_{R2}+α)	6	Manyame R. (Downstream)	PL6	Pollution Loading from Prince Edward WTP	1		
			PL9	Non point Pollution Loading (Unsewered, Livestock)	890		
			PL9'	Non point Pollution Loading (Natural Pollution)	164		
			R_{R3}*	R_{R3}'*+ NP_{RR3}	2,670	516.0	5.2
			R_{R3}'*	(C_{L1}` + $R_{R2}$` + PL9) * 0.4	815		
			NP_{RR3}	NP_{CL1}+ NP_{RR2}+ PL6 + PL9'	1,855		

※Purification coefficient of rivers and lakes affects the pollution quantity of "Unsewered", "Livestock", “Pollution though STW”
※Purification coefficient of rivers and lakes doesn't affect the pollution quantity of "Natural Pollution"Figure

Figure 6.3.12 Reached Pollution Load by Sub-basin (Present, T-N, Annual) (1/2)

	No.	Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Annual ($1000*m^3/d$)	Conc. (mg/L)
C_{R2} ($R_{R3}+R_{R4}$)			C_{R2}	$C_{R2}' + NP_{CL2}$	5,142	730.0	7.0
			C_{R2}'	$R_{R3}'+R_{R4}'$	3,060		
			NP_{CR2}	$NP_{RR3}+NP_{RR4}$	2,082		
R_{R5}	7	Marimba River	PL12	Non point Pollution Loading (Unsewered, Livestock)	10		
			PL12'	Non point Pollution Loading (Natural Pollution)	311		
			PL13	Pollution Loading through STP	7,491		
			R_{R5}	R_{R5}' + PL13	3,311	131.0	25.3
			R_{R5}'*	PL12 + PL13	3,000		
			NP_{RR5}	PL12'	311		
C_{L2} ($C_{R2}+R_{R5}+\alpha$)	8	Lake Chivero	PL14	Non point Pollution Loading (Unsewered, Livestock)	40		
			PL14'	Non point Pollution Loading (Natural Pollution)	251		
			C_{L2}	$C_{L2}' + NP_{CL2}$	675	76.5	8.8
			C_{L2}'	($C_{R2}'+R_{R5}'$+PL14)*Self-Purification Coefficient*0.243	33		
			NP_{CL2}	$NP_{CR2}+NP_{RR5}$ + PL14' * 0.243	642		

※"0.243" is the ratio of volum to Lake Manyame River from Lake Chivero (Rest of volum heads to WTP).

	No.	Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Annual ($1000*m^3/d$)	Conc. (mg/L)
R_{R6}	9	Muzururu River	PL16	Non point Pollution Loading (Unsewered, Livestock)	136		
			PL16'	Non point Pollution Loading (Natural Pollution)	306		
			R_{R6}	$R_{R6}' + NP_{RR6}$	320	113.9	2.8
			R_{R6}'	PL16*0.1	14		
			NP_{RR6}	PL16'	306		
R_{R7}	10	Gwebi River	PL17	Pollution Loading through STP	144		
			PL18	Non point Pollution Loading (Unsewered, Livestock)	274		
			PL18'	Non point Pollution Loading (Natural Pollution)	956		
			R_{R7}	$R_{R7}'+NP_{RR7}$	1,082	282.5	3.8
			R_{R7}'	(PL17 + PL18)*0.3	126		
			NP_{RR7}	PL18'	956		
C_{L3} ($C_{L2}+R_{R6}$ $+R_{R7}+\alpha$)	11	Lake Manyame	PL15	Pollution Loading from Morton JaffrayWTP	2,111		
			PL19	Pollution Loading through STP	651		
			PL20	Non point Pollution Loading (Unsewered, Livestock)	69		
			PL20'	Non point Pollution Loading (Natural Pollution)	582		
			C_{L3}	$C_{L7}'+NP_{RR7}$	4,618	261.8	17.6
			C_{L3}'	($C_{L2}' + R_{R6}' + R_{R7}'$ + PL19 + PL20)*Self-Purification Coefficient	20		
			NP_{CL3}	$NP_{CL2} + NP_{RR6} + NP_{RR7}$ + PL15 + PL20'	4,598		

※Purification coefficient of rivers and lakes affects the pollution quantity of "Unsewered", "Livestock", “Pollution though STW”
※Purification coefficient of rivers and lakes doesn't affect the pollution quantity of "Natural Pollution"Figure

Figure 6.3.12 Reached Pollution Load by Sub-basin (Present, T-N, Annual) (2/2)

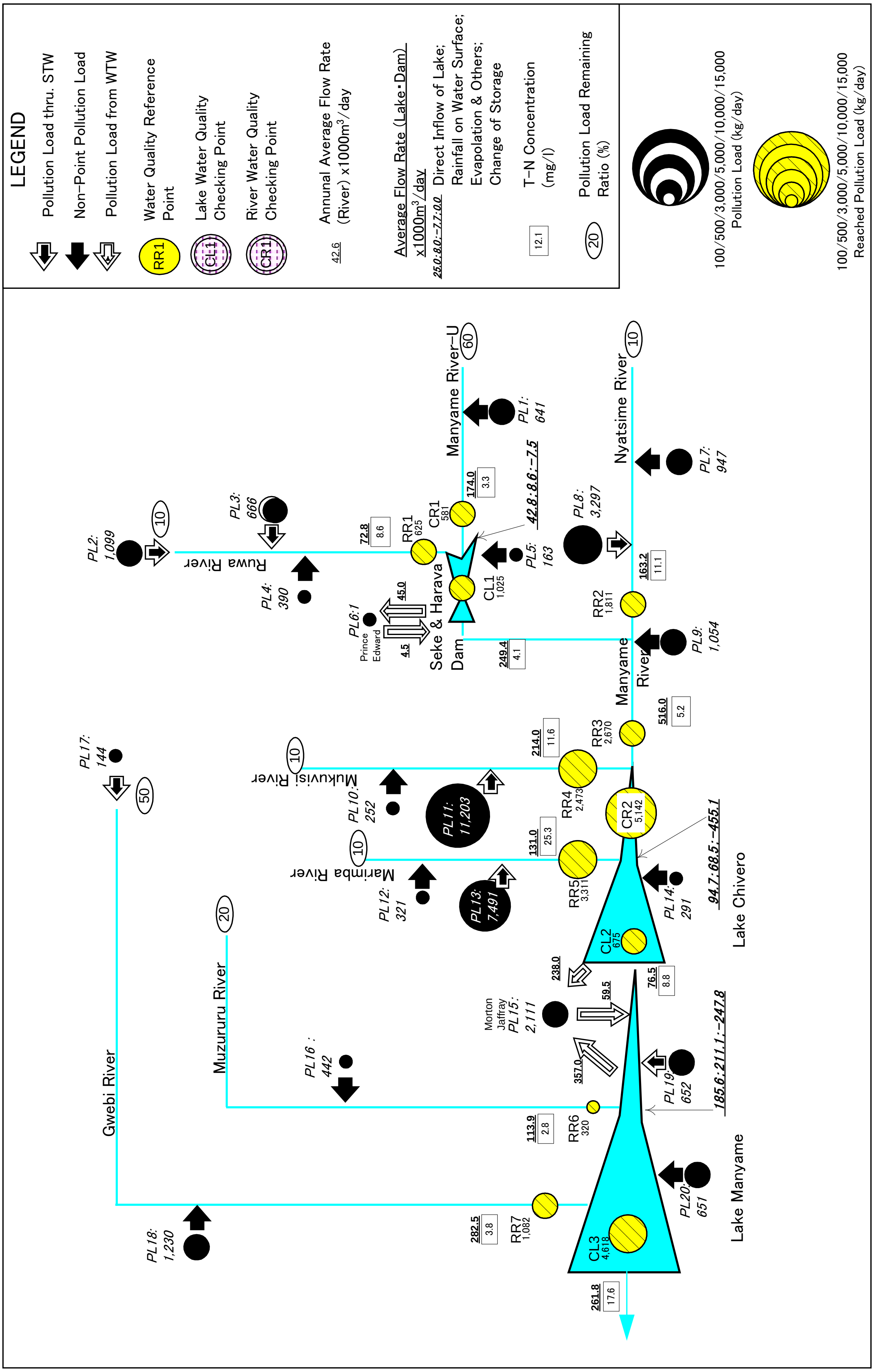


Figure 6.3.13 Pollution Load Run-off Model for Present Water Pollution Analysis (T-N, Annual)

Table 6.3.17 Reached Pollution Load by Sub-basin by Pollution Source (Present, T-P, Annual)

(kg/day)

Water Quality Checking Points	Sub-basin	Domestic Sewage			Industrial	Livestock	Natural Pollution	Water Treatment Works***	Total
		Sewered	Unsewered	Total	Unsewered**				
C_{R1}	1 Manyame R (Upstream)	-	0.4	0.4	—	11	47	-	58
R_{R1}	2 Ruwa River	192	12	204	-	6	20	-	230
C_{L1}	3 Seke & Harava Dams	-	2	2	—	4	9	-	15
R_{R2}	4 Nyatsime River	366	6	372	-	19	64	-	455
R_{R4}	5 Mukuvisi River	1,346	1	1,347	2	1	19	-	1,369
C_{R2} R_{R3}*	6 Manyame R. (Downstream)	90	5	95	-	3	14	-	112
R_{R5}	7 Marimba River	866	0.1	866	-	1	26	-	893
C_{L2}	8 Lake Chivero	-	0.3	0.3	—	6	21	-	27
R_{R6}	9 Muzururu River	-	0.4	0.4	—	23	25	-	48
R_{R7}	10 Gwebi River	15	1	16	—	47	80	-	143
C_{L3}	11 Lake Manyame	71	1	72	1	9	48	172	301
Grand Total		2,946	30	2,976	3	130	373	172	3,653

*: Before confluence of Mukuvisi River

**: Pollution load of industries in sewared area is counted as a part of domestic pollution load sewered area.

***: Pollution load of Water Treatment Works;

Prince Edward WTW;
- Amount of water intake; 45,000 m^3/day
- T-P concentration of intake water; 0.070 mg/l (Seke Dam)
- Concentrated T-P load; 0 kg/day (to Manyame River (Downstream))

Morton Jaffray WTW;
Water Quality from MJ WTW to Lake Manyame is assumed that pollution loads come from only Lake Chivero.
※According to "9-4-2Ff", Pollution Load reached to C_{L2} is 226 kg/day
And according to "9-5-4Ff", flow rate from Lake Chivero to MJ WTW is 238,000(76% of total flow rate).
Therefore pollution load of Water Treatment Works reach to Manayme river is 226 *0.76 = 172kg/day

		Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Annual ($1000*m^3/d$)	Conc. (mg/L)
C_{R1}	1	Manyame R (Upstream)	PL1	Non point Pollution Loading (Unsewered, Livestock)	11		
			PL1'	Non point Pollution Loading (Natural Pollution)	47		
			C_{R1}	$C_{R1}' + NP_{CR1}$	49	174.0	0.3
			C_{R1}'	PL1*0.2	2		
			NP_{CR1}	PL1'	47		
R_{R1}	2	Ruwa River	PL2	Pollution Loading through STP	120		
			PL3	Pollution Loading through STP	72		
			PL4	Non point Pollution Loading (Unsewered, Livestock)	18		
			PL4'	Non point Pollution Loading (Natural Pollution)	20		
			R_{R1}	$R_{R1}' + NP_{RR1}$	62	72.8	0.9
			R_{R1}'	(PL2 + PL3 + PL4)*0.2	42		
			NP_{RR1}	PL4'	20		
C_{L1} ($C_{R1}+R_{R1}+\alpha$)	3	Seke & Harava Dams	PL5	Non point Pollution Loading (Unsewered, Livestock)	6		
			PL5'	Non point Pollution Loading (Natural Pollution)	9		
			C_{L1}	$C_{L1}' + NP_{CR1} + NP_{CL1}$	83	249.4	0.3
			C_{L1}'	($C_{R1}'+R_{R1}'$+PL5)*Self-Purification Coefficient	7		
			NP_{CL1}	$NP_{CR1} + NP_{RR1}$+PL5'	76		
R_{R2}	4	Nyatsime River	PL7	Non point Pollution Loading (Unsewered, Livestock)	25		
			PL7'	Non point Pollution Loading (Natural Pollution)	64		
			PL8	Pollution Loading through STP	366		
			R_{R2}	$R_{R2}' + NP_{RR2}$	181	163.2	1.1
			R_{R2}'	(PL7 + PL8)*0.3	117		
			NP_{RR2}	PL7'	64		
R_{R4}	5	Mukuvisi River	PL10	Non point Pollution Loading (Unsewered, Livestock)	4		
			PL10'	Non point Pollution Loading (Natural Pollution)	19		
			PL11	Pollution Loading through STP	1,346		
			R_{R4}	$R_{R4}' + NP_{RR4}$	289	214.0	1.4
			R_{R4}'	(PL10 + PL11)*0.2	270		
			NP_{RR4}	PL10'	19		
R_{R3} ($C_{L1}+R_{R2}+\alpha$)	6	Manyame R. (Downstream)	PL6	Pollution Loading from Prince Edward WTP	0		
			PL9	Non point Pollution Loading (Unsewered, Livestock)	98		
			PL9'	Non point Pollution Loading (Natural Pollution)	14		
			R_{R3}*	$R_{R3}'* + NP_{RR3}$	243	516.0	0.5
			R_{R3}'*	(C_{L1}` + $R_{R2}$` + PL9) * 0.4	89		
			NP_{RR3}	$NP_{CL1} + NP_{RR2}$+ PL6 + PL9'	154		

※Purification coefficient of rivers and lakes affects the pollution quantity of "Unsewered", "Livestock", “Pollution though STW”
※Purification coefficient of rivers and lakes doesn't affect the pollution quantity of "Natural Pollution"Figure

Figure 6.3.14 Reached Pollution Load by Sub-basin (Present, T-P, Annual) (1/2)

	No.	Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Annual ($1000*m^3/d$)	Conc. (mg/L)
C_{R2} ($R_{R3}+R_{R4}$)			C_{R2}	$C_{R2}' + NP_{CL2}$	532	730.0	0.7
			C_{R2}'	$R_{R3}'+R_{R4}'$	359		
			NP_{CR2}	$NP_{RR3}+NP_{RR4}$	173		
R_{R5}	7	Marimba River	PL12	Non point Pollution Loading (Unsewered, Livestock)	1		
			PL12'	Non point Pollution Loading (Natural Pollution)	26		
			PL13	Pollution Loading through STP	866		
			R_{R5}	R_{R5}' + PL13	373	131.0	2.8
			R_{R5}'*	PL12 + PL13	347		
			NP_{RR5}	PL12'	26		
C_{L2} ($C_{R2}+R_{R5}+\alpha$)	8	Lake Chivero	PL14	Non point Pollution Loading (Unsewered, Livestock)	6		
			PL14'	Non point Pollution Loading (Natural Pollution)	21		
			C_{L2}	$C_{L2}' + NP_{CL2}$	55	76.5	0.7
			C_{L2}'	($C_{R2}'+R_{R5}'$+PL14)*Self-Purification Coefficient*0.243	1		
			NP_{CL2}	$NP_{CR2}+NP_{RR5}$ + PL14' * 0.243	53		

※"0.243" is the ratio of volum to Lake Manyame River from Lake Chivero (Rest of volum heads to WTP).

	No.	Sub-basin	PL No.	Type of Loading	Quantity (kg/day)	FR, Annual ($1000*m^3/d$)	Conc. (mg/L)
R_{R6}	9	Muzururu River	PL16	Non point Pollution Loading (Unsewered, Livestock)	23		
			PL16'	Non point Pollution Loading (Natural Pollution)	25		
			R_{R6}	$R_{R6}' + NP_{RR6}$	27	113.9	0.2
			R_{R6}'	PL16*0.1	2		
			NP_{RR6}	PL16'	25		
R_{R7}	10	Gwebi River	PL17	Pollution Loading through STP	15		
			PL18	Non point Pollution Loading (Unsewered, Livestock)	48		
			PL18'	Non point Pollution Loading (Natural Pollution)	80		
			R_{R7}	$R_{R7}'+NP_{RR7}$	99	282.5	0.4
			R_{R7}'	(PL17 + PL18)*0.3	19		
			NP_{RR7}	PL18'	80		
C_{L3} ($C_{L2}+R_{R6}$ $+R_{R7}+\alpha$)	11	Lake Manyame	PL15	Pollution Loading from Morton JaffrayWTP	172		
			PL19	Pollution Loading through STP	71		
			PL20	Non point Pollution Loading (Unsewered, Livestock)	10		
			PL20'	Non point Pollution Loading (Natural Pollution)	48		
			C_{L3}	$C_{L3}'+NP_{RR7}$	380	261.8	1.5
			C_{L3}'	($C_{L2}' + R_{R6}' + R_{R7}'$ + PL19 + PL20)*Self-Purification Coefficient	1		
			NP_{CL3}	$NP_{CL2} + NP_{RR6} + NP_{RR7}$ + PL15 + PL20'	378		

※Purification coefficient of rivers and lakes affects the pollution quantity of "Unsewered", "Livestock", "Pollution though STW"
※Purification coefficient of rivers and lakes doesn't affect the pollution quantity of "Natural Pollution"Figure

Figure 6.3.14 Reached Pollution Load by Sub-basin (Present, T-P, Annual) (2/2)

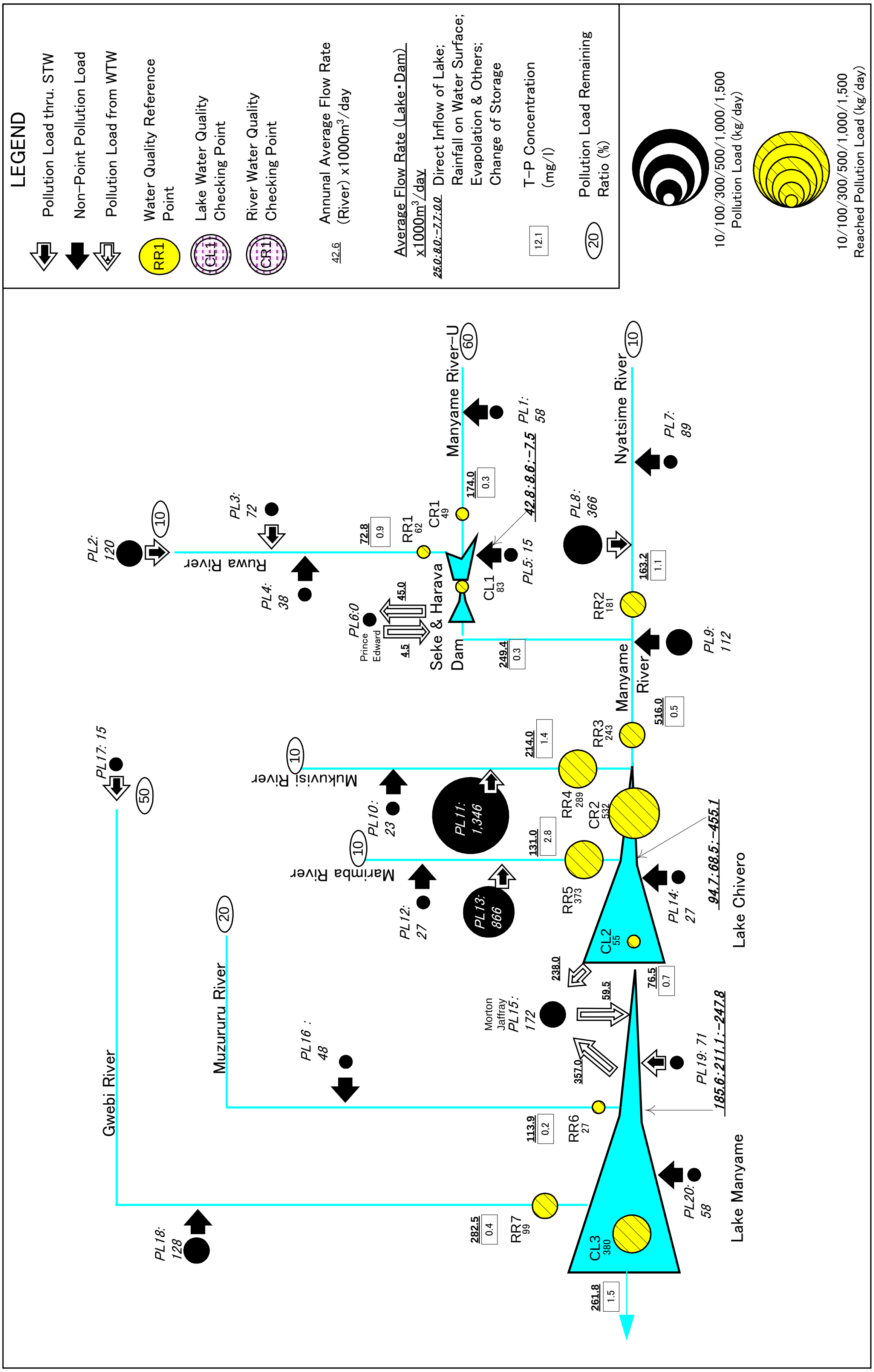


Figure 6.3.15 Pollution Load Run-off Model for Present Water Pollution Analysis (T-P, Annual)

6.3.5 Current Water Pollution Analysis

(1) General

In the pollution analysis of the rivers, the pollution load ratios of the respective rivers were identified in terms of BODs under the dry season conditions. These ratios were adopted for future pollution analysis. In the pollution analysis of lakes, self-purification coefficients of the respective lakes were sampled for T-N, T-P and COD under the annual average conditions. These coefficients were also adopted for future pollution analysis.

(2) Rivers

The self-purification coefficient of the river is usually computed to express the self-purification capacity of rivers with reference to the pollution load discharge location. However, sufficient data on time of flow, flow rate and water quality for each sub-section of the rivers are essential for the analysis. Because of the lack of these data in the study area and the limited period for the study, the pollutant load remaining ratios of each river section were roughly computed.

The pollution load remaining ratios of the respective rivers were computed using a pollution load run-off model as presented in Table 6.3.18. Muzururu River shows comparatively high self-purification capacity, i.e. six percent of pollution load remaining ratios, while Manyame River (downstream) and Marimba River show rather low self-purification capacity, i.e. 36% and 32%, respectively.

These remaining ratios imply not only the self-purification capacity of the river, but also an adjustment factor on assumptions of concentration ratios and generated pollution loads. The application of pollution load remaining ratios to future pollution analysis was modified as presented in Table 6.3.18.

Table 6.3.18 Pollution Load Remaining Ratio of River

River	Calculated PLRR	Applied
Manyame River (Upstream)	18.6%	20%
Ruwa River	17.5%	20%
Nyatsime River	29.2%	30%
Mukuvisi River	18.6%	20%
Manyame River (Downstream)	35.9%	40%
Marimba River	31.6%	40%
Muzururu River	6.0%	10%
Gwebi River	21.7%	30%

Source: JICA Project Team

(3) Lakes/dams

Based on the pollution load run off models presented in Figures 6.3.10 to 6.3.15, self-purification coefficients of the lakes for each pollutant were computed as presented in Tables 6.3.21 to 6.3.17. Calculation results are summarised in Table 6.3.19. These values were adopted for future pollution analysis of the lakes.

Table 6.3.19 Self-purification Coefficients of Lakes

Coefficients*	Seke & Harava Dams	Lake Chivero	Lake Manyame
σN	0.23301	0.02197	0.02231
σP	0.14719	0.00808	0.01420
σCOD	0.00492	0.004	0.00039
α (N)	138.8%	167.9%	202.1%

*Self-Purification coefficients in following formula (refer Table 8.3.25 to 8.3.27)

$N = L(N) / ((\rho w + \sigma N) \times V)$

$P = L(P) / ((\rho w + \sigma P) \times V)$

$COD = L(COD) / ((\rho w + \sigma COD) \times V) + \Delta COD$

$\Delta COD = \alpha(N) \times T\text{-}N \times 17.73$

Source: JICA Project Team

Table 6.3.20 Pollution Load Remaining Ratio of the Rivers (Present, BOD, Dry Season)

Water Quality Checking Points		Sub-basin	Run-off BOD Load at Upstream(kg/day)	Reached BOD Load in Sub-basin (kg/day)	Total BOD Load (kg/day)	BOD Concentration at Downstream (mg/l)	Flow Rate at Downstream (m^3/day)	Run-off BOD Load at Downstream (kg/day)	Pollution Load Remaining Ratio (%)
C_{R1}		1 Manyame R (Upstream)	0	183	183	1.1	31,000	34	18.6%
	R_{R1}	2 Ruwa River	0	297	297	3.8	13,600	52	17.5%
C_{L1}		3 Seke & Harava Dams	86	77	163	1.6	40,000	64	—
	R_{R2}	4 Nyatsime River	0	243	243	2.1	33,900	71	29.2%
	R_{R4}	5 Mukuvisi River	0	581	581	2.0	54,000	108	18.6%
C_{R2}	R_{R3}*	6 Manyame R. (Downstream)	135	71	206	1.0	73,900	74	35.9%
	R_{R5}	7 Marimba River	0	580	580	8.7	21,000	183	31.6%
C_{L2}		8 Lake Chivero	365	968	1,333	2.4	16,000	38	—
	R_{R6}	9 Muzururu River	0	167	167	0.5	20,000	10	6.0%
	R_{R7}	10 Gwebi River	0	369	369	1.6	50,200	80	21.7%
C_{L3}		11 Lake Manyame	129	1,146	1,275	2.0	211,000	414	—

Note: 1. Before confluence of Mukuvisi River

2. Run-off BOD load at upstream for the Manyame River (downstream) is the pollution load from Prince Edward WTW.

3. Total BOD load of Manyame River (downstream) includes Run-off load from Nyatsime River.

Table 6.3.21 Water Pollution Analysis of the Lakes (Seke and Harava Dams)

Volume of Dams:		12,406,000		m^3
Inflow Water Volume:		290,661		m^3/day
Rivers;	Manyame;		174,000	m^3/day
	Ruwa;		72,846	m^3/day
Direct inflow;			42,750	m^3/day
Rainfall;			8,598	m^3/day
Evaporation & Others;			-7,533	m^3/day
Outflow Water Volume;		290,661		m^3/day
Manyame River;			245,661	m^3/day
Prince Edward WTW;			45,000	m^3/day
Detention Time of Dam Lake		43		days

Pollution Load Inflow: (kg/day)

	T-N	T-P	COD
Manyame(U/S)	581	49	598
Ruwa	625	62	3,395
Direct	163	15	374
Total	1,368	127	4,367

Present Water Quality: (mg/l)

T-N	T-P	COD	Min.COD (soluble COD)	
0.430	0.060	23.00	12.42	factor 0.54

Formula for Pollution Analysis: (Vollenweider Model)

$N = L(N) / ((\gamma w + \sigma N) \times V)$

$P = L(P) / ((\gamma w + \sigma P) \times V)$

$COD = L(COD) / ((\gamma w + \sigma COD) \times V) + \Delta COD$

where;

N:	Concentration of Nitrogen of Lake (g/m^3)	=	0.430
P:	Concentration of Phosphorus of Lake (g/m^3)	=	0.060
COD:	Concentration of COD of Lake (g/m^3)	=	23.00
L(N):	Quantity of inflow Nitrogen to Lake (g/day)	=	1,368,000
L(P):	Quantity of inflow Phosphorus to Lake (g/day)	=	127,000
L(COD):	Quantity of inflow COD to Lake (g/day)	=	4,367,000
γw:	Rate of change of water (l/day)	=	0.023429
σ N:	Self-purification (reduction) coefficient for Nitrogen		
σ P:	Self-purification (reduction) coefficient for Phosphorus		
σ COD:	Self-purification (reduction) coefficient for inflow COD		
V:	Volume of lake (m^3)	=	12,406,000
Δ COD:	Secondary produced COD (Calculated as below)	=	10.58

Computation of Self-purification Coefficients:

$\sigma N = L(N) / (N \times V) - \gamma w =$ 0.23301

$\sigma P = L(P) / (P \times V) - \gamma w =$ 0.14719

$\sigma COD = L(COD) / ((COD - \Delta COD) \times V) - \gamma w =$ 0.00492 (adopted Min. COD)

Computation of Conversion Rate for DCOD

$\Delta COD = \alpha(N) \times T\text{-}N \times 17.73$ or $\alpha(P) \times T\text{-}P \times 128.70$

where;

α (N):	Conversion rate of Nitrogen to Δ COD
17.73:	Theoretical COD (assumed to be 90% of TOD) quantity produced by phytoplankton from unit nitrogen quantity
α (P):	Conversion rate of Phosphorus to Δ COD
128.70:	Theoretical COD (assumed to be 90% of TOD) quantity produced by phytoplankton from unit nitrogen quantity
Δ COD:	Average COD - Minimum COD (COD without effect of phytoplankton)

$\alpha(N) = ((COD - Min.COD) / (T\text{-}N \times 17.73))$

= 138.8%

$\alpha(P) = ((COD - Min.COD) / (T\text{-}P \times 128.70))$

= 137.0%

N/P = 7.2 < 20 and P = 0.06 >0.02

Nitrogen is regarded to be the Restriction Factor for Secondary production of COD.

Conversion Rate of a(N) will be adopted for Future Pollution Analysis.

Table 6.3.22 Water Pollution Analysis of the Lakes (Lake Chivero)

Volume of Dams:		257,181,000		m^3
Inflow Water Volume:		569,158		m^3/day
Rivers;	Manyame;		516,000	m^3/day
	(Nyatsime;		163,200	m^3/day)
	(Prince Edward WTW;		4,500	m^3/day)
	Mukuvisi;		214,000	m^3/day
	Marimba;		131,000	m^3/day
Direct inflow;			94,690	m^3/day
Rainfall;			68,532	m^3/day
Evaporation & Others;			-455,064	m^3/day
Outflow Water Volume;		569,158		m^3/day
Lake Manyame;			76,500	m^3/day
Morton Jaffray WTW;			238,000	m^3/day
Water level Increase;			254,658	m^3/day
Detention Time of Dam Lak		452		days

Pollution Load Inflow: (kg/day)

	T-N	T-P	COD
Manyame(D/S)	767	78	6,008
Mukuvisi	2,473	289	25,322
Marimba	3,311	373	29,724
Direct	291	27	398
Total	6,842	768	61,451

Present Water Quality: (mg/l)

T-N	T-P	COD	Min.COD (soluble COD)
1.100	0.290	71.20	38.45

Formula for Pollution Analysis: (Vollenweider Model)

$N = L(N) / ((\gamma w + \sigma N) \times V)$

$P = L(P) / ((\gamma w + \sigma P) \times V)$

$COD = L(COD) / ((\gamma w + \sigma COD) \times V) + \Delta COD$

where;

N:	Concentration of Nitrogen of Lake (g/m^3)	=	1.100
P:	Concentration of Phosphorus of Lake (g/m^3)	=	0.290
COD:	Concentration of COD of Lake (g/m^3)	=	71.20
L(N):	Quantity of inflow Nitrogen to Lake (g/day)	=	6,842,000
L(P):	Quantity of inflow Phosphorus to Lake (g/day)	=	768,000
L(COD):	Quantity of inflow COD to Lake (g/day)	=	61,451,000
γw:	Rate of change of water (l/day)	=	0.002213
σ N:	Self-purification (reduction) coefficient for Nitrogen		
σ P:	Self-purification (reduction) coefficient for Phosphorus		
σ COD:	Self-purification (reduction) coefficient for inflow COD		
V:	Volume of lake (m^3)	=	257,181,000
Δ COD:	Secondary produced COD (Calculated as below)	=	32.75

Computation of Self-purification Coefficients:

$\sigma N = L(N) / (N \times V) - \gamma w =$ 0.02197

$\sigma P = L(P) / (P \times V) - \gamma w =$ 0.00808

$\sigma COD = L(COD) / ((COD - \Delta COD) \times V) - \gamma w =$ 0.00400 (adopted Min. COD)

Computation of Conversion Rate for DCOD

$\Delta COD = \alpha (N) \times T\text{-}N \times 17.73$ or $\alpha (P) \times T\text{-}P \times 128.70$

where;

α (N):	Conversion rate of Nitrogen to Δ COD
17.73:	Theoretical COD (assumed to be 90% of TOD) quantity produced by phytoplankton from unit nitrogen quantity
α (P):	Conversion rate of Phosphorus to Δ COD
128.70:	Theoretical COD (assumed to be 90% of TOD) quantity produced by phytoplankton from unit nitrogen quantity
Δ COD:	Average COD - Minimum COD (COD without effect of phytoplankton)

$\alpha (N) = ((COD - Min.COD) / (T\text{-}N \times 17.73))$

= 167.9%

$\alpha (P) = ((COD - Min.COD) / (T\text{-}P \times 128.70))$

= 87.8%

N/P = 3.8 < 20 and P = 0.29 >0.02

Nitrogen is regarded to be the Restriction Factor for Secondary production of COD.

Conversion Rate of a(N) will be adopted for Future Pollution Analysis.

Table 6.3.23 Water Pollution Analysis of the Lakes (Lake Manyame)

Volume of Dams:		480,236,000		m^3
Inflow Water Volume:		681,307		m^3/day
Rivers;	Lake Chivero;		76,500	m^3/day
	Muzururu;		113,900	m^3/day
	Gwebi;		282,540	m^3/day
Direct inflow;			185,640	m^3/day
Rainfall;			211,066	m^3/day
Evaporation & Others;			-247,839	m^3/day
Morton Jaffray WTW;			59,500	m^3/day
Outflow Water Volume;		681,307		m^3/day
Lake Manyame;			261,800	m^3/day
Morton Jaffray WTW;			357,000	m^3/day
Water level Increase;			62,507	m^3/day
Detention Time of Dam Lak		705		days

Pollution Load Inflow: (kg/day)

	T-N	T-P	COD
Lake Chivero	84	22	5,447
Morton Jaffray WTW	2,111	172	2,131
Muzururu	320	27	346
Gwebi	1,082	99	1,576
Direct	1,302	129	6,251
Total	4,899	450	15,751

Present Water Quality: (mg/l)

T-N	T-P	COD	Min.COD (soluble COD)	
0.430	0.060	33.50	18.09	Result of Harava used for convenience's sake

Formula for Pollution Analysis: (Vollenweider Model)

$N = L(N) / ((\gamma w + \sigma N) \times V)$

$P = L(P) / ((\gamma w + \sigma P) \times V)$

$COD = L(COD) / ((\gamma w + \sigma COD) \times V) + \Delta COD$

where;

N:	Concentration of Nitrogen of Lake (g/m^3)	=	0.430
P:	Concentration of Phosphorus of Lake (g/m^3)	=	0.060
COD:	Concentration of COD of Lake (g/m^3)	=	33.50
L(N):	Quantity of inflow Nitrogen to Lake (g/day)	=	4,899,000
L(P):	Quantity of inflow Phosphorus to Lake (g/day)	=	450,000
L(COD):	Quantity of inflow COD to Lake (g/day)	=	15,751,000
γw:	Rate of change of water (l/day)	=	0.001419
σ N:	Self-purification (reduction) coefficient for Nitrogen		
σ P:	Self-purification (reduction) coefficient for Phosphorus		
σ COD:	Self-purification (reduction) coefficient for inflow COD		
V:	Volume of lake (m^3)	=	480,236,000
Δ COD:	Secondary produced COD (Calculated as below)	=	15.41

Computation of Self-purification Coefficients:

$\sigma N = L(N) / (N \times V) - \gamma w =$ 0.02231

$\sigma P = L(P) / (P \times V) - \gamma w =$ 0.01420

$\sigma COD = L(COD) / ((COD - \Delta COD) \times V) - \gamma w =$ 0.00039 (adopted Min. COD)

Computation of Conversion Rate for DCOD

$\Delta COD = \alpha (N) \times T\text{-}N \times 17.73$ or $\alpha (P) \times T\text{-}P \times 128.70$

where;

α (N):	Conversion rate of Nitrogen to Δ COD
17.73:	Theoretical COD (assumed to be 90% of TOD) quantity produced by phytoplankton from unit nitrogen quantity
α (P):	Conversion rate of Phosphorus to Δ COD
128.70:	Theoretical COD (assumed to be 90% of TOD) quantity produced by phytoplankton from unit nitrogen quantity
Δ COD:	Average COD - Minimum COD (COD without effect of phytoplankton)

$\alpha (N) = ((COD - Min.COD) / (T\text{-}N \times 17.73))$

= 202.1%

$\alpha (P) = ((COD - Min.COD) / (T\text{-}P \times 128.70))$

= 199.6%

N/P = 7.2 < 20 and P = 0.06 >0.02

Nitrogen is regarded to be the Restriction Factor for Secondary production of COD.

Conversion Rate of a(N) will be adopted for Future Pollution Analysis.

6.3.6 Discussion and Conclusion

Result of the pollution analysis for the current status is summarised below:

(1) Generated pollution load

The biggest pollution loads in the catchment area are from Harare City, which is about 110,000kg-BOD/day. The reached pollution load to the Chivero Lake is assumed to be about 33,000 kg-BOD/day, reducing about 70% of the load in the river. Chitungwiza Municipality comes in second, discharging a pollution load about 13,000 kg-BOD/day. The reached pollution load to the Manyame river is assumed to be 3,900 kg BOD/day reducing about 70 % of the load in the river. While the reduction of the pollution load in the river is quite significant, the influence of these loads is still serious as evidenced by the continuing deterioration of water quality in the rivers and lakes as shown in (2).

Influence of non-point sources such as natural pollution and pollution from livestock is not significant compared with the load from the urban area.

(2) Status of river pollution

Other than the Upper-Manyame river, the entire aquatic environment is seriously polluted.

Upper-Manyame river:	Clean (1.3 mg BOD/l) with low pollution load
Ruwa river:	Polluted (113 mg BOD/l) with high pollution load from Ruwa
Downstream of Seke:	Clean (1.7 mg BOD/l)
Nyatsime river:	Heavily polluted (126 mg BOD/l) by Chitungwiza pollution load
Manyame river before Chivero:	Polluted (43 mg BOD/l) with high pollution load
Lake Chivero:	Polluted (4.4 mg BOD/l, 8.8 mg N/l, 0.7 mg P/l)
Lake Manyame:	Polluted (1.8 mg BOD/l, 17.6 mg N/l, 1.5 mg P/l)

Remarks: BOD was used for the Lakes for the simplicity, instead of COD

The rivers receive sewage from Harare and Chitungwiza and are seriously polluted with pollution loads coming from both urban and rural areas.

Eutrophication of the lakes is also serious as indicated by concentrations of N and P. One of the problems is the low flow rate of the rivers especially in the dry season when flow rate is one-third that of rainy season and dilution of nutrients does not work effectively.

(3) Purification capability of the lakes

The purification of the rivers and lakes of pollution loads is evaluated to be very effective in the improvement of water quality according to the model. Water quality of the intake for the water treatment plant is actually much better than the computed result. It shows the high performance of the lakes in the water treatment capability.

6.4 FUTURE WATER POLLUTION ANALYSIS

6.4.1 General

Future water pollution analysis was undertaken to predict water quality using a model made from the present water pollution analysis of the rivers and lakes using the same method with the study on the current status shown in the former section. Five scenarios were studied as follows:

Scenario 0 : Same condition with current condition as of 2012 (Zero option with no improvement) Scenario 1 : All the STPs operation under condition after the urgent improvement Scenario 2 : All the STPs operation with 3 STPs upgrading BNR (from TF or WSP to BNR) Scenario 3 : All the STPs operation with 100% irrigation Scenario 4 : No improvement for the ZSTP to confirm the influence of pollutant discharge from Chitungwiza Municipality

Analytic models cover both human and natural pollution loads generated for point and non-point sources. The flow model employs the same flow shown in the current analysis of the entire basin for future water pollution analysis. Population projection was conducted for 2020 and 2030 with 1.6% of population increase ratio in Chitungwiza and 1.4% of ratio in other areas after considering the current status and trends.

(1) In the scenario 0, no improvement was considered to predict the worst pollution status.
(2) Scenario 1 took urgent measures for Crowborough STP and Firle STP for Harare (Rehabilitation of BNR and Trickling Filters by Zim Fund), Zengeza STP for Chitungwiza (Rehabilitation of Trickling Filters by AWF project), and rehabilitation of Norton STP by some donor. The Ruwa STP was planned as existing in this case, which is waste stabilization pond (Table 6.4.2).
(3) Scenario 2 is planned to predict the effect of the employment of the BNR process for Firle STP, Crowborough STP and Zengeza STP (Table 6.4.3).
(4) Scenario 3 was planned to evaluate the effect of the irrigation by which the pollution loads can be completely transferred outside of the catchment (Table 6.4.4).
(5) Scenario 4 is excluding the improvement of only Chitungwiza Municipality to evaluate the scale of the effect of the pollutant discharge from the municipality (Table 6.4.5).

6.4.2 Planning Frame and Pollution Load by Sub-basin

(1) Domestic/Commercial institutional/ Sewage

The population project in the years 2020 and 2030 were distributed to sewered and unsewered areas as shown in Tables 6.4.6. Generated and discharged pollution loads were assumed by sewered/ unsewered area by applying unit pollution load of domestic sewage discussed in the sub-section 6.2.

The pollution load collected from the sewered area flows into the sewage treatment works. The discharged pollution load was calculated by using planned treatment efficiency. The calculation results are presented in Appendix 6.4 where treatment efficiencies of STPs were assumed from the future arrangements of sewerage systems as follows (Table 6.4.1).

Table 6.4.1 Treatment Efficiency by Treatment Method

Treatment Method	Treatment efficiency (Pollution Load Reducing Ratio)				Memo
	BOD_5	COD	T-N	T-P	
Biological Nutrient Removal	95%	90%	80%	75%	Irrigation 0%
Tricking Filter	90%	85%	30%	30%	Irrigation 100%
Wastewater Stabilization Pond	90%	85%	50%	30%	Irrigation 100%
Irrigation	100%	100%	100%	100%	

Source: JICA Project Team

Table 6.4.2 Comparison of Operation Status between Present and Future (Scenario 1)

Sub-basin	Sewage Treatment Works	2012							2020 and 2030						
		Eff. Flow (m^3/day)	Irrigation	Average Effluent Water Quality (mg/l)					Eff. Flow (m^3/day)	Irrigation	Average Effluent Water Quality (mg/l)				
		Annual	Reuse (%)	BOD	COD	T-N	P-P	T-P [a]	Annual	Reuse (%)	BOD	COD	T-N	P-P	T-P [a]
Marimba R.	Crowborough (TF)	16,800	29%	28.0	80.6	37.9	5.23	8.4	16,800	100%	98.1	282.0	37.9	5.23	8.4
do	Crowborough (BNR)	18,000	0%	18.9	91.3	9.3	1.54	2.7	18,000	0%	18.9	91.3	9.3	1.54	2.7
do	Crowborough Total	34,800							34,800						
L. Chivero	Firle Units 1&2 (TF)	30,000	68%	137.8	268.0	38.7	4.49	7.2	83,900	100% [c]	137.8	268.0	38.7	4.49	7.2
Mukuvisi R.	Firle Unit 3 (BNR)	18,000	0%	13.8	107.6	13.7	2.84	4.7	18,000	0%	13.8	107.6	13.7	2.84	4.7
do	Firle Unit 4 (BNR)	18,000	0%	18.2	94.7	13.0	2.23	3.7	18,000	0%	18.2	94.7	13.0	2.23	3.7
do	Firle Unit 5 (BNR)	72,000	0%	18.2	94.7	13.0	2.23	3.7	72,000	0%	18.2	94.7	13.0	2.23	3.7
do	Firle Total (Mukuvisi)	108,000							108,000						
Gwebi R.	Marlborough (WSP)[b]	2,000	100%	51.4	161.9	36.4	4.04	6.5	2,000	100%	51.4	161.9	36.4	4.04	6.5
Ruwa R.	Donnybrook-1 (WSP)[b]	400	100%	40.6	162.1	99.6	10.97	17.3	400	100%	40.6	162.1	99.6	10.97	17.3
do	Donnybrook-2 (WSP)[b]	1,400	100%	40.6	162.1	99.6	10.97	17.3	1,400	100%	40.6	162.1	99.6	10.97	17.3
do	Donnybrook-3 (WSP)[b]	1,400	100%	40.6	162.1	99.6	10.97	17.3	1,400	100%	40.6	162.1	99.6	10.97	17.3
do	Donnybrook-4 (WSP)[b]	2,400	100%	40.6	162.1	99.6	10.97	17.3	2,400	100%	40.6	162.1	99.6	10.97	17.3
do	Donnybrook Total [h]	5,600							5,600						
Nyatsime R.	Zengeza (TF)[b]	22,000	0%	800.0	1,600.0	54.0		16.6	22,000	100%	130.0	540.0	54.0		16.6
	Zengeza (TF)b								20,000	100%	60.0	120.0	37.8		16.6
L. Manyame	Norton (TF)	2,700	0%	520.0	1,191.9	65.8	7.60	12.0	2,700	100%	520.0	1,191.9	65.8	7.60	12.0
Ruwa R.	Ruwa (WSP)[b]	2,900	100%	123.0	278.0	6.1	2.38	4.0	2,900	100%	123.0	278.0	6.1	2.38	4.0
	Total	208,000							281,900						

Note:
a) T-P is calculated from P-P values using following correlation formula which is derived from measurement results by the Study Team.
T-P = P-P x 1.5482 + 0.2682 P-P; Phosphate Phosphorus
b) COD values of STPs with " b " are calculated from BOD values using following correlation formula which is derived from measurement results of other STPs with trickling filter method.
COD = BOD (annual average) x 2.08
c) The irrigation farm of the Firle STP is located in the Lake Chivero sub-basin.
d) The irrigation farm of the Zengeza STP is located outside of the Upper Manyame river basin. 100% of effluent is reused at present. Previously, 50% of it was discharged to Nyatsime River (conditions for calculation of COD, T-N and T-P).
e) Water quality of Zengeza STP is from measurement results surveyed by JICA team.
f) Reaching ratios of pollution loads are; 100% ; for irrigation reuse 0%
g) Values for dry season are adopted for calculation regarding BOD.
h) Treated effluent of Donnybrook Nos. 1 and 4 are flowing into Nos. 2 and 3 respectively.
i) T-N for Ruwa STP is calculated from Anmonia-N values using following correlation formula which is derived from measurement results of same WSP effluent of Donnybrook STP.
T-N = A-N x 1.58

Table 6.4.3 Comparison of Operation Status between Present and Future (Scenario 2)

Sub-basin	Sewage Treatment Works	2012							2020 and 2030							
		Eff. Flow (m^3/day)	Irrigation	Average Effluent Water Quality (mg/l)					Eff. Flow (m^3/day)	Irrigation	Average Effluent Water Quality (mg/l)					Process Change
		Annual	Reuse (%)	BOD	COD	T-N	P-P	T-P [a]	Annual	Reuse (%)	BOD	COD	T-N	P-P	T-P [a]	
Marimba R.	Crowborough (TF)	16,800	29%	28.0	80.6	37.9	5.23	8.4	16,800	0%	18.9	91.3	9.3	1.54	2.7	From TF to BNR
do	Crowborough (BNR)	18,000	0%	18.9	91.3	9.3	1.54	2.7	18,000	0%	18.9	91.3	9.3	1.54	2.7	
do	Crowborough Total	34,800							34,800							
L. Chivero	Firle Units 1&2 (TF)	30,000	68%	137.8	268.0	38.7	4.49	7.2	83,900	0%	13.8	107.6	13.7	2.84	4.7	From TF to BNR
Mukuvisi R.	Firle Unit 3 (BNR)	18,000	0%	13.8	107.6	13.7	2.84	4.7	18,000	0%	13.8	107.6	13.7	2.84	4.7	
do	Firle Unit 4 (BNR)	18,000	0%	18.2	94.7	13.0	2.23	3.7	18,000	0%	18.2	94.7	13.0	2.23	3.7	
do	Firle Unit 5 (BNR)	72,000	0%	18.2	94.7	13.0	2.23	3.7	72,000	0%	18.2	94.7	13.0	2.23	3.7	
do	Firle Total (Mukuvisi)	108,000							108,000							
Gwebi R.	Marlborough (WSP)[b]	2,000	100%	51.4	161.9	36.4	4.04	6.5	2,000	100%	51.4	161.9	36.4	4.04	6.5	
Ruwa R.	Donnybrook-1 (WSP)[b]	400	100%	40.6	162.1	99.6	10.97	17.3	400	100%	40.6	162.1	99.6	10.97	17.3	
do	Donnybrook-2 (WSP)[b]	1,400	100%	40.6	162.1	99.6	10.97	17.3	1,400	100%	40.6	162.1	99.6	10.97	17.3	
do	Donnybrook-3 (WSP)[b]	1,400	100%	40.6	162.1	99.6	10.97	17.3	1,400	100%	40.6	162.1	99.6	10.97	17.3	
do	Donnybrook-4 (WSP)[b]	2,400	100%	40.6	162.1	99.6	10.97	17.3	2,400	100%	40.6	162.1	99.6	10.97	17.3	
do	Donnybrook Total [h]	5,600							5,600							
Nyatsime R.	Zengeza (TF)[b]	22,000	0%	800.0	1,600.0	54.0		16.6	22,000	100%	130.0	540.0	54.0		16.6	
	Zengeza (TF)b								20,000	0%	18.2	94.7	13.0	2.23	3.7	From TF to BNR
L. Manyame	Norton (TF)	2,700	0%	520.0	1,191.9	65.8	7.60	12.0	2,700	0%	18.2	94.7	13.0	2.23	3.7	From TF to BNR
Ruwa R.	Ruwa (WSP)[b]	2,900	100%	123.0	278.0	6.1	2.38	4.0	2,900	100%	123.0	278.0	6.1	2.38	4.0	
Total		208,000							281,900							

Note:

a) T-P is calculated from P-P values using following correlation formula which is derived from measurement results by the Study Team.

T-P = P-P x 1.5482 + 0.2682 P-P; Phosphate Phosphorus

b) COD values of STPs with " b " are calculated from BOD values using following correlation formula which is derived from measurement results of other STPs with trickling filter method.

COD = BOD (annual average) x 2.08

c) The irrigation farm of the Firle STP is located in the Lake Chivero sub-basin.

d) The irrigation farm of the Zengeza STP is located outside of the Upper Manyame river basin. 100% of effluent is reused at present. Previously, 50% of it was discharged to Nyatsime River (conditions for calculation of COD, T-N and T-P).

e) Water quality of Zengeza STP is from measurement results surveyed by JICA team.

f) Reaching ratios of pollution loads are; 100% ; for irrigation reuse 0%

g) Values for dry season are adopted for calculation regarding BOD.

h) Treated effluent of Donnybrook Nos. 1 and 4 are flowing into Nos. 2 and 3 respectively.

i) T-N for Ruwa STP is calculated from Anmonia-N values using following correlation formula which is derived from measurement results of same WSP effluent of Donnybrook STP.

T-N = A-N x 1.58

Table 6.4.4 Comparison of Operation Status between Present and Future (Scenario 3)

Sub-basin	Sewage Treatment Works	2012								2020 and 2030							
		Eff. Flow (m^3/day)	Irrigation	Average Effluent Water Quality (mg/l)					Eff. Flow (m^3/day)	Irrigation	Average Effluent Water Quality (mg/l)				
		Annual	Reuse (%)	BOD	COD	T-N	P-P	T-P [a]	Annual	Reuse (%)	BOD	COD	T-N	P-P	T-P [a]
Marimba R.	Crowborough (TF)	16,800	29%	28.0	80.6	37.9	5.23	8.4	16,800	100%	98.1	282.0	37.9	5.23	8.4
do	Crowborough (BNR)	18,000	0%	18.9	91.3	9.3	1.54	2.7	18,000	100%	18.9	91.3	9.3	1.54	2.7
do	Crowborough Total	34,800							34,800						
L. Chivero	Firle Units 1&2 (TF)	30,000	68%	137.8	268.0	38.7	4.49	7.2	83,900	100% [c]	137.8	268.0	38.7	4.49	7.2
Mukuvisi R.	Firle Unit 3 (BNR)	18,000	0%	13.8	107.6	13.7	2.84	4.7	18,000	100%	13.8	107.6	13.7	2.84	4.7
do	Firle Unit 4 (BNR)	18,000	0%	18.2	94.7	13.0	2.23	3.7	18,000	100%	18.2	94.7	13.0	2.23	3.7
do	Firle Unit 5 (BNR)	72,000	0%	18.2	94.7	13.0	2.23	3.7	72,000	100%	18.2	94.7	13.0	2.23	3.7
do	Firle Total (Mukuvisi)	108,000							108,000						
Gwebi R.	Marlborough (WSP) [b]	2,000	100%	51.4	161.9	36.4	4.04	6.5	2,000	100%	51.4	161.9	36.4	4.04	6.5
Ruwa R.	Donnybrook-1 (WSP) [b]	400	100%	40.6	162.1	99.6	10.97	17.3	400	100%	40.6	162.1	99.6	10.97	17.3
do	Donnybrook-2 (WSP) [b]	1,400	100%	40.6	162.1	99.6	10.97	17.3	1,400	100%	40.6	162.1	99.6	10.97	17.3
do	Donnybrook-3 (WSP) [b]	1,400	100%	40.6	162.1	99.6	10.97	17.3	1,400	100%	40.6	162.1	99.6	10.97	17.3
do	Donnybrook-4 (WSP) [b]	2,400	100%	40.6	162.1	99.6	10.97	17.3	2,400	100%	40.6	162.1	99.6	10.97	17.3
do	Donnybrook Total [h]	5,600							5,600						
Nyatsime R.	Zengeza (TF) [b]	22,000	0%	800.0	1,600.0	54.0		16.6	22,000	100%	130.0	540.0	54.0		16.6
	Zengeza (TF)b								20,000	100%	60.0	120.0	37.8		16.6
L. Manyame	Norton (TF)	2,700	0%	520.0	1,191.9	65.8	7.60	12.0	2,700	100%	520.0	1,191.9	65.8	7.60	12.0
Ruwa R.	Ruwa (WSP) [b]	2,900	100%	123.0	278.0	6.1	2.38	4.0	2,900	100%	123.0	278.0	6.1	2.38	4.0
Total		208,000							281,900						

Note:

a) T-P is calculated from P-P values using following correlation formula which is derived from measurement results by the Study Team.
T-P = P-P x 1.5482 + 0.2682 P-P; Phosphate Phosphorus

b) COD values of STPs with " b " are calculated from BOD values using following correlation formula which is derived from measurement results of other STPs with trickling filter method.
COD = BOD (annual average) x 2.08

c) The irrigation farm of the Firle STP is located in the Lake Chivero sub-basin.

d) The irrigation farm of the Zengeza STP is located outside of the Upper Manyame river basin. 100% of effluent is reused at present. Previously, 50% of it was discharged to Nyatsime River (conditions for calculation of COD, T-N and T-P).

e) Water quality of Zengeza STP is from measurement results surveyed by JICA team.

f) Reaching ratios of pollution loads are; 100% ; for irrigation reuse 0%

g) Values for dry season are adopted for calculation regarding BOD.

h) Treated effluent of Donnybrook Nos. 1 and 4 are flowing into Nos. 2 and 3 respectively.

i) T-N for Ruwa STP is calculated from Anmonia-N values using following correlation formula which is derived from measurement results of same WSP effluent of Donnybrook STP.
T-N = A-N x 1.58

Table 6.4.5 Discharged Pollution Load at Sewerage Treatment Works (Scenario 4)

Table6.4.5 Discharged Pollution Load at Sewage Treatment Works (Scenario 4)

Sub-basin	Sewage Treatment Works	2012							2020 and 2030						
		Eff. Flow (m^3/day)	Irrigation	Average Effluent Water Quality (mg/l)					Eff. Flow (m^3/day)	Irrigation	Average Effluent Water Quality (mg/l)				
		Annual	Reuse (%)	BOD	COD	T-N	P-P	T-P [a]	Annual	Reuse (%)	BOD	COD	T-N	P-P	T-P
Marimba R.	Crowborough (TF)	16,800	29%	28.0	80.6	37.9	5.23	8.4	16,800	100%	98.1	282.0	37.9	5.23	8
do	Crowborough (BNR)	18,000	0%	18.9	91.3	9.3	1.54	2.7	18,000	0%	18.9	91.3	9.3	1.54	2
do	Crowborough Total	34,800							34,800						
L. Chivero	Firle Units 1&2 (TF)	30,000	68%	137.8	268.0	38.7	4.49	7.2	83,900	100% [c]	137.8	268.0	38.7	4.49	7
Mukuvisi R.	Firle Unit 3 (BNR)	18,000	0%	13.8	107.6	13.7	2.84	4.7	18,000	0%	13.8	107.6	13.7	2.84	4
do	Firle Unit 4 (BNR)	18,000	0%	18.2	94.7	13.0	2.23	3.7	18,000	0%	18.2	94.7	13.0	2.23	3
do	Firle Unit 5 (BNR)	72,000	0%	18.2	94.7	13.0	2.23	3.7	72,000	0%	18.2	94.7	13.0	2.23	3
do	Firle Total (Mukuvisi)	108,000							108,000						
Gwebi R.	Marlborough (WSP)[b]	2,000	100%	51.4	161.9	36.4	4.04	6.5	2,000	100%	51.4	161.9	36.4	4.04	6
Ruwa R.	Donnybrook-1 (WSP)[b]	400	100%	40.6	162.1	99.6	10.97	17.3	400	100%	40.6	162.1	99.6	10.97	17
do	Donnybrook-2 (WSP)[b]	1,400	100%	40.6	162.1	99.6	10.97	17.3	1,400	100%	40.6	162.1	99.6	10.97	17
do	Donnybrook-3 (WSP)[b]	1,400	100%	40.6	162.1	99.6	10.97	17.3	1,400	100%	40.6	162.1	99.6	10.97	17
do	Donnybrook-4 (WSP)[b]	2,400	100%	40.6	162.1	99.6	10.97	17.3	2,400	100%	40.6	162.1	99.6	10.97	17
do	Donnybrook Total [h]	5,600							5,600						
Nyatsime R.	Zengeza (TF)[b]	22,000	0%	800.0	1,600.0	54.0		16.6	22,000	100%	800.0	1,600.0	54.0		1
	Zengeza (TF)b								20,000	100%	800.0	1,600.0	54.0		1
L. Manyame	Norton (TF)	2,700	0%	520.0	1,191.9	65.8	7.60	12.0	2,700	100%	520.0	1,191.9	65.8	7.60	12
Ruwa R.	Ruwa (WSP)[b]	2,900	100%	123.0	278.0	6.1	2.38	4.0	2,900	100%	123.0	278.0	6.1	2.38	4
	Total	208,000							281,900						

Note:

a) T-P is calculated from P-P values using following correlation formula which is derived from measurement results by the Study Team.

T-P = P-P x 1.5482 + 0.2682 P-P; Phosphate Phosphorus

b) COD values of STPs with " b " are calculated from BOD values using following correlation formula which is derived from measurement results of other STPs with trickling filter method.

COD = BOD (annual average) x 2.08

c) The irrigation farm of the Firle STP is located in the Lake Chivero sub-basin.

d) The irrigation farm of the Zengeza STP is located outside of the Upper Manyame river basin. 100% of effluent is reused at present. Previously, 50% of it was discharged to Nyatsime River (conditions for calculation of COD, T-N and T-P).

e) Water quality of Zengeza STP is from measurement results surveyed by JICA team.

f) Reaching ratios of pollution loads are; 100% ; for irrigation reuse 0%

g) Values for dry season are adopted for calculation regarding BOD.

h) Treated effluent of Donnybrook Nos. 1 and 4 are flowing into Nos. 2 and 3 respectively.

i) T-N for Ruwa STP is calculated from Anmonia-N values using following correlation formula which is derived from measurement results of same WSP effluent of Donnybrook STP.

Table 6.4.6 Estimated Sewered Ratio and Population in each year (2012 / 2020 / 2030)

Sub-basin/District	Increase Rate		Population					
	2012-2020	2020-2030	2012		2020		2030	
	% per year	% per year	Sewered	Unsewered	Sewered	Unsewered	Sewered	Unsewered
1. Manyame River (U.stream) S/B								
Goromonzi Rural	3.50	3.50	-	2,255	-	2,962	-	4,120
Harare Rural	15.00	12.00	-	568	-	1,740	-	5,440
Manyame Rural	3.50	3.50	-	1,498	-	1,965	-	2,713
Total			-	4,321	-	6,667	-	12,273
2. Ruwa River S/B								
Harare City	0.50	0.50	95,381	-	99,298	-	104,360	-
Ruwa Local Board	9.00	9.00	55,766	534	112,000	-	265,000	-
Epworth Local Board	3.50	3.50	-	103,578	-	136,385	-	192,326
Goromonzi Rural	3.50	3.50	-	535	-	697	-	925
Harare Rural	15.00	12.00	-	19,482	-	59,597	-	185,135
Total	-		151,147	124,129	211,298	196,680	369,360	378,386
3. Seke & Harava Dams S/B								
Epworth Local Board	3.50	3.50	-	11,651	-	15,327	-	21,503
Goromonzi Rural	3.50	3.50	-	10	-	13	-	19
Harare Rural	15.00	12.00	-	10,592	-	32,403	-	100,674
Manyame Rural	15.00	12.00	-	623	-	1,908	-	5,961
Total			-	22,876	-	49,651	-	128,156
4. Nyatsime River S/B								
Chitungwiza Municipality	1.17	1.26	279,379	-	306,647	-	347,392	-
Manyame Rural	15.00	12.00	-	6,519	-	19,944	-	61,978
Marondera Rural Total x 30%	15.00	12.00						
Total x 70%	3.50	3.50	-	60,000	-	110,363	-	249,006
Total			279,379	66,519	306,647	130,307	347,392	310,984
5. Mukuvisi River S/B								
Harare City	0.50	0.50	680,857	30,755	740,614	-	778,473	-
Epworth Local Board	3.50	3.50	-	273	-	352	-	438
Harare Rural	15.00	12.00	-	8,679	-	26,553	-	82,503
Zvimba Rural	15.00	12.00	-	142	-	437	-	1,391
Total			680,857	39,849	740,614	27,341	778,473	84,332
6. Manyame River (D.stream) S/B								
Chitungwiza Municipality	1.17	1.26	75,121	-	82,453	-	93,408	-
Harare Rural	15.00	12.00	-	46,674	-	142,779	-	443,484
Manyame Rural	15.00	12.00	-	939	-	2,875	-	8,963
Total	-		75,121	47,613	82,453	145,653	93,408	452,447
7. Marimba River S/B								
Harare City	0.50	0.50	573,685	-	597,072	-	627,590	-
Zvimba Rural	15.00	12.00	-	882	-	2,700	-	8,422
Total			573,685	882	597,072	2,700	627,590	8,422
8. Lake Chivero S/B								
Harare City	0.50	0.50	-	-	-	-	-	-
Chegutu Rural	0.50	0.50	-	672	-	733	-	755
Manyame Rural	0.50	0.50	-	1,292	-	1,379	-	1,433
Zvimba Rural	0.50	0.50	-	1,563	-	1,661	-	1,730
Total			-	3,527	-	3,773	-	3,918
9. Muzururu River S/B								
Zvimba Rural	0.50	0.50	-	4,606	-	4,828	-	5,058
Total			-	4,606	-	4,828	-	5,058
10. Gwebi River S/B								
Harare City	0.50	0.50	11,057	50,097	63,677	-	66,918	-
Mazowe Rural	0.50	0.50	-	5,100	-	5,342	-	5,599
Zvimba Rural	0.50	0.50	-	6,688	-	6,994	-	7,336
Total			11,057	61,885	63,677	12,336	66,918	12,935
11. Lake Manyame S/B								
Norton Town	8.00	8.00	55,016	3,384	108,000	-	233,000	-
Chegutu Rural	0.50	0.50	-	2,928	-	3,081	-	3,223
Zvimba Rural	0.50	0.50	-	4,119	-	4,321	-	4,526
Total			55,016	10,431	108,000	7,402	233,000	7,748
Grand Total			1,826,263	386,637	2,109,761	587,339	2,516,141	1,404,659

Table 6.4.7 Removal Ratio of Sewered by Each Sub-bas in Each Scenario

Sub-basin/District	Removal Ratio of Each Scenario *1				Specification of STP		
	S0	S1	S2	S3	STP Name	Method *2	Memo
1. Ruwa River S/B							
Harare City	0%	*	*	100%	Donnybrook	BNR	*BOD95%, COD90%, N80%, P75%
Ruwa Local Board	0%	70%	70%	100%	Donnybrook	WSP	
2. Nyatsime River S/B							
Chitungwiza Municipality	0%	100%	*	100%	Zengeza	TF	S2 → Change to BNR, *BOD95%, COD90%, N80%, P75%
3. Mukuvisi River S/B							
Harare City	0%	*	*	100%	Firle	BNR	*BOD95%, COD90%, N80%, P75%
4. Manyame River (D.stream) S/B							
Chitungwiza Municipality	0%	100%	100%	100%	Norton	TF	
5. Marimba River S/B							
Harare City	0%	100%	*	100%	Crowgrough	TF, BNR	S2 → Change to BNR, *BOD95%, COD90%, N80%, P75%
6. Lake Chivero S/B							
Harare City	0%	100%	*	100%	Firle1&2	TF	S2 → Change to BNR, *BOD95%, COD90%, N80%, P75%
7. Gwebi River S/B							
Harare City	0%	100%	100%	100%	Morlborough	WSP	
8. Lake Manyame S/B							
Norton Town	0%	100%	100%	100%	Norton	TF	

*1: S0, S1, S2, S3: Scenario0, 1, 2, 3,
*2: BNR- Biological Nutrient Removal, TF- Trickling Filter, WSP- Wastewater Stabilization Pond
Remarks: Scenario 4 Removal Ratio of S1 for 2. Chitungwiza STP is 0%. Other ratios are the same with S1

(2) Industrial wastewater

1) Industrial wastewater flow

The future industrial wastewater flow was calculated by multiplying the unit industrial wastewater flow per employee and the number of employees in the future, as shown in the Appendix 6.4

2) Pollution load

The future pollution load was calculated by multiplying the unit pollution load of industrial wastewater per employee and the number of employees in the future, as presented in Appendix 6.3.

3) Sewered/unsewered wastewater

The future wastewater flow and pollution load were calculated by sub-basin under the category of sewered and unsewered area based on the present sewerage service coverage. The results are shown in Appendix 6.4. The pollution load of industrial wastewater in the unsewered area is also presented in Table 6.4.5 and Table 6.4.6 in Appendix 6.4. Industrial wastewater in the sewered area is considered as a part of the effluent discharged from STWs.

(3) Other pollution load

In addition to aforementioned pollution loads, that caused by the following pollution sources were considered in the calculation.

1) Livestock

The number of major livestock and unit generation rate of pollution are assumed to be same as 2012. The data for livestock is shown in Table 6.3.11.

2) Farmland / Natural land

The pollution loads calculated for each sub-basin are shown in Table 6.3.12. The unit pollution load presented in Table 6.3.13 was assumed to be constant through the future.

3) Water Treatment Works

Pollution Load from water treatment works is assumed to be same as 2012.

6.4.3 Modelling of Pollution Load Run-off

(1) Flow run-off model

The pollution load remaining ratio of the river and the purification coefficient of the lakes are shown in 6.3.5. In the computation, natural pollution was treated as not decreasing since it is considered as non-degradable in the flow. In the scenario 1, 2, 3 and 4, the pollution load remaining ratio of the effluent from STPs in the rivers does not decrease since the load that remains after treatment is no longer biodegradable. However, it will be treated as degradable in the lake due to its long detention time. Therefore, purification for each pollution load is assumed as follows:

Table 6.4.8 Biodegradability of the loads

Scenario	Type of Load	Degradability	
		River	Lake
0	Sewered（Dom./Com./Ins./Ind.）	Yes	Yes
	Unsewered（Dom./Com./Ins./Ind.）・Livestock	Yes	Yes
	Natural Pollution, WTP discharging	No	No
1,2,3,4	Sewered（Dom./Com./Ins./Ind.）	No	Yes
	Unsewered（Dom./Com./Ins./Ind.）・Livestock	Yes	Yes
	Natural Pollution, WTP discharging	No	No

Source: JICA Project Team

(2) Detailed calculation

Detailed calculation followed the same computation process with the current pollution analysis. To make this chapter concise and easy-to-read, voluminous computation process of the analysis was shown in the Appendix 6.4.

6.4.4 Discussion and Conclusion

The result of the pollution analysis for the current status in the dry season is summarised below:

(1) General

Based on the load run-off model established, the concentration of the parameters at water quality checking points of rivers was conducted and projected for each scenario for the years 2020 and 2030.

(2) Rivers

The result of the pollution analysis for the current status in the dry season is summarised below:

1) General

Based on the load run-off model established, the concentration of the parameters at water quality checking points of rivers was conducted and projected for each scenario for the years 2020 and 2030.

2) Rivers

< Scenario 0, - no improvement >

According to the rehabilitation plan, reached pollution loads from Harare City 1.8 times, or from the current 98,000 kg-BOD/day to about 172,000 kg-BOD/day in 2030. Load from Chitungwiza will also increase from the current 17,000 kg-BOD/day to 30,000 kg-BOD/day in 2030.

Water quality in the Ruwa River, Mukuvisi River, Marimba River will be serious. T-N and T-P show the same tendency.

Ruwa river: Polluted (113 mg BOD/l ⇒675 mg BOD/l) with high pollution load from Ruwa

Nyatsime river: Polluted (126 mg BOD/l⇒226 mg BOD/l) with high pollution load from ChitungwizaManyame river before Chivero:

Polluted (43 mg BOD/l⇒82 mg BOD/l) with high pollution load from

Ruwa and ChitungwizaThus, no improvement will bring the disastrous influence to the Lake Chivero and Lake Manyame. The situation must be avoided because Water source for the WTPs will be lost. Ground water source will be polluted as well by infiltration of sewage into the ground.

< Scenario 1, 2 >

From Harare, generated pollution loads to the rivers will decrease to about 2,900 kg-BOD/day from the current 98,000 kg-BOD/day in scenario 1, 2 in 2030. Chitungwiza Municipality will discharge no pollution loads due to irrigation use. T-N and T-P show the same tendency with the BOD_5.

Ruwa river: Improved (113 mg BOD/l ⇒21 mg BOD/l) with less pollution load from Ruwa

Nyatsime river: Improved (126 mg BOD/l⇒11 mg BOD/l) with less pollution load from Chitungwiza

Manyame river before Chivero:

Improved (43 mg BOD/l⇒12 mg BOD/l) with less pollution load from Ruwa and Chitungwiza

Improvement of Sewerage of City of Harare by Zim-Fund project and Chitungwiza by AWF project will improve the current status drastically. Followed augmentation/continued effort of maintenance will keep the ambient environment as improved.

< Scenario 3 >

From Harare, generated pollution loads to the rivers will decrease to zero in scenario 3 in 2030. Chitungwiza Municipality will discharge no pollution load due to irrigation use. T-N and T-P show the same tendency with the BOD.

Ruwa river: Improved (113 mg BOD/l ⇒21 mg BOD/l) with less pollution load from Ruwa

Nyatsime river: Improved (126mg BOD/l⇒11 mg BOD/l) with less pollution load from Chitungwiza

Manyame river before Chivero:

Improved (43 mg BOD/l⇒12 mg BOD/l) with less pollution load from Ruwa and Chitungwiza

Generally speaking, the measures of wastewater treatment will be effective for water quality improvement.

< Scenario 4 >

From Harare, generated pollution loads to the rivers will decrease to zero in scenario 4 in 2030. Chitungwiza Municipality will discharge biggest pollution load to Nyatsime River, about 25,000 kg-BOD/day because of no improvement of sewerage. T-N and T-P show the same tendency with the BOD_5.

Ruwa river: Improved (113 mg BOD/l ⇒21 mg BOD/l) with less pollution load

Nyatsime river: Polluted (126mg BOD/l⇒226 mg BOD/l) with increased pollution

ChitungwizaManyame river before Chivero: Improved (43 mg BOD/l⇒52 mg BOD/l) by dilution

Nyatsime River will be polluted very badly because of pollutant discharge from Chitungwiza Municipality. Inflowing pollution load to Lake Chivero will be 6,000 kg-BOD/day increased from 4,000 kg-BOD/day which is 1.7 times bigger than Scenario 1. Influence of no-treatment at ZSTP will drastically aggravate the water quality in the Nyatsime River.

(3) Lakes / dams

The improvement of water quality of lakes/dams from the present status is shown below:

Although the change in water quality will be very slow compared with the case of the river, water quality will become worse in scenario 0 but will see improvement in scenario 1, 2, 3 and 4. Concentration of T-N and T-P is relatively high in every case. In the scenario 2, employing BNR for all facilities will be significant in terms of water cycle however, water quality in Lake Chivero will be a bit worse than scenario 1 in which irrigation is employed for the facilities other than BNR. Thus, effect of irrigation is great in terms of water quality since all the pollutant will be discharged to the farms.

Table 6.4.9 Water Quality Projection in Seke and Harava Dam

Items	Scenario Number	Water Quality(mg/L)			Remarks
		2012	2020	2030	
COD	Scenario 0	3.6	3.7	4.0	
	Scenario 1	-	3.5	3.6	
	Scenario 2	-	3.5	3.6	
	Scenario 3	-	3.5	3.6	
	Scenario 4	-	3.5	3.6	
(BOD_5)	Scenario 0	1.7	1.8	2.7	Reference Value
	Scenario 1	-	1.5	1.6	Reference Value
	Scenario 2	-	1.5	1.6	Reference Value
	Scenario 3	-	1.5	1.6	Reference Value
	Scenario 4	-	1.5	1.6	Reference Value
T-N	Scenario 0	4.1	4.4	5.1	
	Scenario 1	-	3.7	3.7	
	Scenario 2	-	3.7	3.7	
	Scenario 3	-	3.7	3.7	
	Scenario 4	-	3.7	3.7	
T-P	Scenario 0	0.3	0.4	0.4	
	Scenario 1	-	0.3	0.3	
	Scenario 2	-	0.3	0.3	
	Scenario 3	-	0.3	0.3	
	Scenario 4	-	0.3	0.3	

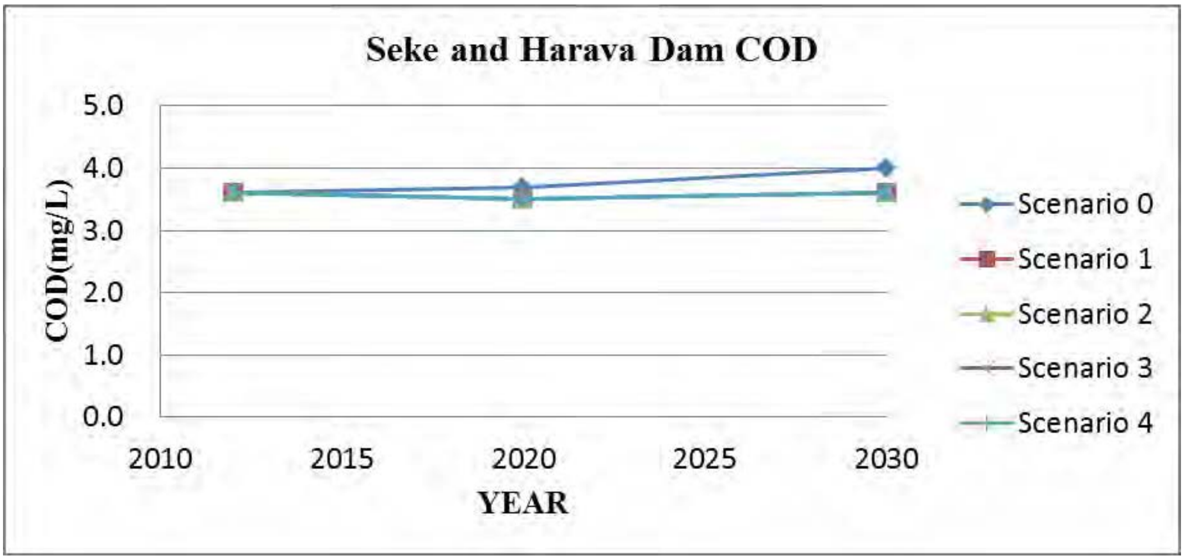


Figure 6.4.1 Water Quality Projection in Seke and Harava Dam (COD)

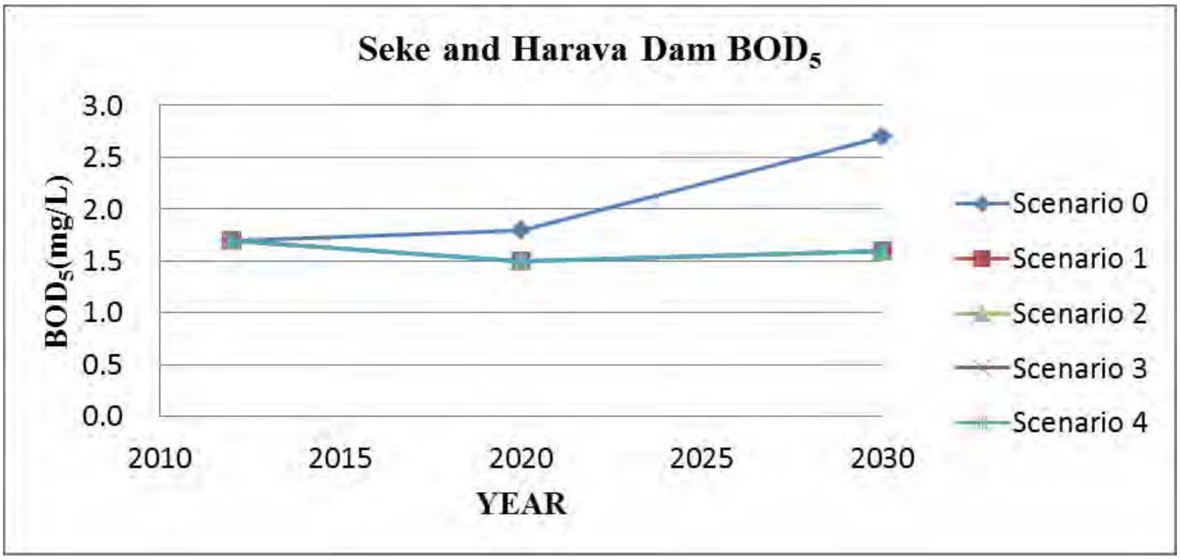


Figure 6.4.2 Water Quality Projection in Seke and Harava Dam (BOD_5)

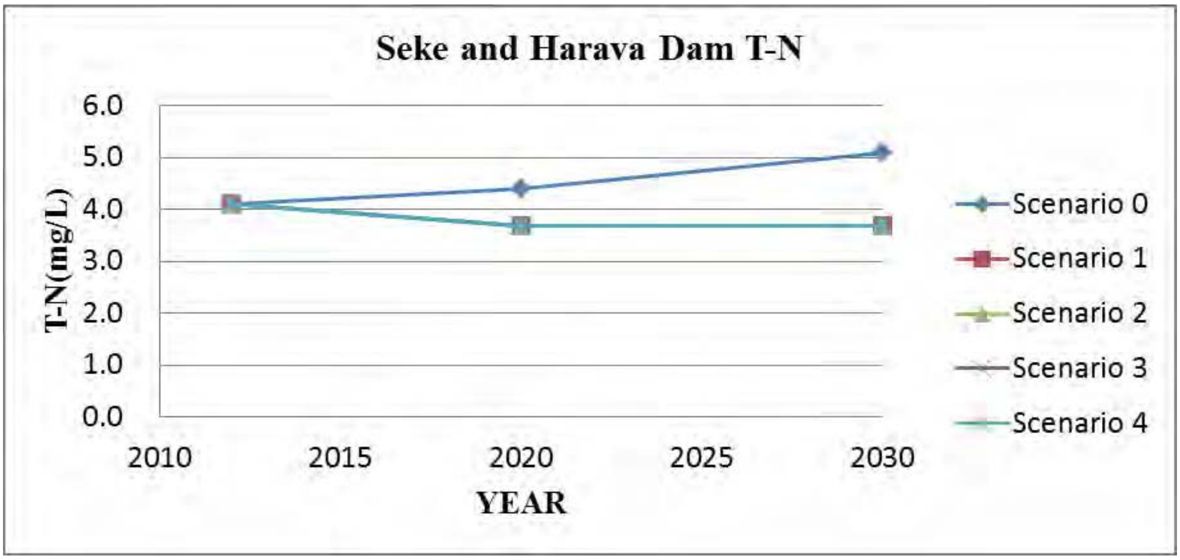


Figure 6.4.3 Water Quality Projection in Seke and Harava Dam (T-N)

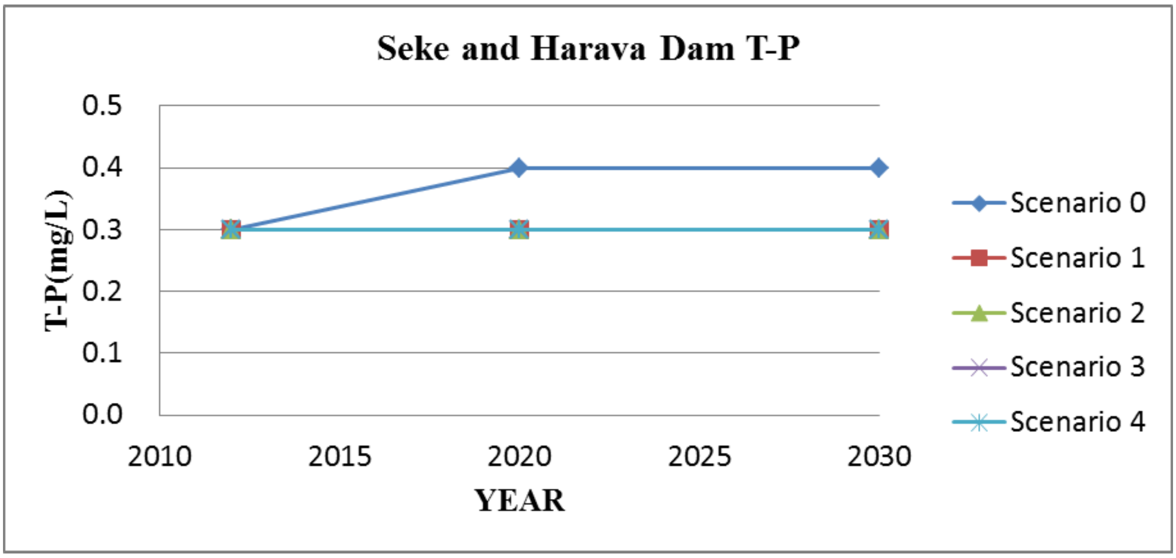


Figure 6.4.4 Water Quality Projection in Seke and Harava Dam (T-P)

Table 6.4.10 Water Quality Projection in Lake Chivero

Items	Scenario Number	Water Quality(mg/L)			Remarks
		2012	2020	2030	
COD	Scenario 0	8.9	9.2	9.3	
	Scenario 1	-	8.3	8.3	
	Scenario 2	-	8.4	8.4	
	Scenario 3	-	8.1	8.2	
	Scenario 4	-	8.3	8.5	
(BOD_5)	Scenario 0	4.4	4.9	5.2	Reference Value
	Scenario 1	-	2.8	2.9	Reference Value
	Scenario 2	-	2.9	3.0	Reference Value
	Scenario 3	-	2.6	2.7	Reference Value
	Scenario 4	-	2.9	3.0	Reference Value
T-N	Scenario 0	8.8	8.9	9.0	
	Scenario 1	-	8.6	8.6	
	Scenario 2	-	8.8	8.9	
	Scenario 3	-	8.4	8.4	
	Scenario 4	-	8.6	8.7	
T-P	Scenario 0	0.7	0.7	0.7	
	Scenario 1	-	0.7	0.7	
	Scenario 2	-	0.7	0.7	
	Scenario 3	-	0.7	0.7	
	Scenario 4	-	0.7	0.7	

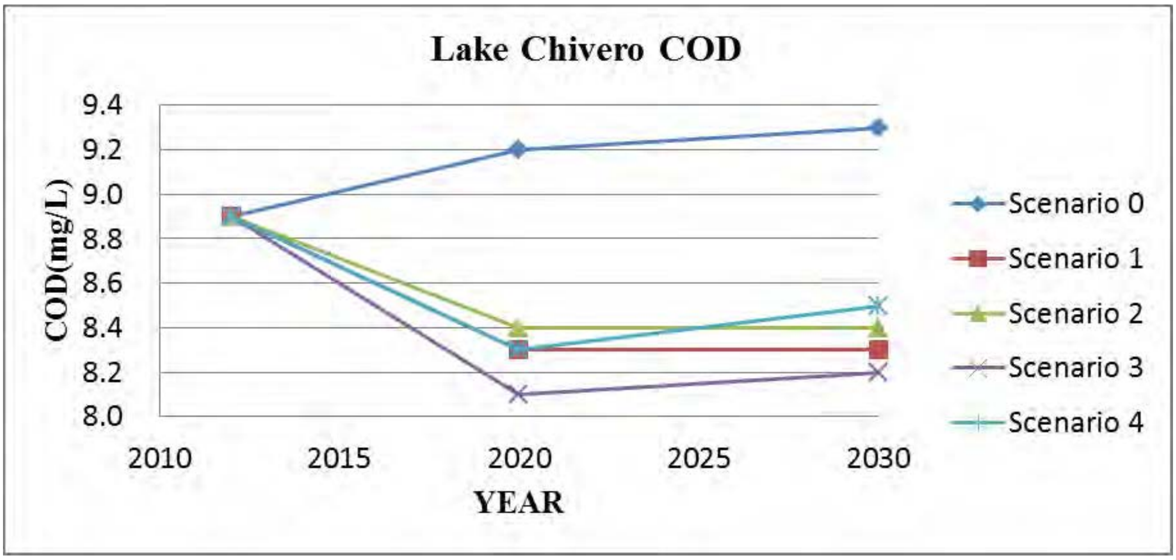


Figure 6.4.5 Water Quality Projection in Lake Chivero (COD)

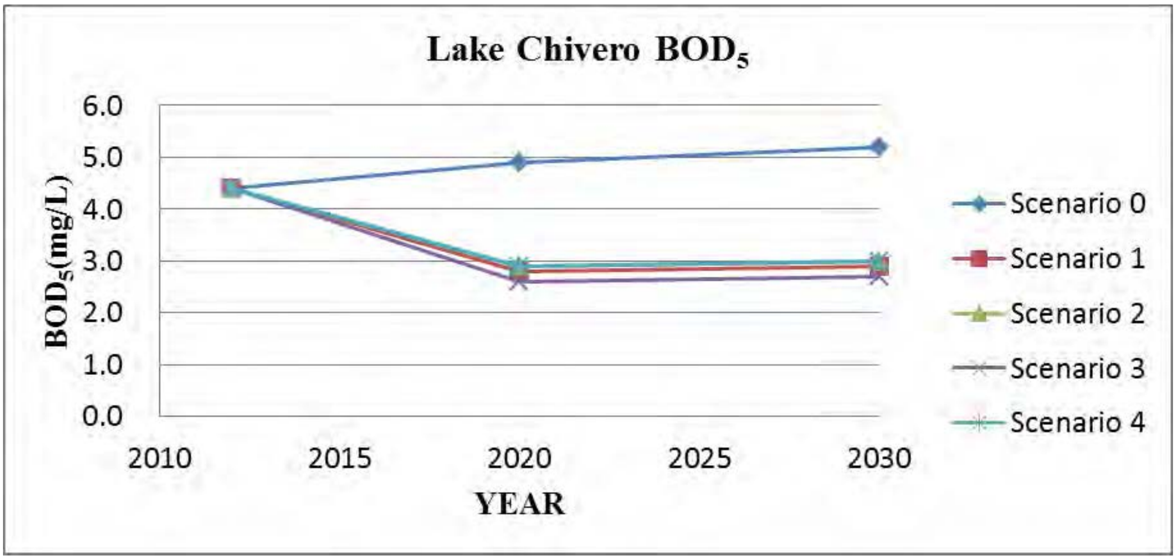


Figure 6.4.6 Water Quality Projection in Lake Chivero (BOD_5)

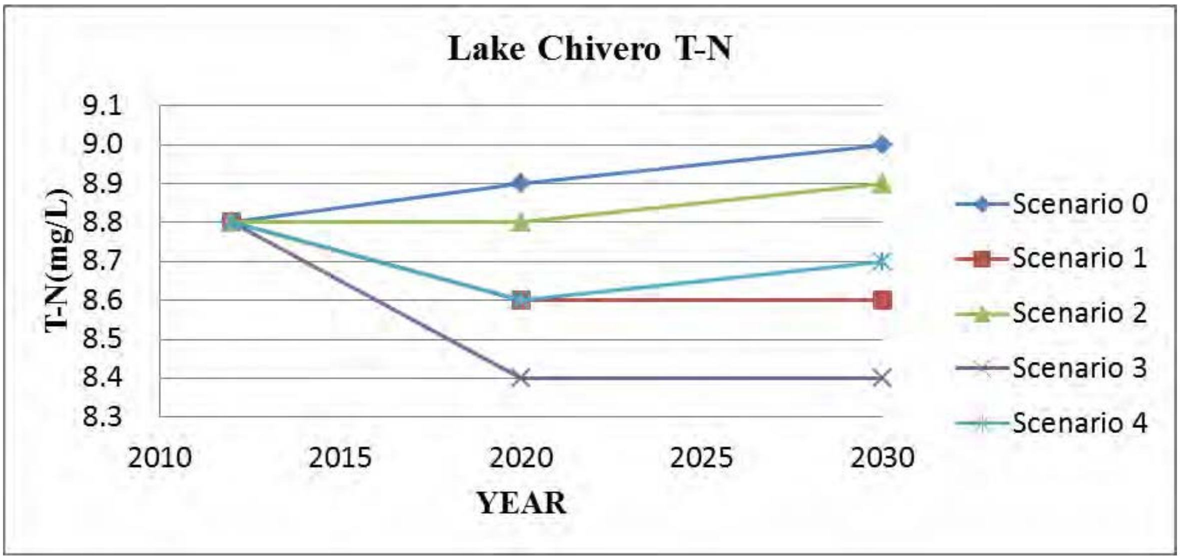


Figure 6.4.7 Water Quality Projection in Lake Chivero (T-N)

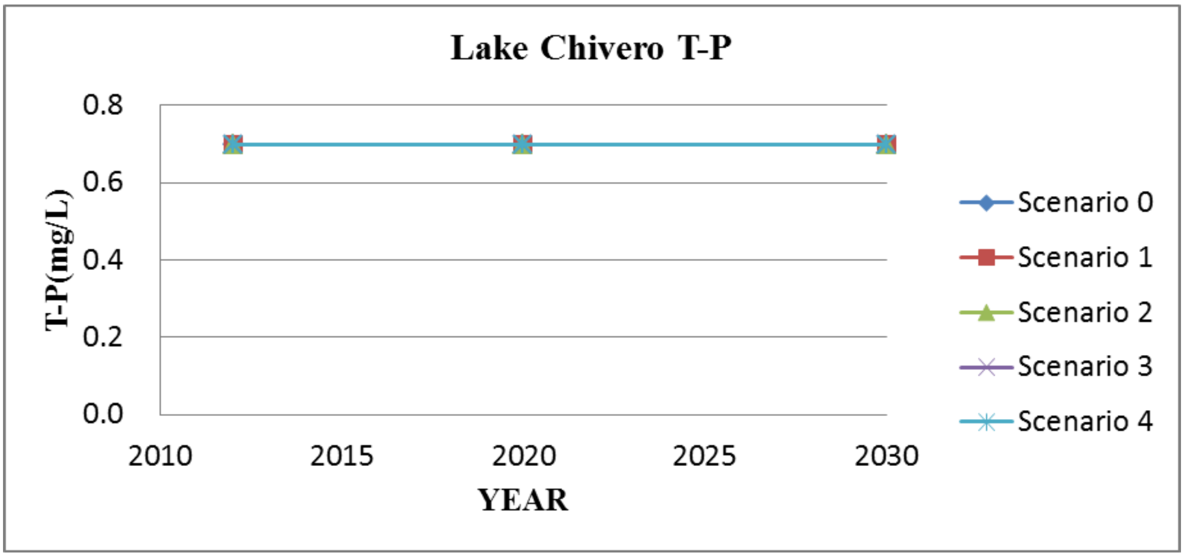


Figure 6.4.8 Water Quality Projection in Lake Chivero (T-P)

Table 6.4.11 Water Quality Projection in Lake Manyame

Items	Scenario Number	Water Quality(mg/L)			Remarks
		2012	2020	2030	
COD	Scenario 0	17.3	17.5	17.7	
	Scenario 1	-	16.7	16.8	
	Scenario 2	-	16.8	16.8	
	Scenario 3	-	16.6	16.6	
	Scenario 4	-	16.7	16.8	
(BOD_5)	Scenario 0	1.8	2.0	2.0	Reference Value
	Scenario 1	-	1.4	1.4	Reference Value
	Scenario 2	-	1.5	1.5	Reference Value
	Scenario 3	-	1.4	1.4	Reference Value
	Scenario 4	-	1.5	1.5	Reference Value
T-N	Scenario 0	17.6	17.8	18.0	
	Scenario 1	-	17.4	17.5	
	Scenario 2	-	17.5	17.6	
	Scenario 3	-	17.2	17.2	
	Scenario 4	-	17.4	17.4	
T-P	Scenario 0	1.5	1.5	1.5	
	Scenario 1	-	1.4	1.4	
	Scenario 2	-	1.4	1.5	
	Scenario 3	-	1.4	1.4	
	Scenario 4	-	1.4	1.4	

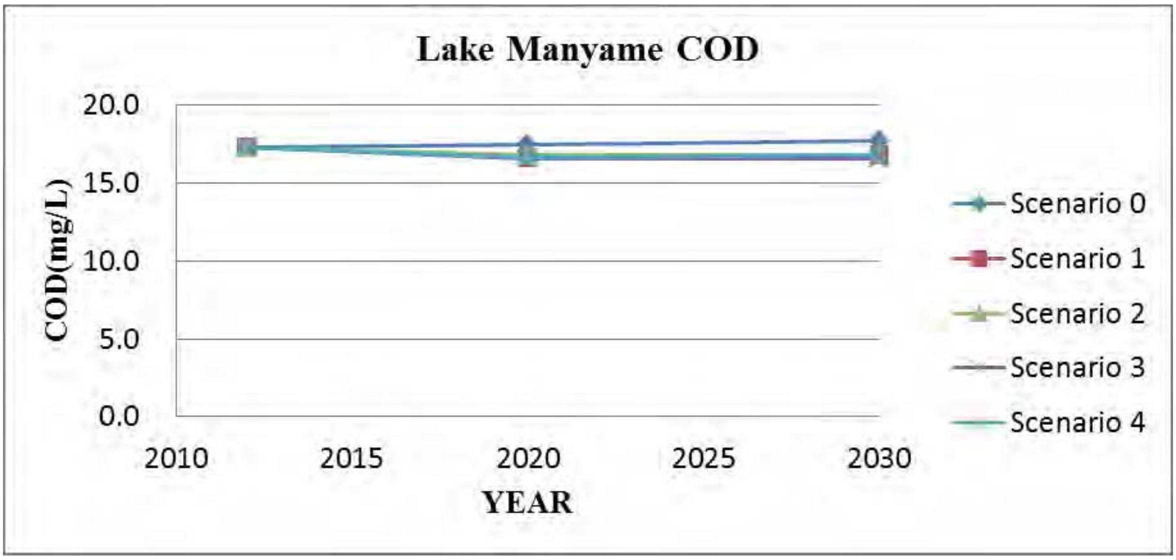


Figure 6.4.9 Water Quality Projection in Lake Manyame (COD)

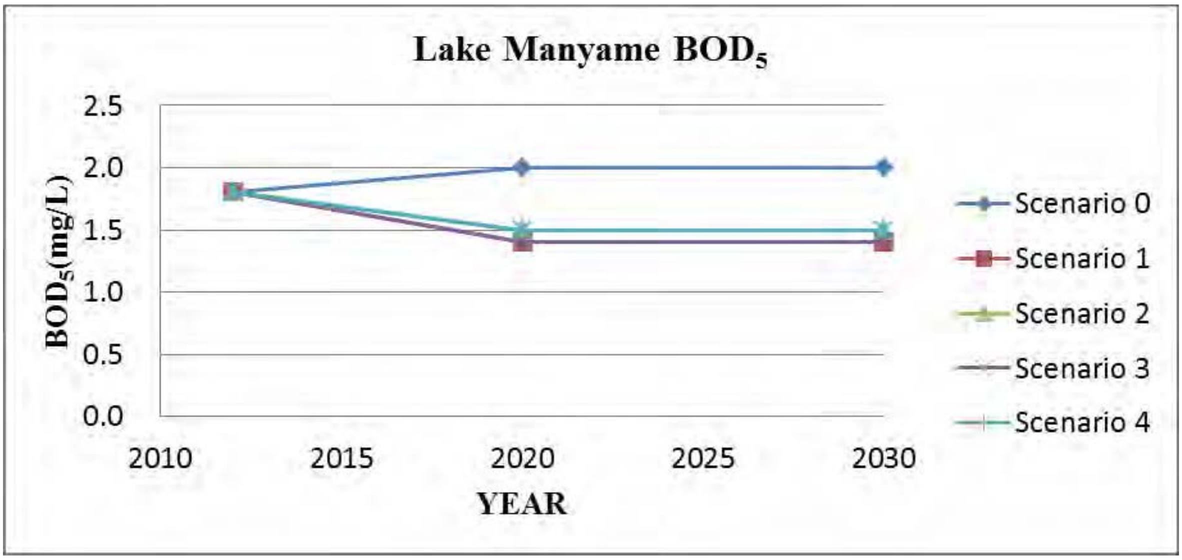


Figure 6.4.10 Water Quality Projection in Lake Manyame (BOD_5)

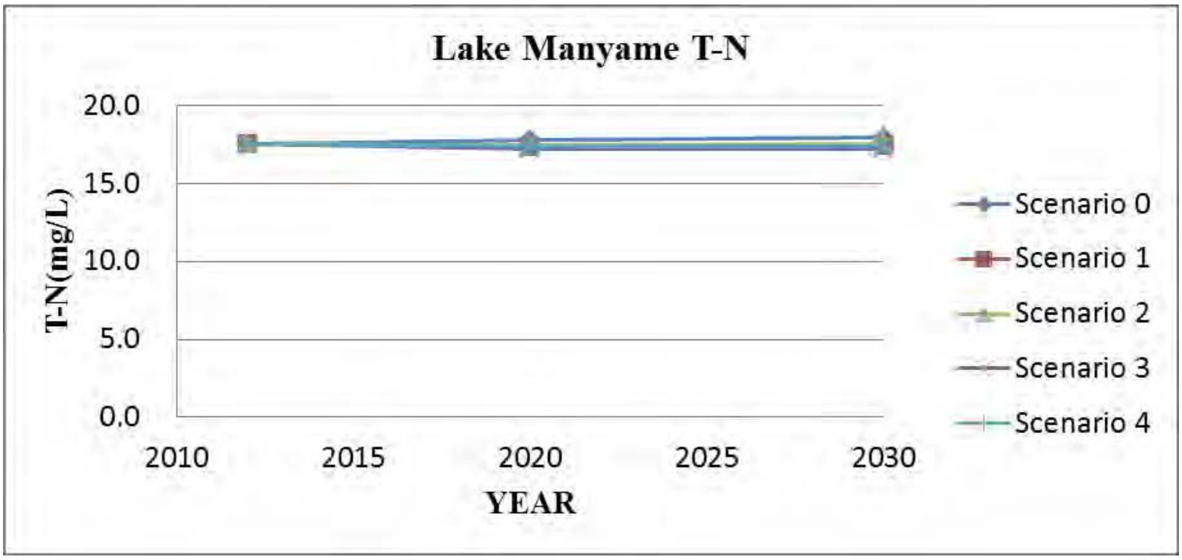


Figure 6.4.11 Water Quality Projection in Lake Manyame (T-N)

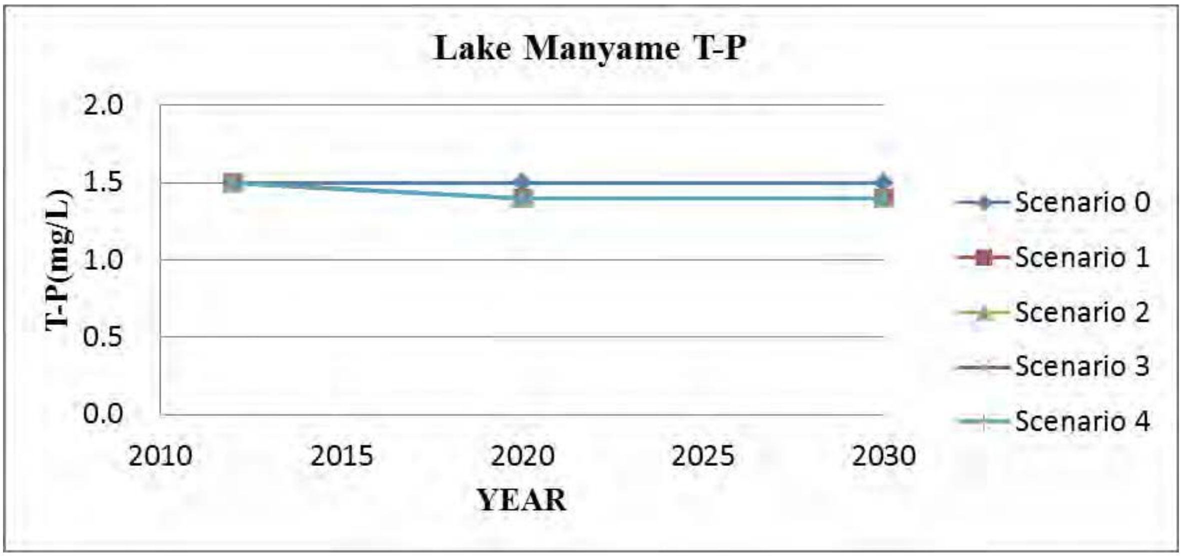


Figure 6.4.12 Water Quality Projection in Lake Manyame (T-P)