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REPUBLIC OF KENYA

NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT (FEASIBILITY STUDY)

FINAL REPORT

VOLUME (IV) SUPPORTING REPORT (2)

MARCH 1994

JAPAN INTERNATIONAL COOPERATION AGENCY

MINISTRY OF LOCAL GOVERNMENT

NIPPON KOEI CO., LTD.
NIHON SUIDO CONSULTANTS CO., LTD.

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- A : Geotechnical Investigation
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- E : Preliminary Pollution Load Estimate
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- I : Preliminary Design
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ABBREVIATION AND LOCAL TERMS

1. Abbreviation of Measures

1.1 Length

mm	=	millimeter
cm	=	centimeter
m	=	meter
km	=	kilometer
"	=	inch

1.2 Area

m^2, sq.m	=	square meter
ha	=	hectare
km^2, sq.km	=	square kilometer

1.3 Volume

cc	=	cubic centimeter
lit, l, L	=	liter
lcd	=	liter per capita per day
m^3, cu.m	=	cubic meter

1.4 Weight

mg	=	milligram
g	=	gram
kg	=	kilogram
t	=	ton

1.5 Time

s, sec	=	second
min	=	minute
h, hr	=	hour
d	=	day
yr	=	year

1.6 Money

KShs.	=	Kenya Shilling (unit of Kenya currency)
US$, $	=	US Dollar
¥	=	Japanese Yen

1.7 Electric Measures

A	=	ampere
V	=	volt
KV	=	kilovolt
KW	=	kilowatt
KWh	=	kilowatt hour
KVA	=	kilovolt ampere
Hz	=	hertz

1.8 Other Measures

mS	=	milli Siemens
mmho	=	micromho = conductance
ppb	=	parts per billion
ppm	=	parts per million
MPN	=	most probable number
‰	=	per mil
%	=	percent
PS	=	0.736 kW
°	=	degree
'	=	minute
"	=	second
℃	=	degree centigrade
BOD	=	biochemical oxygen demand
COD	=	chemical oxygen demand
T-N	=	total nitrogen
I -	=	inorganic
O -	=	organic
T-P	=	total - phosphorus
DO	=	dissolved oxygen
pH	=	exponent of hydrogen ion concentration
TDS	=	total dissolved solids
SS	=	suspended solids
VS	=	volatile solids

1.9 Derived Measures Based on the Same Symbols

cm/sec	=	centimeter per second
m/s, m/sec	=	meter per second
cm^3/min	=	cubic centimeter per minute
m^3/sec, cu.m/sec	=	cubic meter per second
m^3/s, cu.m/s	=	cubic meter per second

m^3/min, cu.m/min	=	cubic meter per minute
m^3/h, cu.m/h	=	cubic meter per hour
m^3/day, cu.m/day	=	cubic meter per day
m^3/d, cu.m/d	=	cubic meter per day
lpcd	=	liter per capita per day
m^3/m^2/day	=	cubic meter per square meter per day
m^3/sec/km^2	=	cubic meter per second per square kilometer
kg/day	=	kilogram per day
ton/m^2	=	ton per square meter
kg/day/km^2	=	kilogram per day per square kilometer
mg/kg	=	milligram per kilogram
mS/cm	=	milli Siemens per centimeter
mg/L	=	milligram per litre
g/cm^3	=	gram per cubic centimeter

2. Other Abbreviations

BS	=	British Standards
JIS	=	Japanese Industrial Standards
ASTM	=	American Society of Testing and Material
GDP	=	gross domestic product
GNP	=	gross national products
GRDP	=	gross regional domestic product
El.	=	elevation
NOL	=	normal operation level
FOB	=	free on board
CIF	=	cost, insurance and freight
STW	=	sewage treatment works
Q'ty	=	quantity
Srl	=	serial
GL	=	Ground level
SD	=	Sewerage District
EIA	=	Environmental Impact Assessment

3. Abbreviation of Organization

GOJ	=	Government of Japan
GOK	=	Government of Kenya
JICA	=	Japan International Cooperation Agency
KWS	=	Kenya Wildlife Service
MOENR	=	Ministry of Environment and Natural Resources
MOF	=	Ministry of Finance
MOALD	=	Ministry of Agriculture and Livestock Development
MOLG	=	Ministry of Local Government
MOLRRWD	=	Ministry of Land Reclamation, Regional and Water Development
MOC & I	=	Ministry of Commerce and Industry
MOL & S	=	Ministry of Land Settlement
MOTC	=	Ministry of Transport and Communication
MOTW	=	Ministry of Tourism and Wildlife
MOLMD	=	Ministry of Labour and Manpower Development
MOH	=	Ministry of Health
NES	=	National Environmental Secretariat
NWCPC	=	National Water Conservation and Pipeline Corporation
ODA	=	Overseas Development Administration, Britain
OECF	=	Overseas Economic Cooperation Fund, Japan
OP	=	Office of President
SOK	=	Survey of Kenya
WWF	=	World Wide Fund for Nature
NMC	=	Nakuru Municipal Council
PHD	=	Public Health Department, NMC
WSD	=	Water and Sewerage Department, Nakuru Municipal Council
Ramsar Convention	=	Convention on Wetlands of International Importance especially as Waterfowl Habitat
UNICED	=	United Nations Conference on Environment and Development
UNEP	=	United Nations Environment Programme
IMCE	=	The Inter Ministerial Committee on Environment
NCST	=	National Council for Science and Technology
KSTC	=	Kenya Science Teachers College
NEAP	=	National Environment Action Plan

IWG	=	Inter-ministerial Working Group
DDC	=	District Development Committee
UDD	=	Urban Development Department, MOLG
NGO	=	Non-governmental Organization
KEWI	=	Kenya Water Institute, MOLRRWD
TECU	=	Trade Effluent Control Unit, WSD
WAB	=	Water Apportionment Board
WRD	=	Water Resources Division, MOLRRWD
AALAE	=	African Association for Literacy and Adult Education
ANEN	=	African NGO's Environmental Network
APEMAM	=	African Pesticide and Environment Management Foundation
AWF	=	African Wildlife Foundation
CARE	=	Care International
CHEK	=	Council for Human Ecology Kenya
ELCI	=	Environmental Liaison Center International
ICRAF	=	International Council for Research in Agroforestry
WCK	=	Wildlife Clubs of Kenya
IOCN	=	The International Union for Conservation of Nature
ACTS	=	African Centre for Technology Studies

G : PRELIMINARY POLLUTION CONTROL PLAN

G: PRELIMINARY POLLUTION CONTROL PLAN

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G1. APPROACH TO THE PLANNING

G1.1 General Approach

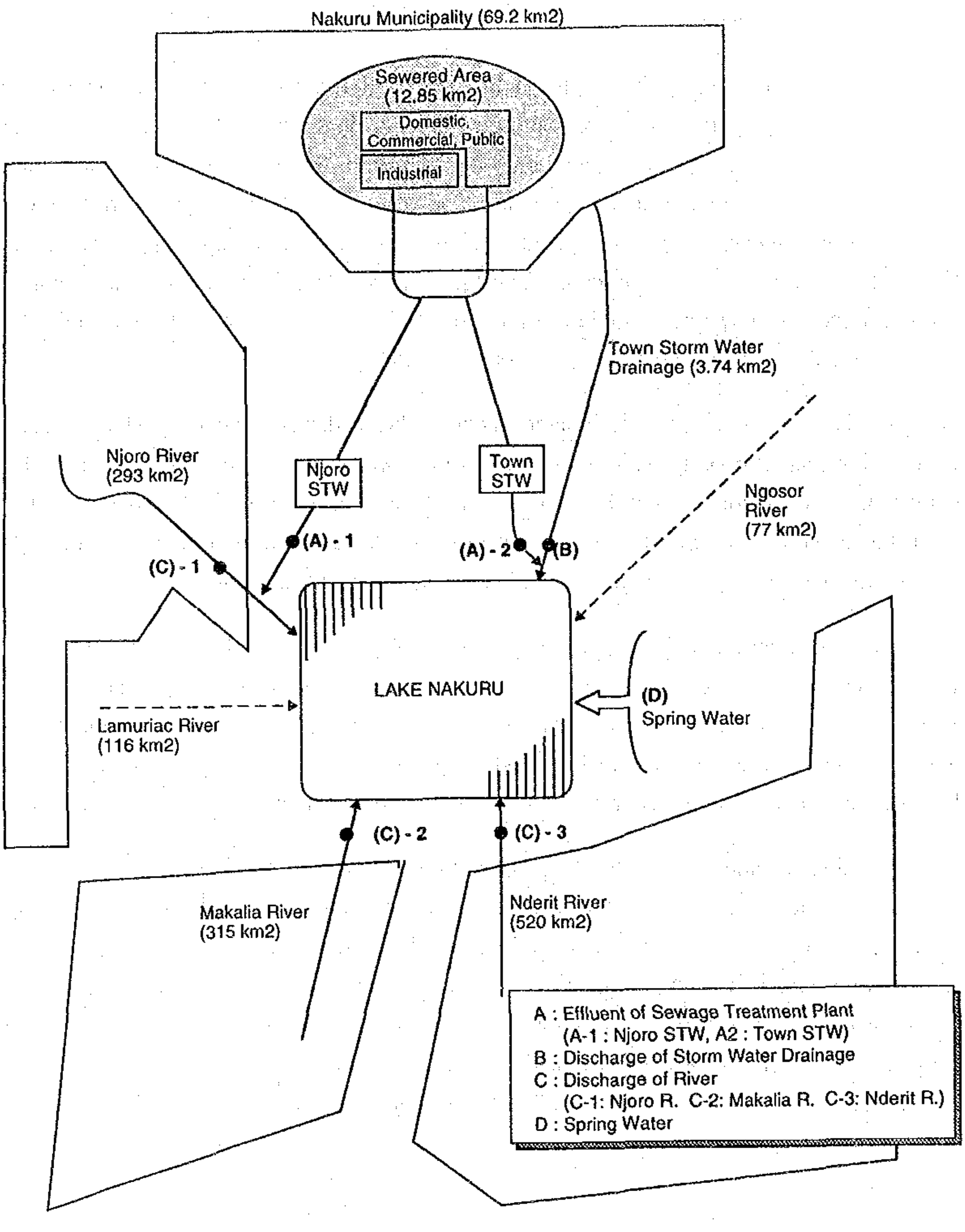
The pollutant load investigation has clarified the source, type and quantity of pollutant load discharging into Lake Nakuru from its drainage area. It is presumed that such exercise might have not been attempted so far. Through the investigation it is recognized that there are three major routes of pollutant load sources : one is sewage treatment works, the second stormwater drainage channel, and the third rivers and springs, as depicted in Fig. G-1. Pollutant load through the sewage treatment works is accrued from Nakuru Municipality and is the predominant among the three routes, followed by the stormwater drain which also originates from the Nakuru Municipality.

Lake Nakuru has been designated as one of the wetlands registered under the Ramsar Convention and its ecology is known widely to be very sensitive and delicate, although its details are not known yet wholly. For its long term conservation GOK has been placing importance and has organized an Inter-ministerial Working Group in order to coordinate and control various development activities within the catchment area.

On the other hand Nakuru Municipality is ranked as the fourth largest urban center in Kenya and it is expected to grow continuously as one of the strategic areas to be developed. In fact the municipality has been subjected to more population growth than the national average and there have been various and progressive development activities by human beings, which eventually discharges or contributes more pollutant load into Lake Nakuru.

In due consideration of the above it could be concluded that, for the conservation of ecology of Lake Nakuru, it is indispensable to establish and bring about adequate and proper countermeasures. In a short range an additional water supply of 13,300 m^3/day is expected to be commissioned, for which the current Project has been launched. Even after completion of the proposed Project, it is absolutely necessary to implement continuously medium and long term measures to cope with further increasing pollutant load owing to increasing population and continuous expansion of various development activities in the lake basin area.

Fig. G-1



THE REPUBLIC OF KENYA	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT	TITLE ROUTE OF POLLUTANT LOAD
MINISTRY OF LOCAL GOVERNMENT	JAPAN INTERNATIONAL COOPERATION AGENCY	

G1.2 Evaluation of Pollutant Load Condition into Lake Nakuru

Pollution into Lake Nakuru could be classified into a number of categories. In order to formulate efficient, rational and practical water pollution control plan, it is crucial to keep in mind the characteristics and effect of every category of pollutant load.

(1) Organic matters

Through the previous investigation it has been revealed that the northern part of Lake Nakuru is in an anaerobic state owing to accumulation of organic sedimentation, which might have originated mainly from the Nakuru Municipality and transported to the lake through sewage treatment works and stormwater drainage channel.

Under the current conditions, BOD load into Lake Nakuru is estimated at 1,471 ton /year, of which 43 % is estimated to be accrued from the existing sewage works. Further industrial activity is estimated to contribute a large part of pollutant load being generated in the sewered area. It is also estimated that 78 % of the total pollution concentrates on the northern part of the lake since there gathers the treated effluent from the sewage treatment works (43%), drainage water (11%) through channel and streamflow of the Njoro river (24%).

According to the pollutant load estimate in Supporting Report (E), the present organic pollution into Lake Nakuru is shown in Table G-1. As the measure of pollutant load reduction method, the rehabilitation and expansion of sewage works is anticipated to be effective.

Table G-1 Present Organic Pollutant load into Lake Nakuru

Route of Pollutant load	BOD		COD	
	Amount (ton/year)	Proportion (%)	Amount (ton/year)	Proportion (%)
1. Sewage works	626	43	807	42
2. Storm water drainage	161	11	215	11
3. Rivers and springs	684	46	894	47
Total	1,471	100	1,916	100

(2) Nutrient

Two types of nutrient (Nitrogen and Phosphorus) are the limiting factor for algae nutrition. When the recycling of the two types within the water or influent into the lake is decreased, the nutrient demands of phytoplanktons including Spirulina is not adequately met.

Nutrient control measure is considered as a prevention measure of eutrophication in general. In the case of Lake Nakuru algae generation is the most important issue from viewpoint of flamingo feeding. Therefore, before establishment of a strict control measure on nutrient, it will be necessary to conduct a detail study on the relationship between nutrient and the ecology of Lake Nakuru.

Table G-2 Present Nutrient Pollutant load into Lake Nakuru

Route of Pollutant load		T-N		T-P	
		Amount (ton/year)	Proportion (%)	Amount (ton/year)	Proportion (%)
1.	Sewage works	490.6	90	151.1	91
2.	Storm water drainage	12.4	2	12.5	7
3.	Rivers and springs	44.3	8	3.2	2
	Total	547.3	100	166.8	100

(3) Other

(a) Heavy Metal

It is clarified that the sources of heavy metals are industrial factories and only limited factories generates heavy metal pollution. There are several industrial factories in the Study Area which are supposed producing harmful heavy metals. However, according to the water quality investigation, any heavy metal item exceeding the standard value is detected at all.

Heavy metals are conservation materials, and their existence becomes toxic in water body when their amount reached a certain level. Once they flow into the lake, they accumulate in the lake and/or in animals without dissolving. Thus heavy metals are so dangerous to animals, or to human beings.

A strict control of heavy metal is recommended to be come into effect. As a measure against heavy metal pollution, a treatment at pollution source (at each industrial factory) is the most effective and efficient and is widely adopted in a number of developed and developing countries.

(b) *Pesticide*

Pesticide was not detected through the current water quality investigation. It is however known that pesticide causes damage on ecological condition. Adequate precautions will be required aiming at regulating the use of pesticide.

(c) Oil

Oil once flow into the lake covers its water surface, and remains a long time and accumulate in the lake. As a result it obstructs oxygen supply into the lake. Existence of oil must be eliminated to ensure every animal activity.

Oil value was actually found out only in storm water running through the existing drainage channel. KWS in fact seriously warns of inflowing oil into the lake and keen to realize appropriate measure to prevent oil inflow.

G1.3 Process of Control Planning

The water pollution control plan presented herein is a short term measure to immediately relieve the present sewage treatment condition and increasing sewage to be generated from the additional water supply and it is formulated through the following procedures :

(1) To estimate the augmentation of pollutant load into Lake Nakuru due to increase of sewage generation upon commissioning of the additional water supply of 13,300 m^3/day.

(2) To formulate a control plan for the respective pollutant load route including a comparative study in selection of sewage treatment process most suitable to the Project.

(3) To assess qualitatively and quantitatively the effect of the Project.

For the medium and long term measures, mainly non-structural proposal will be put forward in the later stage of the Study.

G2. FORECAST OF SEWAGE AND POLLUTANT LOAD UNDER ADDITIONAL WATER SUPPLY

G2.1 Conditions for Forecast

It is prerequisite to forecast an increase of pollutant load subsequent to additional water supply of 13,300 m^3/day in order to formulate and evaluate the water pollution control plan. The forecast was achieved under the following conditions :

(1)	Additional water supply	:	13,300 m^3/day to the Nakuru Municipality.
(2)	Sewerage condition	:	Sewered area remains the same as the present but sewer connection ratio increase to 92% from the present 85%.
(3)	Increased Sewage Generation	:	8,015 m^3/day to Njoro and Town STWs due to above (1) & (2) conditions. (refer to Supporting Report (D))
(4)	Stormwater drain served area	:	Same condition as the present.
(5)	Socio-economic condition	:	Same condition as the present in the Nakuru Municipality and other part of the lake basin area.
(6)	Industrial activity	:	Same condition as the present in the Nakuru Municipality and other part of the lake basin area.
(7)	Land use and agricultural activity	:	Same conditions as the present throughout the lake basin area.
(8)	Nakuru Sewerage Project	:	To be realized and implemented as stated in the sub-section 3.3.4 of this report.

G2.2 BOD Pollutant load Forecast with Greater Nakuru Water Supply

The pollutant load into Lake Nakuru flows through three different routes, such as (1) sewage treatment works, (2) storm water drainage and (3) rivers and springs, as schematically shown in Fig. G-1. Prior to forecast, an assessment of pollutant load generation was deliberated based on the results of the present pollution generation presented in Supporting Report (D).

(1) Sewage treatment works route

This is the predominant source of pollutant load into Lake Nakuru as analyzed in Chapter 4 of this report. Subsequent to the increased water supply, influent to the sewage treatment works eventually increases largely as forecast in the above.

(2) Storm drainage route

The source of pollutant load of this route is from accumulated pollution in the urban area in the Nakuru Municipality. This pollution breaks out irrespective of the potable water supply, so that the amount of pollutant load remains the same as the present.

(3) Rivers and springs route

The pollution source of this route could be divided into two areas as follows :

(a) Nakuru Municipality

Wastewater generated in the sewered area in the Nakuru Municipality wholly flows into sewers and conveyed into the sewage treatment works, whereas, as reported in Chapter 4 of this report, that in unsewered area discharges little into rivers under the present infrastructure condition. This situation is presumed to be continued since no drastic expansion of the sewer network is realized under the Project.

(b) Outside Nakuru Municipality

The Greater Nakuru Water Supply Project, Eastern Division Stage-1 feeds only the Nakuru Municipality. Accordingly it is deemed that the pollutant load from area outside the municipal area remains the same as the present.

The above assessment leads to conclusion that pollutant load increase is limited to only the sewage treatment works route.

In forecasting incremental pollutant load, it is assumed that the forecast augmented raw sewage of 8,015 m^3/day flows directly into Lake Nakuru without any treatment as schematically shown in Fig. G-2 and has a BOD strength of 800 mg/L. This BOD strength value is obtained from a study report of the on-going Nakuru Sewerage Project by NWCPC According to the report, a statistical analysis was made for the BOD values of influents recorded at Njoro STW during the period from 1988 to 1992 and as a result it is found out that the BOD value at 75 % non-exceedance probability is 800 mg/l in 1992, which is the highest among the five years. This value has actually been adopted in the design of the Nakuru Sewage Works Project.

The incremental pollutant load is calculated at 2,322 ton/year by multiplying the increased sewage volume by the given BOD strength. Table G-3 presents the pollutant load of the respective route before and after water supply.

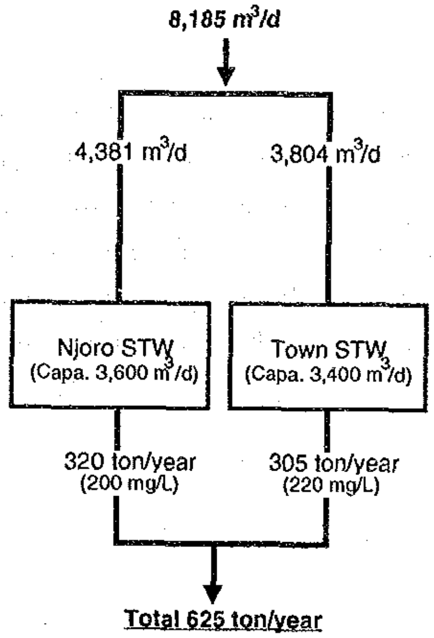
Table G-3 BOD Pollution Load Forecast with Additional Water Supply

Route of Pollutant Load	Present Condition		After Augmented Water Supply of 13,300 m^3/day	
	Amount (ton/year)	Proportion (%)	Amount (ton/year)	Proportion (%)
1. Sewage works	635	43	3,403	80
2. Storm water drainage	161	11	161	4
3. Rivers and springs				
- Njoro river	356	24	356	8
- Makalia river	122	8	122	3
- Nderit river	152	10	152	4
Springs	54	4	54	1
Total	1,480	100	4,248	100

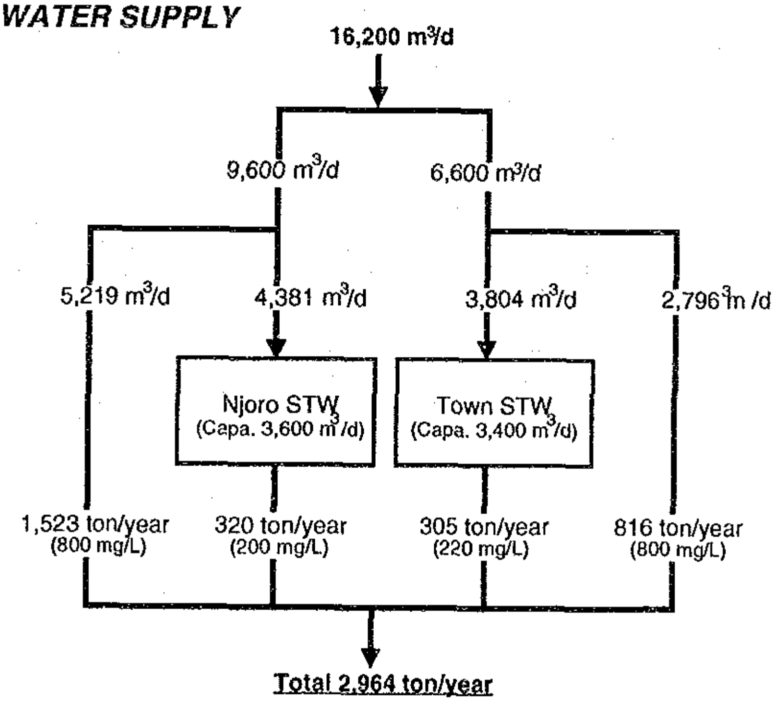
As shown in the above, pollutant load into Lake Nakuru is forecast to amount 4,248 ton/year, corresponding to 287 % of the present volume, if no adequate countermeasure is taken up in line with the additional water supply of 13,300 m^3/day. To this end it is strongly recommended that an adequate measure be keenly and urgently implemented to restrain inflow of pollutant load more than the present days.

Fig. G-2

PRESENT CONDITION



AFTER ADDITIONAL WATER SUPPLY



Note : Volume of sewage is expressed in unit of m3/d and that of pollutant load in unit of ton/year.

THE REPUBLIC OF KENYA	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT	TITLE BOD POLLUTANT LOAD FORECAST THROUGH SEWAGE TREATMENT WORKS
MINISTRY OF LOCAL GOVERNMENT	JAPAN INTERNATIONAL COOPERATION AGENCY	

With the additional water supply it is forecast that BOD pollutant load increases by 2,768 ton/year, of which 80 % is estimated to be attributed to two sewage treatment works routes.

The organic pollution in Lake Nakuru is a serious concern even at the present days and situation would be worse than the present with commencement of the additional water supply and increase of sewer pipe connection rate. Emphasis shall therefore be placed on immediate realization of the organic pollutant load reduction plan. Since the industrial activity is identified to be the major source of BOD pollutant load, it is also advisable to realize adequate measure to curb the load at its source.

G3. PRELIMINARY POLLUTION CONTROL PLAN

G3.1 Basic Strategy for Planning

The forecast and evaluation of pollutant load have revealed that there is an urgent need for establishment of an adequate, practical and rational countermeasure for each of the three pollutant load routes. Basic strategy adaptable to each route was studied and deliberated from the technical and financial viewpoints as described below :

(1) Sewage treatment works

The pollutant load through this route is the substantial among the others and it is therefore the most effective and rational to place emphasis on this route. As the reason of high pollutant load generation from sewage treatment works, following issues are considered;

(a) Lack of treatment capacity

There are two sewage treatment works in the Nakuru Municipality, which have 7,000 m^3/d of sewage treatment capacity in total. But sewage generation amount is expected to 16,200 m^3/d after augmented water supply of 13,300 m^3/d by Greater Nakuru Water Supply Project. That means there is a short of *treatment capacity amounting to 3,200 m3/d, even after completion of a new* sewage treatment work of 6000 m3/d.

(b) Lack of sludge treatment

De-sludging work has not been done properly. There is a great amount of sludge accumulated in the ponds. These sludge make wastewater retention time in the ponds todecrease, and release pollutant load such as organic and nutrient matter.

(c) High concentration wastewater

The influent BOD concentration into the sewage treatment works is estimated about 800 mg/L, which is considered to come from high pollution source such as industrial facilities.

(2) Stormwater drainage

Although stormwater drainage bears only about 11 % of the pollutant load as presented in Sections G1.2 and G1.3 of this report, it has been affecting the environment of Lake Nakuru. Major concerns are oil and high organic, which are normally accumulated elsewhere in town and runs down into drainage channels when storm rainfall occurring. The stormwater also washes down solid waste, inorganic matters and sediments from town to the lake. In order to reduce any kind of pollutant load into Lake Nakuru, stormwater retention pond and some non-structure measures are required for pollution reduction measure.

(3) Rivers and springs

For every catchment areas of the rivers feeding Lake Nakuru, major source of pollutant load generation is, in general, assessed to be livestock, wildlife, agricultural activities and other human activity on the riparian lands. Especially animals, which are supposed to be the predominant among the others, always moves around the catchment area so that it is hardly possible to control its pollution. However it may be possible to control the other sources with a special attention to harmful material such as heavy metal and pesticide by means of introduction of appropriate regulation / by-laws.

The Njoro town has been subjected to grow rapidly keeping pace with expansion of Nakuru Municipality. It could be foreseeable that the town with the current population of about 15,000 turns to a potential pollution source in future, if no control is exercised timely by IWG for development . Adequate precaution needs to be taken up within an overall framework of Lake Nakuru environment conservation so as not to create a new pollutant load source.

G3.2 Strategy for acheivement of "Wastewater Standards for Discharge into Lake Nakuru"

In this context GOK has issued "Wastewater Standards for Discharge into Lake Nakuru" in June 1993, which is presented in Supporting Report (F), and NMC is drafting " Municipal Council of Nakuru (Trade Effluent) By - Laws" (the By-laws).

One may consider that the above targets could be met simply by means of rehabilitation and expansion of the existing sewage works. However there are very difficult operational and functional constraints in due consideration of a generally accepted sewage treatment technology as briefed below :

(1) A biological process treatment technology is widely applied for sewage treatment. It aims at removing mainly organic matter, but it is hardly possible to remove heavy metals and other similar materials.

(2) In order to remove nutrient matters positively, it is necessary to install a modified biological treatment process or other specific facilities. However it is not possible to ascertain their effect quantitatively.

(3) Particularly in the current case, sewage arriving at sewage works is characterized by extremely high BOD value, 800 mg/l, owing to inflow of highly polluted industrial wastewater and less water consumption in domestic sector. The effluent standards on the other hand specifies very strict BOD value, 10 mg/L. This indicates a BOD reduction rate as high as 99 %, which seems to be hardly attainable only by a normal sewage water treatment technology.

From the above it can be concluded that it is absolutely necessary to formulate a BOD pollution control by means of a combination of on-site (control at source of pollution generation) and off-site (sewage treatment works) measures and only on-site measure for a heavy metal pollution control. In order to realize the on-site measure, adequate regulation/by-laws are to be come into effect.

G3.3 Preliminary Pollution Control Plan

As noted in the section G2.1, the preliminary pollution control plan has been formulated by a combination of structure measure and non-structure measure in line with the strategy for planning and in the light of evaluation of pollutant load.

G3.3.1 Structure Measure

(1) Sewage treatment works

Three measures are particularly proposed as described below.

(a) Rehabilitation of existing sewage works

Effluent BOD value of Njoro and Town STWs are estimated at 200 mg/L and 220 mg/L respectively under the present conditions. Those value are far higher than the design effluent value of both sewage treatment works, resulting in determination of existing facilities. Therefore the rehabilitation of existing facilities is highlighted to restore their original function in order to achieve the original design target and is proposed to be taken place as early as possible.

(b) Installation of additional treatment facilities at existing sewage works

As a result of Supporting Report D it is judged that the waste stabilization pond system with rock filter and grass plot is the most technically and economically sound and compares favourably with other alternative treatment processes in terms of pollutant load reduction . In order to further polish effluent from existing sewage treatment facilities, the rock filter and grass plot are proposed to be installed as additional treatment process at the existing sewage works and Nakuru Sewage Project.

(c) Expansion of sewage works

As forecast in Supporting Report (D) of this report, there is a deficit of 3,186 m^3/day in sewage treatment capacity even after completion of the Nakuru Sewage Project. In order to cope with this, it is therefore proposed to expand Town sewage treatment work by 3,200 m^3/day. This proposal is considered to be most sound and firm from the viewpoints of technical, financial and environmental aspects.

The proposal rehabilitation and expansion plan are as summarized in Table G-4. Table G-5 presents a stage-wise configuration of sewage treatment works.

Table G-4 Rehabilitation and Expansion Plan

Measure	Site	Facility	Proposed Capacity
Rehabilitation	Njoro	AP	2,600 m^3/d
(increasing capacity)	Town	FP	3,400 m^3/d
		MP	2,950 m^3/d
Rehabilitation	Njoro	existing facilities	-
	Town	existing facilities	-
Additional Treatment	Njoro	RF & GP	3,600 m^3/d
	New Njoro	RF & GP	6,000 m^3/d
	Town	RF & GP	3,400 m^3/d
New Construction	Town	AP+FP+MP +RF&GP	3,200 m^3/d

Note :

AP:anaerobic pond, FP:facalutative pond, MP:maturation pond, RF:rock filter, GP:grass plot

Table G-5 Process and Configuration of Sewage Treatment Works Rehabilitation and Expansion

Description	Unit	Present Condition	After Nakuru Sewerage Project	After Implementation of the Project
1. Quantity of Sewage Flow	cu.m/day	8,185	16,200	16,200
Present	cu.m/day	8,185	8,185	8,185
Increase by Augmented Water Supply	cu.m/day	-	8,015	8,015
2. Total Treatment Capacity	cu.m/day	7,000	13,000	16,200
2.1 Existing Njoro STW				
Treatment Capacity	cu.m/day	3,600	3,600	3,600
Anaerobic Pond	cu.m/day	1,000	1,000	3,600
Facultative Pond	cu.m/day	3,600	3,600	3,600
Maturation Pond	cu.m/day	3,600	3,600	3,600
Additional Treatment	cu.m/day			3,600
2.2 Existing Town STW				
Treatment Capacity	cu.m/day	3,400	3,400	3,400
Primary Clarifier	cu.m/day	3,400	3,400	3,400
Trickling Filter	cu.m/day	3,400	3,400	3,400
Secondary Clarifier	cu.m/day	3,400	3,400	3,400
Facultative Pond	cu.m/day	-	-	3,400
Maturation Pond	cu.m/day	450	450	3,400
Additional Treatment	cu.m/day	-	-	3,400
2.3 New Njoro STW (under construction)				
Treatment Capacity	cu.m/day	-	6,000	6,000
Anaerobic Pond	cu.m/day	-	6,000	6,000
Facultative Pond	cu.m/day	-	6,000	6,000
Maturation Pond	cu.m/day	-	6,000	6,000
Additional Treatment	cu.m/day	-	-	6,000
2.4 Expansion by the project				
Treatment Capacity	cu.m/day	-	-	3,200
Anaerobic Pond	cu.m/day	-	-	3,200
Facultative Pond	cu.m/day	-	-	3,200
Maturation Pond	cu.m/day	-	-	3,200
Additional Treatment (Expansion + Rehabilitation)	cu.m/day	-	-	3,200

(2) Sludge treatment and disposal

(a) Sludge generated from sewege treatment works

Sludge generating from the sewage treatment works increases with increase of sewage and would cause another pollutant load into Lake Nakuru depending on treatment and disposal. The volume of raw sludge is estimated at 7,300 m^3/year for the Njoro STW and 2,410 m^3/year for the new 3,200 m^3/day line at Town STW. It is proposed that these raw sludge have to be treated at sludge drying bed, which will be newly constructed at the respective sewage treatment works. The proposed system flow is shown in Fig. G-3.

At the Town STW, the dried sludge is being used by farmers at their cultivated land, while according to the results of sludge quality test, mercury have been detected at one time, although its value of concentration is less than the standard values of other countries. It should also be noted the facts that there are a large number of factories within the sewered area, some of which discharge the heavy and toxic materials without proper pre-treatment into sewer. Although it is preferable to make dosage of the dried sludge on cultivation area, it is recommended to monitor the quality of sludge carefully so as not create the environmental problem.

Under the current study, it is therefore proposed that the dried sludge will be hauled and disposed to the damping site. The NMC should designate appropriate dumping site away from Lake Nakuru and take adequate precautions as well as institute proper dumping method to prevent the adverse effects on the surrounding areas and natural resources.

(b) Septage in un-sewered area

The PHD releases more than 14 m^3/day of septage collected from cesspools/septic tank into public sewer, being one of the main causes for overloading on the sewage treatment works. It is proposed to treat such septage at the sludge drying beds at either Njoro and Town STWs after their construction. The dried sludge will be disposed in the same manner as the dried sludge. The proposed system flow is shown in Fig. G-3.

(c) Disposal of industrial solid waste

After enforcement of Trade Effluent By-Law, large amount of sludge will be generated from industrial facilities due to pre-treatment of industrial wastewater. Some of the industrial sludge may include toxic material such as heavy metal. Currently the industrial solid waste is dumped together with domestic refuse at the Municipal Dumping Site. In order to prevent possible pollution of groundwater by leakage from the dumping site, it is proposed to take such measures as (1) separate dumping site lined by concrete for industrial solid waste disposal and (2) reducing the volume by means of compression or dewatering.

(3) Stormwater Retention Pond

It is proposed to construct a stormwater retention pond in the vicinity of existing Town STW. The drainage water will be retained temporarily at the pond before discharging into the lake so that oil, inorganic matters, solid waste, sediments, etc, could be eliminated. Stormwater retention pond will be designed for a storm return period of once in five years and the duration of 46 minutes which is the time of flow for the remotest location. The capacity is 14,200 m^3.

G3.3.2 Non-structure Measure

The non-structural measures could be divided into a short term plan and a medium-long term plan. Detailed proposal is presented in Supporting Report K. Upon successful accomplishment of the non-structural measures, the Wastewater Standards could be attainable.

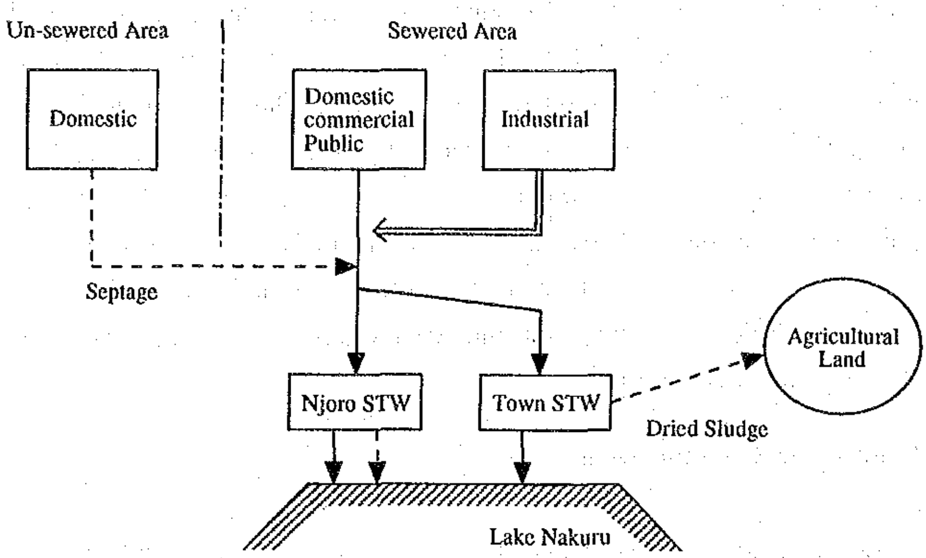
(1) Short term plan

(a) Water-related legislations

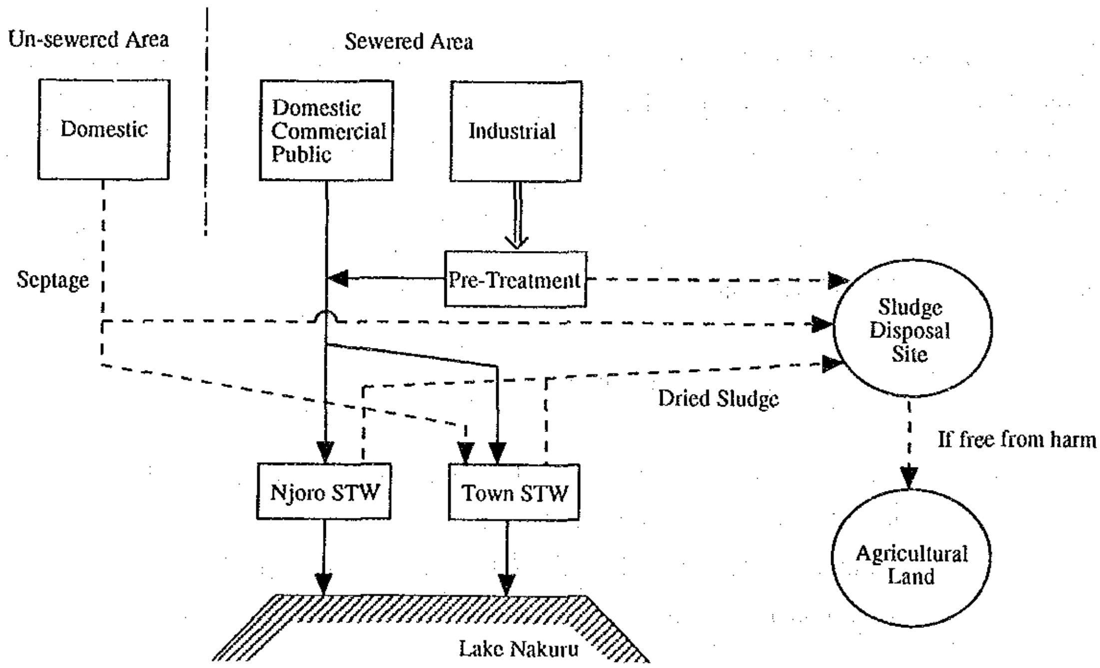
There are many Acts, Rules, Regulations and By-laws with regard to water supply, sewerage, public health and environmental conservation. It is noteworthy to report that the GOK has drafted up "National Environmental Bill" and Trade Effluent By-laws

Fig. G-3

Present Condition



Proposed System



THE REPUBLIC OF KENYA	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT	TITLE WASTE WATER AND SLUDGE FLOW IN SEWAGE ROUTE
MINISTRY OF LOCAL GOVERNMENT	JAPAN INTERNATIONAL COOPERATION AGENCY	

All the existing and drafted legislation has been studied and reviewed in view of conservation and protection of environment of Lake Nakuru as reported in detail in Supporting Report K. As the results the following recommendations are made:

(i) To approve and enact the Trade Effluent By-Laws by MOLG with additional provision for handling and storage of hazardous and toxic substances.

(ii) To enact amendment to the Water Act (Cap 372) to provide for protection of the water resources from pollution.

(iii) To enact amendment to the Local Government Act (Cap 265) in line with the provisions of the By-Laws, especially provision of stiffer penalty against polluting water resources.

(iv) To gazette the National Environmental Bill for enactment

(b) *Overall institutional support*

There is a multiplicity of the government ministries and agencies in implementation of the legislations. Most of the problems encountered arise from a low level of implementation and enforcement of law due to lack of coordination of the ministries and agencies concerned. The GOK has organized the IWG for coordination and supervision of the various institutions that are geared towards environmental protection and management. Fig. G-4 illustrates the proposed institutional organization for environmental conservation and protection of Lake Nakuru.

(c) Monitoring activities

It is a matter of vital importance to monitor pollution loads flowing into Lake Nakuru, the lake water quality and quantity and quality of industrial effluents from the Nakuru Municipality. Especially monitoring of industrial effluents is necessary for the proper enforcement of the Trade Effluent By-Laws, which is the most important and integral element of the proposed pollution control plan.

The monitoring plan is elaborated in detail as presented in Supporting Report K. It is classified into four categories; (1) rivers, channels and springs, (2) industrial effluents and sewage treatment works effluents, (3) lake water quality, and (4) stormwater drainage. For the respective category, sampling frequency and water quality testing items are proposed.

For the above purpose, it is proposed to establish a Water Quality Testing Laboratory, organization of which is elaborated as shown in Fig. G-5. The Laboratory will be operated and maintained through coordination and cooperation among MOLG/MMC, WOLRRWD and KWS and staffed by 11, of which 9 should be of qualified.

(2) Medium and long term plan

(a) Monitoring activities

The monitoring activities proposed as one of the short term plan is required to be continued.

(b) Urban and regional development control

As a strategy for reduction of the increasing pollutant load, it is proposed that urban and regional development activities within the Lake Nakuru basin be controlled. The control plan will envisage:

(i) Restricting the size and type of industries
(ii) Relocation of industries producing heavy metals and causing excessive hydraulic loading on the lake
(iii) Excessive use of fertilizers and agro-chemicals

As noted in the short term plan, all the development activities will be controlled and supervised by the IWG.

(c) Master plan study for Lake Nakuru basin development

It is proposed to formulate a master plan for development and conservation the natural resources of the Lake Nakuru basin. The objectives of the master plan will include, but not limited to (1) assessment of development potential of the natural resources, (2) development of policy guidelines for future development on an environmentally sustainable basis, and (3) development of strategies for Lake Nakuru from degradation.

(d) Master plan for sewerage development

Comprehensive sewerage development plan has not yet been established by GOK for the Nakuru Municipality and other urban areas in the catchment area of Lake Nakuru. It is therefore strongly recommended that a long term master plan on sewerage system development be formulated for every urban areas as soon as possible. The plan shall be elaborated not only on the basis of ordinary methodology and process of the sewerage system development planning, but also in due consideration of unique geographic, environmental and socio-economic condition in the catchment area of Lake Nakuru. Especially it is absolutely necessary to draw attention on resolving the increase of sewage and pollutant loads into the lake owing to implementation of expansion of sewerage systems. In this context it is deemed essential to place emphasis on justification of technical feasibility of inter-basin diversion scheme of treated sewage, which will also associate with re-demarcation of sewerage districts in the Nakuru Municipality.

G4. FORECAST OF POLLUTANT LOADS INTO LAKE NAKURU WITH THE PROJECT

With implementation of the proposed pollution control plan, pollutant loads into Lake Nakuru will be reduced greatly. Especially a great reduction is anticipated to be derived from the sewage treatment works. The reduction of BOD and nutrient is estimated as described below:

G4.1 BOD Load Reduction

BOD pollutant loads into Lake Nakuru estimated for the following five cases:

Case-1	Present conditions
Case-2	After additional water supply of 13,300 m^3/day
Case-3	After Nakuru Sewerage Project
Case-4	After proposed rehabilitation and expansion
Case-5	After implementation and enforcement of Trade Effluent By-Laws

The calculate condition of each cases are shown in Table G-6.

Table G-6 Pollutant Load Forecast Criteria

	Case (1)	Case(2)	Case(3)	Case(4)	Case(5)
Quantity of Sewage Generation (m^3/d)	8,185	16,200	16,200	16,200	16,200
BOD concentration of Raw sewage (mg/L)	800	800	800	800	500
Effluent BOD Concentration (mg/L)					
Njoro 3,600	200	200	200	15	10
Njoro 6,000	-	-	30	15	10
Town 3,400	220	220	220	15	10
Town 3,200	-	-	-	15	10
Total Capacity of STWs (m^3/d)	7,000	7,000	13,000	16,200	16,200
Pollutant Load from Stormwater	Same as present	Same as present	Same as present	30 % reduction	30 % reduction

The estimate for both the Cases 1 and 2 is reported in Section 4.1 of this Chapter. The process of the estimate for Cases 3, 4 and 5 is as illustrated in Fig. G-4 and the results of the estimate are as presented in Table G-7.

Table G-7 Forecast of BOD Pollutant Loads into Lake Nakuru

(Unit: ton/year)

Route of Pollutant Load	Case-1	Case-2	Case-3	Case-4	Case-5
1. Sewage Treatment Works	626	2,964	1,450	89	59
2. Stormwater drainage	161	161	161	113	113
3. Rivers and Springs					
- Njoro River	356	356	356	356	356
- Makalia River	122	122	122	122	122
- Nderit River	152	152	152	152	152
- Springs	54	54	54	54	54
Total	1,471	3,809	2,295	886	856

(Data source: Study Team)

It is clear that pollutant (BOD) load into Lake Nakuru decreases greatly, 1,514 ton/year by Nakuru Sewerage Project and 1,409 ton /year by the contemplated Project, 2,953 ton/year in total corresponding to 78% of the forecast value after the additional water supply. When compared to the present condition, pollutant load decreases to 58% so that a great contribution is expected for conservation of environment of Lake Nakuru.

G4.2 Nutrient Load Forecast

T-N and T-P concentrations are forecast only for Cases 1 and 5 based on typical values that could be achieved when industrial wastes are properly controlled and sewage are properly treated. Such value is 8 mg/L for T-N and 6 mg/L for T-P. The T-N and T-P loads for Case-1 are derived from the results of the water quality investigation.

Table G-8 Forecast of Nutrient Pollutant Loads into Lake Nakuru

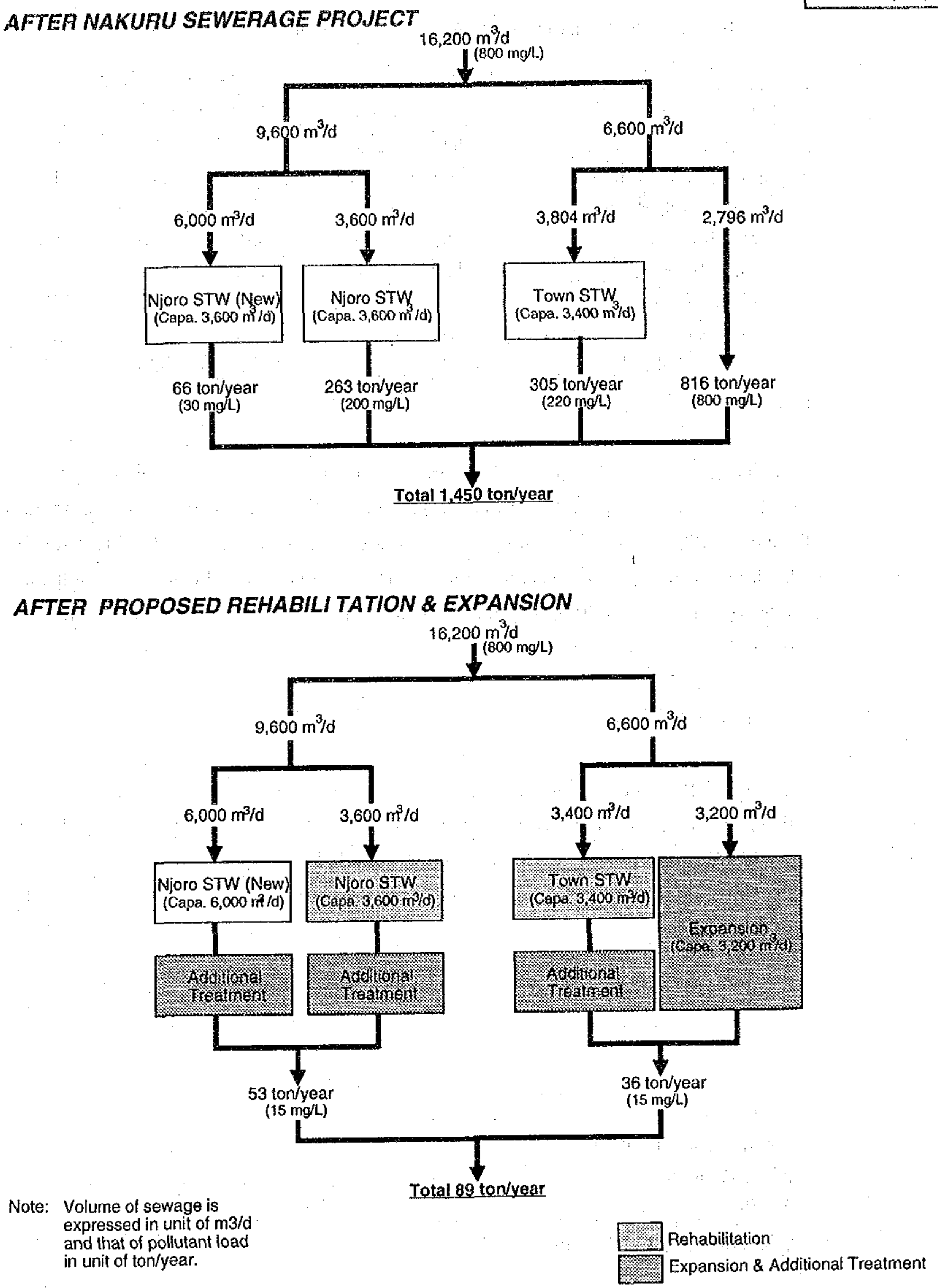
(Unit: ton/year)

	T-N		T-P	
	Case (1)	Case (5)	Case (1)	Case (5)
Sewage Treatment Works	491	47	151	35
Storm water Drainage	12	12	13	13
River & other	44	44	3	3
Total	547	103	167	51

(Data source: Study Team)

It is assumed that the storm water retention pond is of no effect on reduction of nutrients.

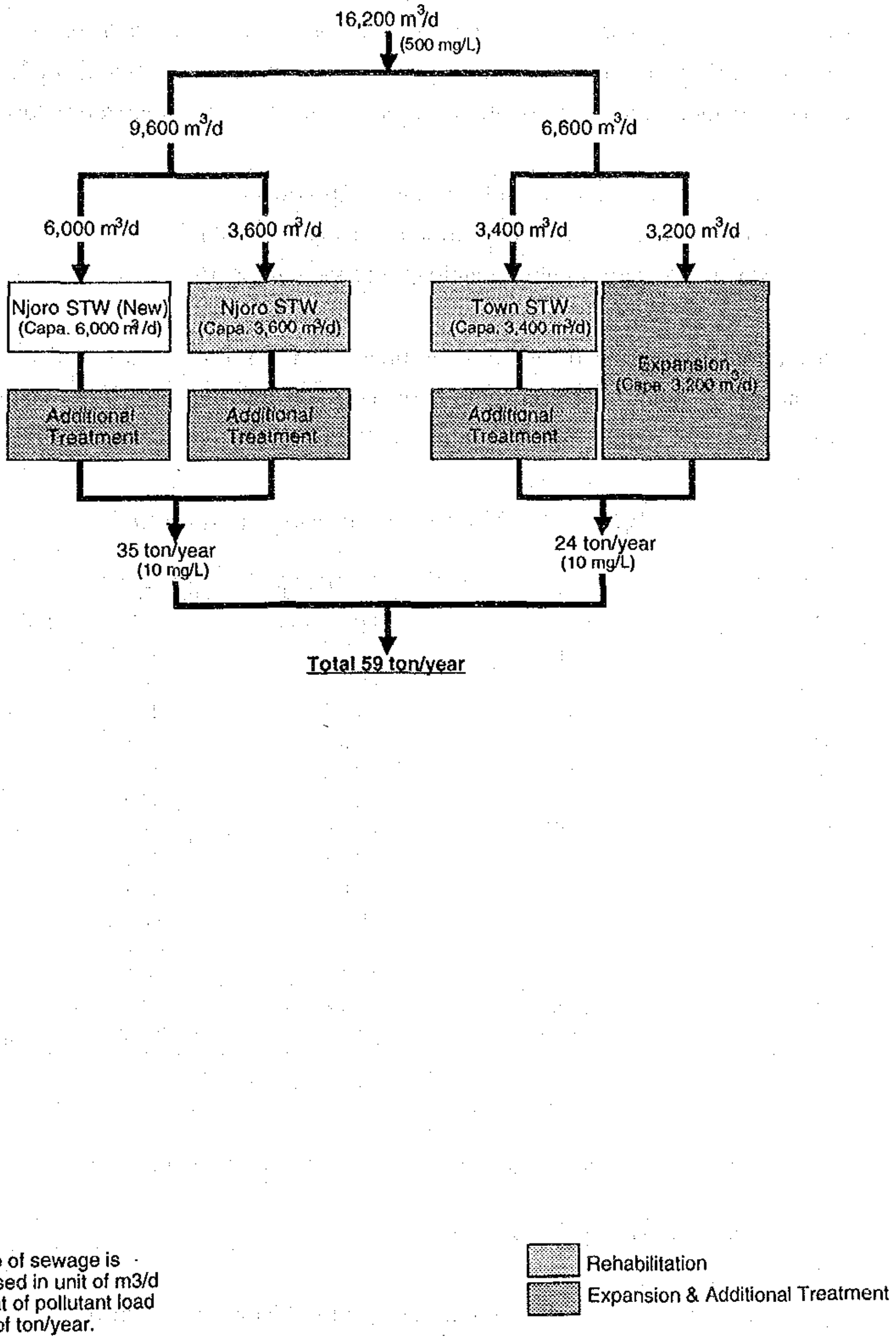
Fig. G-4 (1/2)



Note: Volume of sewage is expressed in unit of m3/d and that of pollutant load in unit of ton/year.

THE REPUBLIC OF KENYA MINISTRY OF LOCAL GOVERNMENT	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY	TITLE BOD POLLUTANT LOAD FORECAST THROUGH SEWAGE TREATMENT WORKS

AFTER IMPLEMENTATION AND ENFORCEMENT OF TRADE EFFLUENT BY-LAWS



Note: Volume of sewage is expressed in unit of m3/d and that of pollutant load in unit of ton/year.

THE REPUBLIC OF KENYA	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT	TITLE BOD POLLUTANT LOAD FORECAST THROUGH SEWAGE TREATMENT WORKS
MINISTRY OF LOCAL GOVERNMENT	JAPAN INTERNATIONAL COOPERATION AGENCY	

G4.3 Effect of Evaporation

As the sewage treatment process mainly depends on waste stabilization ponds, rock filters and grass plots, it is expected that a certain amount of water will be lossed in form of evaporation and evapo-transpiration through such treatment facilities. The effect of evaporation and evapo-transpiration would be as summarized below:

(a) Reduced effluent from sewage treatment works
(b) Increase in concentration of sewage stored in ponds
(c) Increase in retention time of sewage in ponds

An attempt was made to estimate volume of evaporation loss based on monthly rainfall and evaporation records during the period from 1990 and 1992. The total area of the ponds, rock filter and grass plots is 48.2 ha at Njoro STW and 30.9 ha at Town STW.

Table G-9 Monthly Evaporation and Rainfall

Month	Pan Evaporation (1)	Open Water Evaporation (2)	Rainfall (3)	Net Evaporation (4)
Jan.	236.2	165.4	44.2	121.2
Feb.	200.1	140.1	26.8	113.3
Mar.	198.6	139.0	102.7	36.3
Apr.	134.4	94.1	150.2	-56.1
May	124.3	87.0	100.9	-13.9
June	125.7	88.0	40.8	47.2
July	132.3	92.6	89.9	2.7
Aug.	144.7	101.3	100.7	0.6
Sep.	153.9	107.7	69.7	38.0
Oct.	139.1	97.3	74.1	23.2
Nov.	129.6	90.7	58.1	32.6
Dec.	165.1	115.6	46.7	68.9
Total	1,884.0	1,318.8	904.8	414.0

Note : (1) Openwater surface = Pan evaporation x 0.7
(2) (4) = (2) – (3)

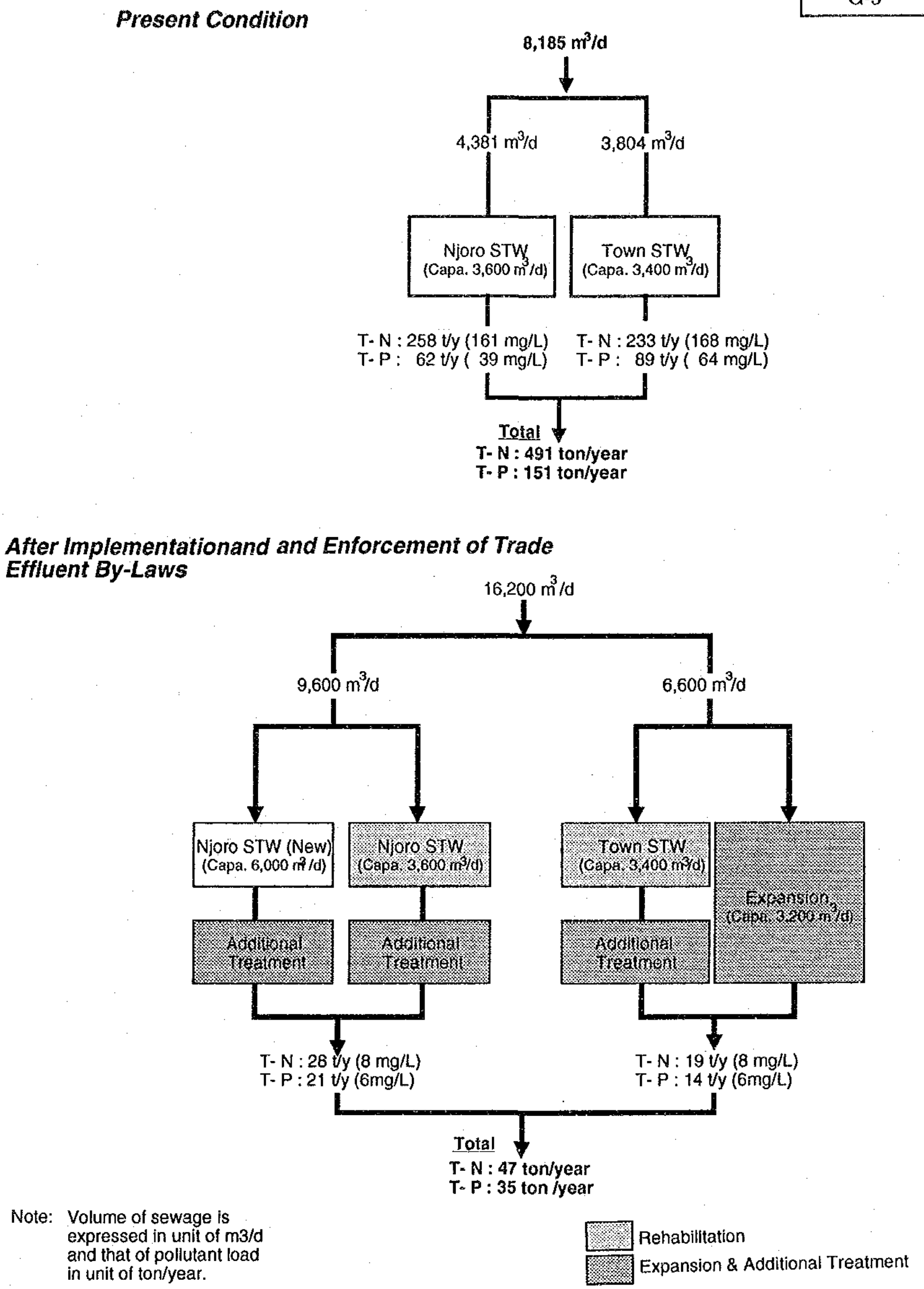
(Data source: Showground climatological station, Study Team)

The evaporation loss is calculated below:

Njoro STW : 482,000 m^2 x 0.414 m/365 days = 546 m^3/day
Town STW : 309,000 m^2 x 0.414 m/365 days = 350 m^3/day

It is supposed that effect of (b) may be offset by that of (c).

Fig. G-5



THE REPUBLIC OF KENYA MINISTRY OF LOCAL GOVERNMENT	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY	TITLE NUTRIENT POLLUTANT LOAD FORECAST THROUGH SEWAGE TREATMENT WORKS

H : ALTERNATIVE STUDY ON SEWAGE TREATMENT WORKS

H: ALTERNATIVE STUDY ON SEWAGE TREATMENT WORKS

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H1. INTRODUCTION

Treatment process adopted for Njoro STW is a series of waste stabilization ponds, while Town STW has a trickling filter and maturation ponds for wastewater treatment and digester for sludge treatment. Design capacity of the sewage treatment facilities is 7,000 m^3/day in total: 3,600 m^3/day for Njoro STW and 3,400 m^3/day for Town STW.

Ongoing expansion project at Njoro STW, the Nakuru Sewerage Project is expected to be completed by September 1994. An increment of the treatment capacity, 6,000 m^3/day, is to cope with the increasing wastewater discharge from the municipality. For the purpose of preliminary comparison of sewage treatment process existing capacity of the Njoro STW is assumed at 9,600 m^3/day.

To draw an outline picture of treatment process and project facilities, followings are considered:

(1) Influent wastewater quality and quantity
(2) Topographical and climatological features of the Study area
(3) Required capital, operation and maintenance costs
(4) Expected life of completed facilities
(5) Environmental impacts on surrounding area
(6) Number of staff and engineers available for proper operation and maintenance
(7) Financial capability of the executing agency

H2. BASIC DESIGN CONDITIONS AND CONCEPTS

H2.1 Basic Design Conditions

Basic design conditions for the sewage treatment process are summarized in Table H-1. Expansion will be to increase the capacity of Town STW by 3,200 m3/day to a total capacity of 6,600 m3/day and additional processes to improve the effluent quality of both Town STW and Njoro STW.

Table H-1 Basic Design Conditions

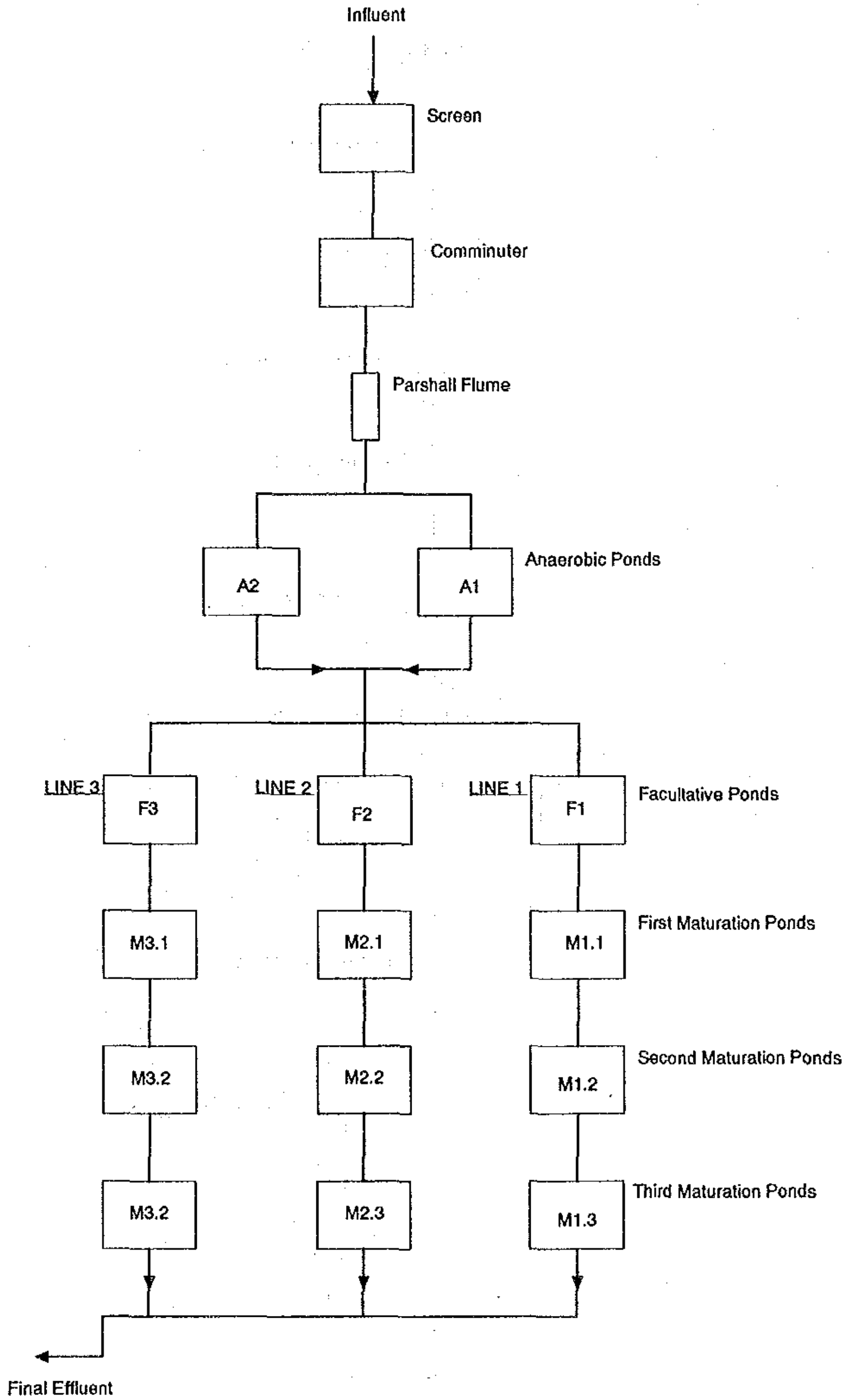
	Njoro STW	Town STW
1) Existing Treatment Process	Waste Stabilization Ponds (Fig. H-1)	Settling Tank + Trickling Filter (Fig. H-2)
2) Design Inflow Rate (m^3/day)		
-Existing Facilities	9,600	3,400
-Expanded	-------	3,200
Total	9,600	6,600
3) Design Influent Quality		
- BOD (mg/L)	500	500
- Feacal Coliform (per 100 mL)	10^8	10^8
4) Temperature (°C)*	16	16
5) Effluent Quality	(Refer to Table F-1.)	

*---- Temperature, an averaged figure in the coldest month, is a value adopted for designing the existing facilities.
(Data Source: Study Team & WSD)

H2.2 Basic Concept for Selection

Required effluent quality is generally achieved by a single process or a combination of several processes. For the current project, the latter is considered appropriate since the effluent quality standards are very stringent.

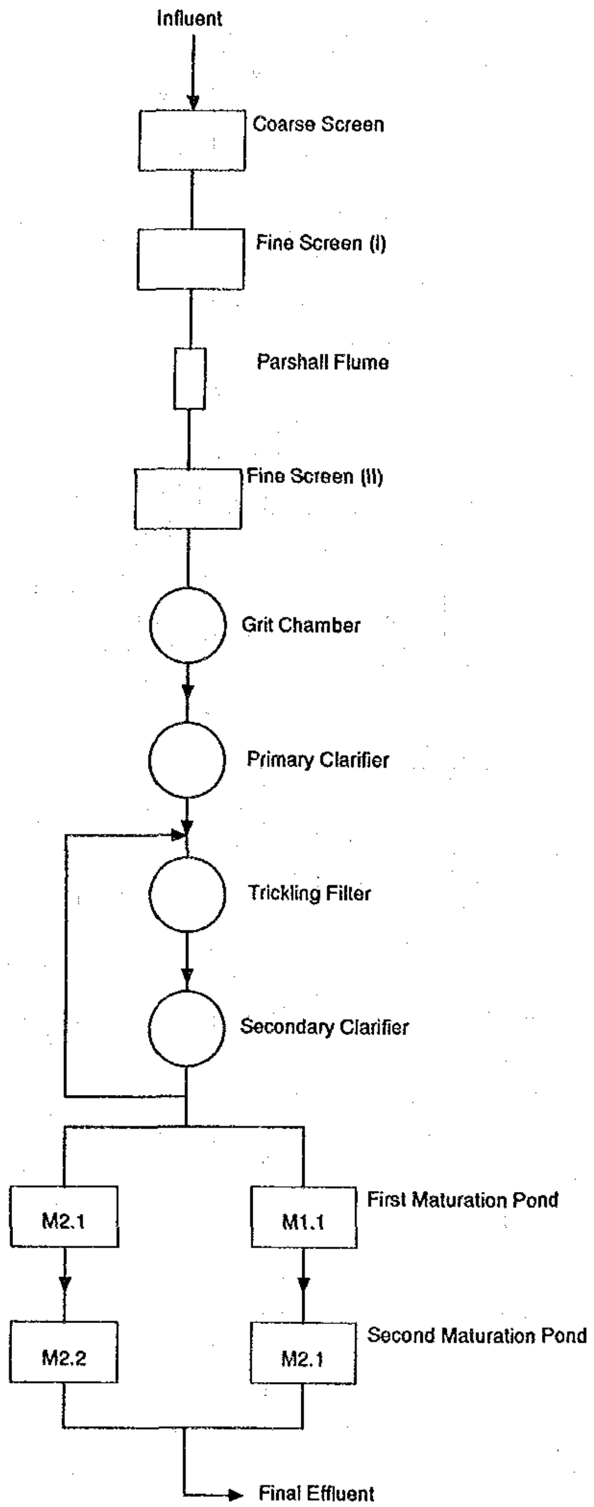
Fig. H-1



(Data source : Study Team & SWD)

THE REPUBLIC OF KENYA MINISTRY OF LOCAL GOVERNMENT	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY	TITLE Schematic Flow Diagram of Njoro STW

Fig. H-2



Data source : Study Team & SWD

THE REPUBLIC OF KENYA MINISTRY OF LOCAL GOVERNMENT	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY	TITLE Schematic Flow Diagram of Town STW

To select alternative treatment processes to be adopted for the sewage treatment works, followings are considered essential:

(1) *Overall processes should be a combination of biological processes.*

(2) Main targets of sewage treatment processes are to remove BOD, SS and faecal coliforms to satisfy the limits of the effluent quality standards. Partial removal of nutrients (nitrogen and phosphorus) will occur during removal of BOD.

(3) Effluent quality standards provided to the Team are relatively stringent as compared with those in various developed countries that apply the state of art technology for sewage treatment processes. Biological processes to meet the standards are not available under the circumstances. Hence, process options are selected among those that may possess potential for satisfactory treatment to GOK.

(4) Effluent quality after treatment at waste stabilization ponds, trickling filter and oxidation ditch is generally around 20mg/L in terms of BOD. To achieve the target (10mg/L of BOD), it is considered necessary to adopt additional treatment with biological processes to improve the secondary treated effluent.

Table H-2 shows target effluent quality at each step.

Table H-2 Required Effluent Quality

Step	Process	Required Effluent Quality
First Step	Secondary	about 20 mg/L of BOD
Second Step	Additional	less than 10 mg/L of BOD and a certain level of nutrients removal

(Data Source: Study Team)

H3. TREATMENT PROCESSES GENERALLY APPLIED

H3.1 Secondary Treatment Method

Secondary treatment processes generally applied are those for the existing treatment works, modified waste stabilization ponds and an activated sludge process. They are summarized in the following Table H-3:

Table H-3 Secondary Treatment Process

Item	Process
Process Currently Adopted	- Wastewater Stabilization Pond (WSP) - Trickling Filter, Maturation pond (TF + MP)
Modified WSP	- Aerated Lagoon (AL)
Activated Sludge	- Oxidation Ditch (OD)

(Data Source: Study Team)

H3.2 Additional Treatment Process

H3.2.1 General Principle

(1) Upgrading method

"Design Manual for Eastern Africa edited by Overseas Development Administration (UK), Lagoon Technology International, 1992" (the Manual) recommends single or combined processes of a rock filter and grass plots as upgrading method of waster stabilization ponds. Removal performance is also described in the Manual and are shown in Table H-4.

Table H-4 Removal Performance of Rock Filter and Grass Plots

Process	BOD	SS	Remarks
Rock Filter	50% removal rate	70% removal rate	Middlebrooks, USA (1988)
Rock Filter + Grass Plots	from 70mg/L to less than 20mg/L	from 100mg/L to 20mg/L, ranging from 50% to 60% removal rate	Witherow and Bledsou (1983)

(Data Source: Design Manual for Eastern Africa by Overseas Development Administration, 1992)

Nutrients are also removed during the upgrading processes though numerical figures are not available.

Supposing that the above removal rates are applicable to the sewage treatment works in Nakuru, introduction of rock filter alone is capable to produce effluent quality within the limits of BOD and SS standards.

Grass plots are used for upgrading of effluents in Kericho, located 90 km west of Nakuru. A field reconnaissance survey was conducted by the Team in August 1993, and no major operational problems were observed.

(2) Land treatment processes (quoted from Wastewater Engineering, Metcalf & Eddy, Inc.)

Five typical land treatment processes are slow infiltration, rapid infiltration, overland flow, wetland application and subsurface application. They involve the use of plants, the soil surface and/or the soil matrix for wastewater treatment.

These typical processes assessed in detail in "Wastewater Engineering, Metcalf & Eddy, Inc." are reproduced as shown in Table H-5.

Table H-5 Comparison of Design Features for Alternative Land-Treatment Process

Feature	Slow Infiltration	Rapid infiltration	Overland flow	Wetland application	Subsurface application
Application techniques	Sprinkler or surface 1)	Usually surface	Sprinkler or surface	Sprinkler or surface	Surface
Annual application rate, m	0.6 - 2.0	6 - 91	7 - 57	5 - 18	5 - 18
Field area required, ha 2)	18 - 59	0.4 - 6.0	0.6 - 4.8	1.9 - 6.6	1.9 - 6.6
Minimum preapplication treatment provided	Primary sedimentation 3)	Primary sedimentation	Screening and grit removal	Primary sedimentation	Primary sedimentation
Disposition of applied wastewater	Evapotranspiration and percolation	Mainly percolation	surface runoff and evapotranspiration with some percolation	Evapotranspiration, percolation and runoff	Percolation with some evapotranspiration
Need for vegetation	Required	Optional	Required	Required	Required

1) Includes ridge and furrow and border strip
2) Field area in hectares not including buffer area, roads, or ditches for 0.044 m^3/s flow
3) Depends on the use of the effluent and the type of crop.

(Source : Wastewater Engineering, Metcalf & Eddy, Inc.)

Disadvantages of the processes are referred to a need for vegetation in the application area and a large fluctuation of design loading depending on climatic conditions.

Table H-6 shows a comparison of expected effluent quality from land treatment systems.

Table H-6 Comparison of Expected Quality of Treated Water from Land-treatment Processes *

Unit : mg/L

Parameter	Slow Infiltration 1)		Rapid infiltration 2)		Overland flow 3)		Subsurface Application
	Average	Maximum	Average	Maximum	Average	Maximum	Average
BOD	<2	<5	2	<5	10	<15	10
Suspended solids (SS)	<1	<5	2	<5	15	25	<10
Ammonia nitrogen as N	<0.5	<2	0.5	<2	1	<3	-
Total nitrogen as N	3	<8	10	<20	5	<8	<5
Total phosphorus as P	<0.1	<0.3	1	<5	4	<6	<2~4

Note :
1) Percolation of primary or secondary effluent through 1.5 m of soil
2) Percolation of primary of secondary effluent through 4.5 m of soil
3) Runoff of comminuted municipal wastewater over about 4.5 m of slope
* It should be noted that these effluent qualities are applicable when treating sewage found elsewhere i.e. raw sewage BOD_5 concentration of 200~250 mg/L

(Source : Wastewater Engineering, Metcalf and Eddy, Inc.)

(3) Others

As an advanced treatment process, combined carbon oxidation and nitrification-denitrification process with coagulants dosage and rapid sand and activated carbon filtration are widely accepted in Japan in the last decade. The former is to remove BOD and nitrogen. Phosphorous is removed as coagulated particles. The latter is to improve effluent quality by filtration and absorbtion of SS and dissolved matter.

This method is a combination of the advanced activated sludge to remove BOD as secondary treatment process and filtration. Hence, it can be said that the method is recognized as secondary and advanced treatment.

The effluent quality is the most stable among the processes proposed herein. In addition, land requirement is minimal. Disadvantages of the method and that a huge capital cost and the number of highly skilled staff required for operation and maintenance.

H3.2.2 Options for Additional Treatment

Among the processes described in H3.2.1, two options are tentatively selected for assessment. They are : 1) rock filter + grass plots (RF + GP) and 2) combined carbon oxidation nitrification-denitrification process with coagulant dosage (CON) + rapid sand filter (RSF) + activated carbon filter (ACF). Following are the reasons for the selection:

(1) Among the land treatment processes, slow infiltration, rapid infiltration and subsurface application are not selected for detail consideration for the following reasons:

(a) slow infiltration would require large land area
(b) stringent soil characteristics are necessary for rapid infiltration
(c) subsurface application requires regular clearing of surface vegetation. Problems related to nuisance of mosquito breeding is also expected.

(2) Overland flow process is similar to grass plots and better effluent quality is reported (Wastewater Engineering, Metcalf & Eddy). It should be noted that the overland flow process alone is not sufficient to improve the waste stabilization pond effluents as reported in the same reference.

(3) Nutrient removal data for grass plots is not reported in the ODA Manual. However, as discussed in (2) above grass plots is similar to overland flow process and considerable removal of nutrients can be expected.

(4) Grass plots is being used in Kericho, Kenya and no major problems are found.

(5) Rock Filter and Grass Plots are recommended as upgrading method for waste stabilization pond effluents by the ODA Manual for Eastern Africa.

It may be difficult to ensure compliance with the effluent quality standards for nutrients because presently influent concentration of total nitrogen and total phosphorous are extremely high (T-N concentration of around 200~300 mg/L and T-P concentration around 10~20 mg/L).

Option 2) which is (CON) + (RSF) + (ACF) is a combination of secondary and advanced treatment that differ much in their operational characteristics and performance.

H3.3 Selected Alternatives for Treatment Process

From the discussions in the foregoing sections five alternatives as shown in Fig. H-3 are selected for assessment. Primary and secondary treatment process in Alternative-1 is similar to the existing Town STW and that of Alternative-2 is similar to that of existing Njoro STW. Alternative-3 and Alternative-4 are modifications of waste stabilization ponds where aeration is used.

Fig. H-3 Selected Alternatives for Assessment

	BOD5 of Effluent (mg/L) ~120	~20	~10
ALT-1	PST + TP + SST	MP	RF + GP
ALT-2	AP + FP + MP		RF + GP
ALT-3	AL + ST		RF + GP
ALT-4	OD + ST		RF + GP
ALT-5	PST + CON + RSF + ACF		

Note:
- PST : a primary settling tank,
- SST : a secondary settling tank,
- FP : facultative ponds,
- RF : a rock filter,
- ST : a settling tank,
- CON : combined carbon oxid. nitri-denitri. process,
- TF : a trickling filter,
- AP : anaerobic ponds,
- MP : maturation ponds,
- AL : an aerated lagoon,
- OD : an oxidation ditch,
- RSF : a rapid sand filter.
- ACF : an activated carbon filter

(Data Source: Study Team)

Nutrient concentration in the effluent for the selected alternatives are shown in Table H-7 for reference. It should be noted that these concentrations are attained when the raw sewage T-N and T-P concentrations are in the order of 40 mg/L and 8 mg/L respectively (typical composition of untreated domestic wastewater, source : Wastewater Engineering, Metcalf & Eddy).

Table H-7 Typical Nutrient Quality of Effluent for Selected Alternatives ‡

Alternative	T-N, mg/L	T-P, mg/L
Alt - 1~4*	5	4
Alt - 5#	9	0.4

Note: * Values quoted in Table H-7
Experience in Japanese STW's
‡ Literature values when treating raw sewage of T-N and T-P concentrations in the order of 40 and 8 mg/L.

(Data Source: Study Team)

H4. SELECTION OF TREATMENT PROCESS

H4.1 Efficiency of Treatment Process

General layout of the above five alternatives are shown in Figs. H-4 to H-8 for a design flow rate of 2,000 m^3/d. Their salient features are shown in Table H-8.

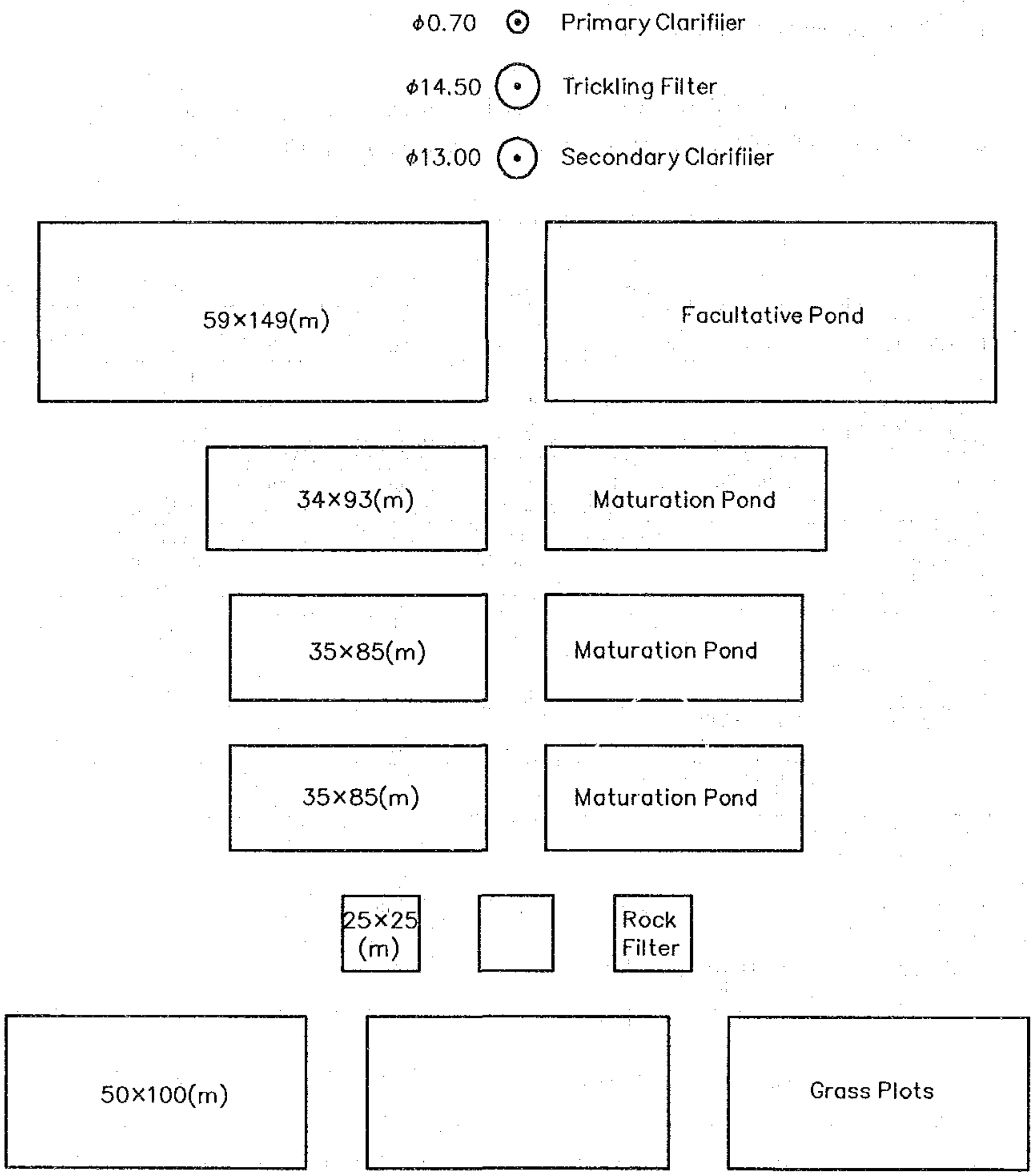
Table H-8 Salient Features of Treatment Processes

Item		Alt - 1	Alt - 2	Alt - 3	Alt - 4	Alt - 5	Remarks
Stability of	Secondary	good	good	good	good	good	
Effluent Quality	Additional	fair	fair	fair	fair	good	
Treatability against fluctuation of pollutant loadings		good	fairly good	fairly good	good	a regulater required	
Established	Secondary	established	established	established	established	established	
system for maintenance	Additional	not established	not established	not established	not established	not established	
Routine Maintenance Required		not much	not required	not much	not much	much required	
Expertise Required		not much	not required	not much	not much	much required	
Volume of Sludge Generated		less	least*	least	less	much	
Experience	Nos.of STW applied	8	26	4	1	0	As secondary treatment
	Capacity (m3/day)	88,000	252,000	-	7,000	0	As secondary treatment
Areas Required (ha) for Q = 2,000 m^3/d		9.3	13.1	5.3	2.7	0.4	
Investment Cost (1000 yen/anum)	Civil Works	2,800	3,100	1,200	4,000	5,500	50 year life
for Q = 2,000 m^3/d	Mechanical /Electrical	10,000	-	5,400	16,400	39,100	15 year life
	O & M	2,000	-	10,500	5,300	50,200	
	Total	14,800	3,100	17,100	25,700	94,800	

Note: * Even though the volume of sludge generated is the least, frequent desludging is required for anaerobic ponds.

(Data Source: Study Team)

Fig. H-4



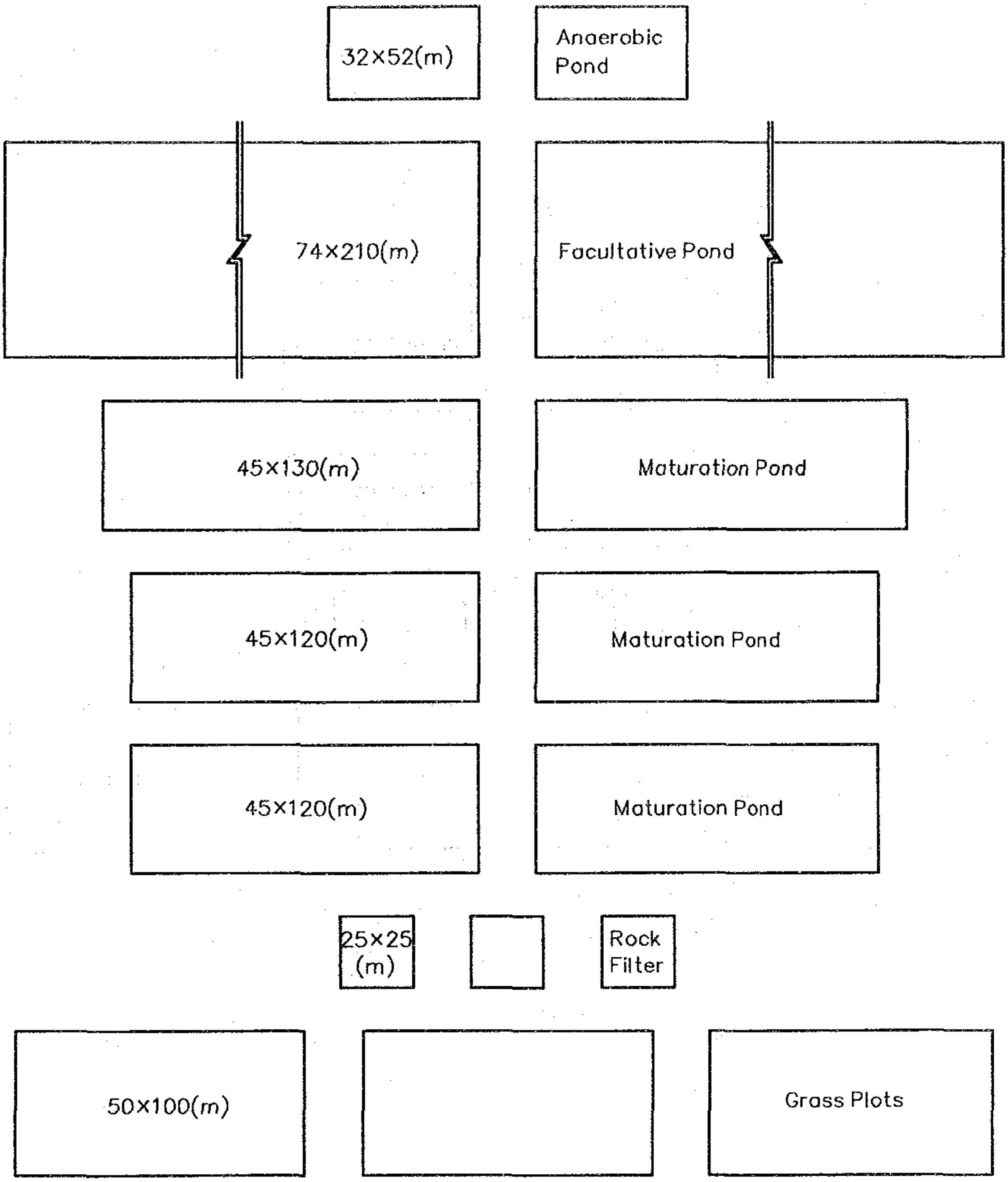
Data source : Study Team

Design Flowrate : 2000 m^3/d

Scale 0 25 50m 1:2,000

THE REPUBLIC OF KENYA MINISTRY OF LOCAL GOVERNMENT	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY	TITLE ALTERNATIVE−1

Fig. H-5



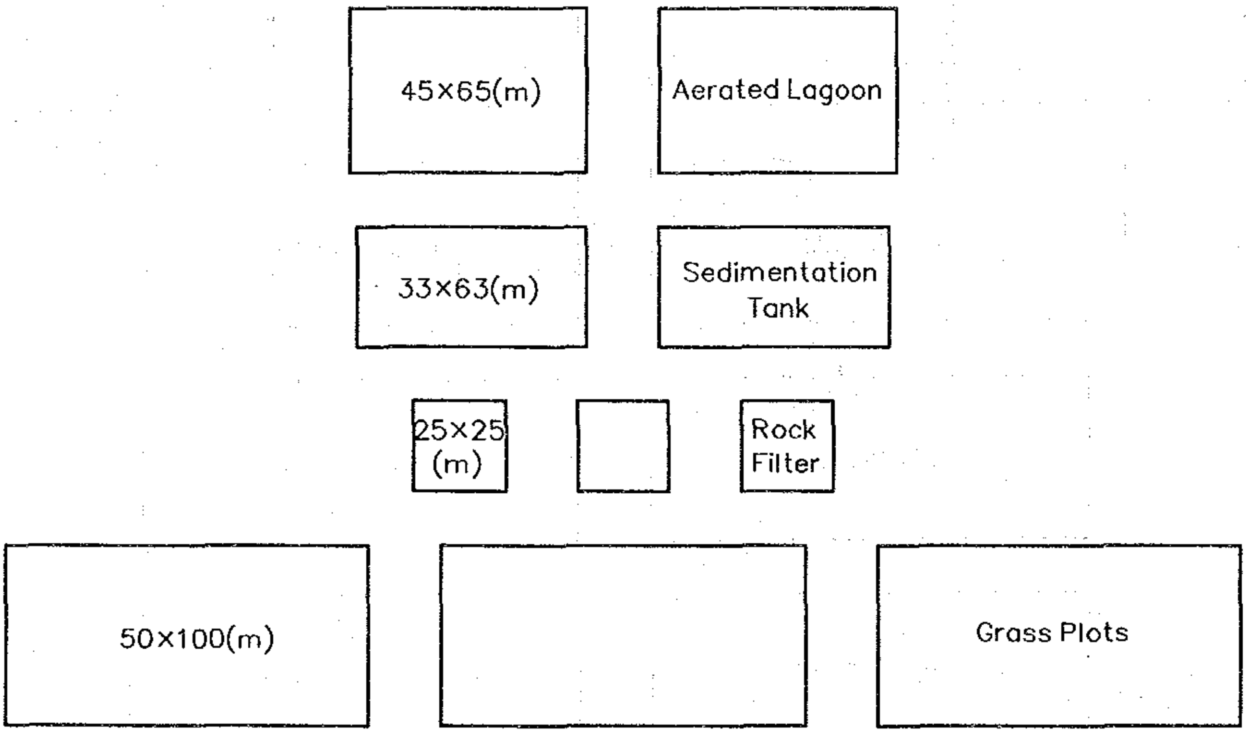
Data source : Study Team

Design Flowrate : 2000 m^3/d

Scale 0 25 50m
1:2,000

THE REPUBLIC OF KENYA MINISTRY OF LOCAL GOVERNMENT	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY	TITLE ALTERNATIVE-2

Fig. H-6



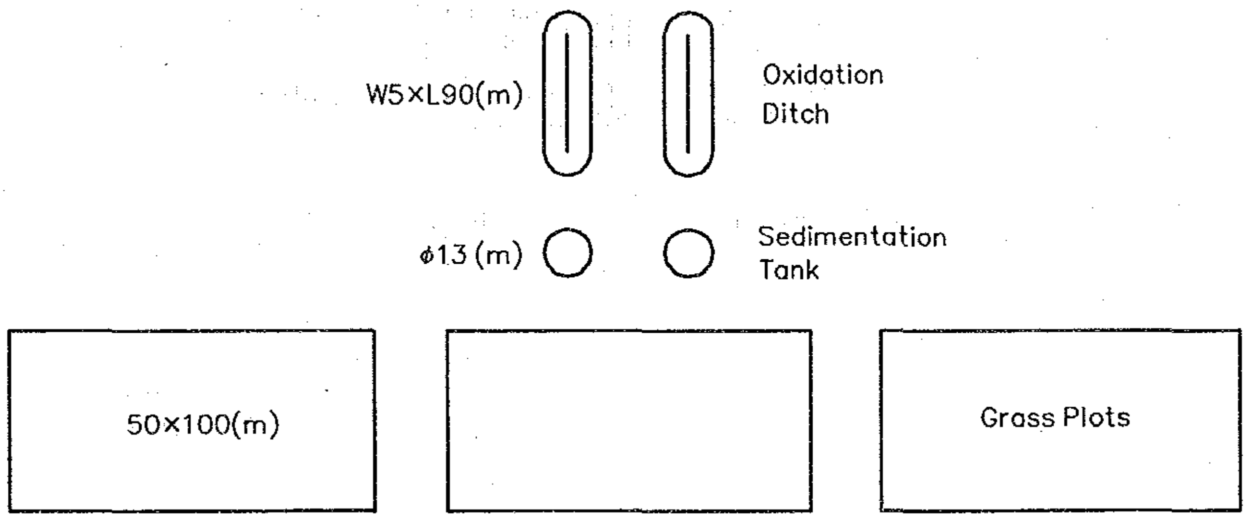
Data source : Study Team

Design Flowrate : 2000 m^3/d

Scale 0 25 50m 1:2,000

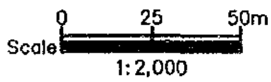
THE REPUBLIC OF KENYA MINISTRY OF LOCAL GOVERNMENT	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY	TITLE ALTERNATIVE-3

Fig. H-7



Data source : Study Team

Design Flowrate : 2000 m^3/d



THE REPUBLIC OF KENYA MINISTRY OF LOCAL GOVERNMENT	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY	TITLE ALTERNATIVE−4

Fig. H-8

4.5×13.0(m) Primary Sedimentation Tank

4.5×40.0(m) Re-actor

4.5×18.0(m) Secondary Sedimentation Tank

3.5×3.5(m)
3.5×5.0(m) Sand Filter + Activated Carbon Filter

25×25 (m) Rock Filter

50×100(m) Grass Plots

Data source : Study Team

Design Flowrate : 2000 m^3/d

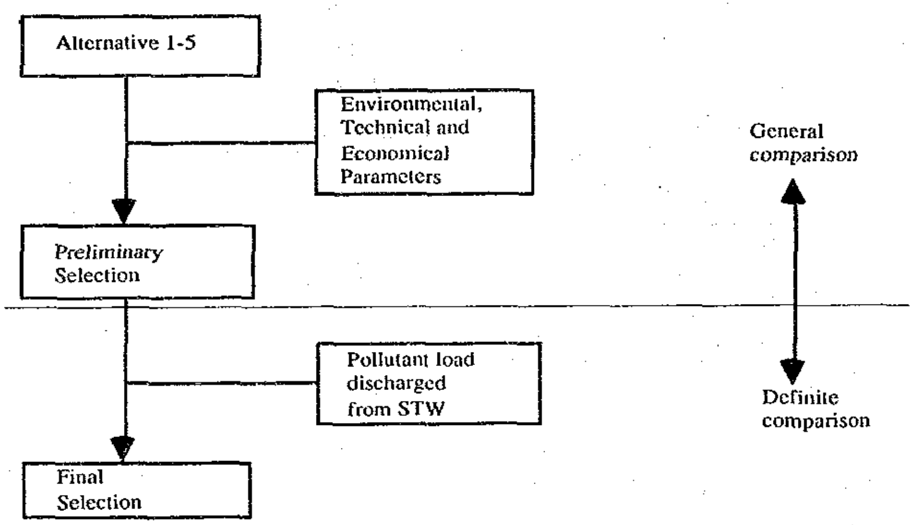
Scale 0 25 50m
1:2,000

THE REPUBLIC OF KENYA MINISTRY OF LOCAL GOVERNMENT	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY	TITLE ALTERNATIVE-5

H4.2 Assessment of Alternatives

Assessment of alternatives will be conducted in two steps as shown in Fig. H-9. In the first step, alternatives will be assessed by comparing environmental, technical and economical parameters to arrive at a preliminary selection of an alternative. Generally available information will be used. Suitability of this alternative will be further assessed in the second step considering the objectives of upgrading wastewter treatment which is the reduction of pollutant load to Lake Nakuru. Definite comparison will be made in this step.

Fig. H-9 Assessment Method of Alternatives



(Data Source : Study Team)

(1) Assessment method for preliminary selection

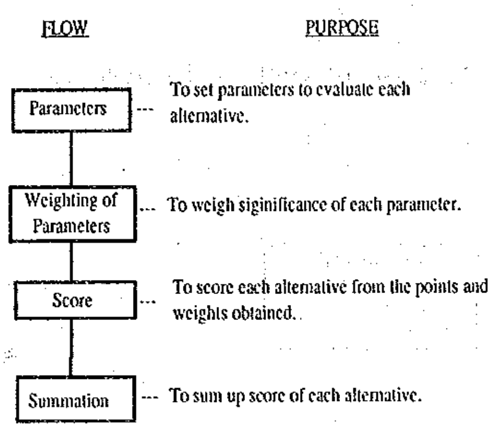
Outline of the assessment method preliminary selection is schematically shown in Fig. H-10.

(2) Parameters considered

Under three categories of environment, technical and economical aspects, relevant parameters are selected.

Project area stands on a gently sloping hillside with mild climate. Vast and spacious land is available. These characteristics should be reflected on design of project facilities. An availability of skilled staff is a key to an effective operation and maintenance of the completed facilities. It is also of vital importance to keep investment and O & M cost minimum.

Fig. H-10 Assessment Method for Preliminary Selection



(Data Source: Study Team)

(3) Quantification of significance

Points given for each alternative varying from minimum zero (0) to maximum five (5), and alternatives are assessed on a basis shown in Table H-9.

Table H-9 List of Parameters for Evaluation of Treatment Process

Parameters	Weight	Evaluation Basis	Points High	Points Low
ENVIRONMENTAL				
Compliance with Climates	7	- Applicable to the Climate	Applicable	Not Applicable
Effects on Environment	1	- Probable Cause of Odour	Not a Cause	A Probable Cause
Area Required	1	- Area Required	Small	Large
Topography	1	- Natural Slope Benefited	Benefited	Not Benefited
TECHNICAL				
Easiness in O & M	5	- Easiness	Easy	Not Easy
O & M Staff Required	1	- Nos. of Staff Required for O & M	Less	Not Less
Spare Parts Required	2	- Spare Parts Locally Available	Available	Not Available
Treatability	2	- Stable Quality of Effluent Against Pollutant Load Fluctuation	Stable	Not Stable
ECONOMICAL				
Construction Cost	3	- Moderate in Construction Cost	Moderate	costly
Availability of Materials	1	- Availability of construction Materials	Available	Not Available
O & M Cost	5	- Moderate in O & M Cost	Moderate	Costly
Chemicals Required	1	- Chemicals Required for Treatment	Not Required	Required

(Data Source: Study Team)

(4) Preliminary Selection of Alternative

Table H-10 shows results of comparison. Alternative-2 is considered the most suitable among the five alternatives from the standpoints of environment, technology and economy.

Table H-10 Evaluation of Treatment Process

Parameters	Weight	Alt - 1		Alt - 2		Alt - 3		Alt - 4		Alt - 5	
		Points	Score	Points	Score	Points	Score	Points	Score	Points	Score
ENVIRONMENTAL											
Compliance with Climates	7	3	21	5	35	5	35	2	14	1	7
Effects on Environment	1	2	2	4	4	2	2	3	3	5	5
Area Required	1	2	2	1	1	3	3	4	4	5	5
Topography	1	3	3	5	5	3	3	3	3	2	2
Sub-total	10		28		45		43		24		19
TECHNICAL											
Easiness in O & M	5	3	15	4	20	2	10	1	5	0	0
O & M Staff Required	1	3	3	5	5	5	5	2	2	1	1
Spare Parts Required	2	3	6	5	10	4	8	3	6	1	2
Treatability	2	3	6	3	6	3	6	4	8	4	10
Sub-total	10		30		41		29		21		13
ECONOMICAL											
Construction Cost	3	2	6	5	15	4	12	3	6	1	3
Availability of Materials	1	2	2	5	5	3	3	2	2	1	1
O & M Cost	5	4	20	5	25	4	20	3	15	1	5
Chemicals Required	1	5	5	5	5	5	5	5	5	1	1
Sub-total	10		33		50		40		28		10
Total	30	-	91	-	136	-	112	-	73	-	42

(Data Source: Study Team)

I : PRELIMINARY DESIGN

I: PRELIMINARY DESIGN

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I1. INTRODUCTION

This Supporting Report presents the preliminary designs of the sewage treatment works and stormwater retention pond and guidelines for operation and maintenance. Various survey, investigation and studies have been carried out in order to formulate the rehabilitation and expansion of the sewage treatment works and they are compiled in the respective supporting report. The following supporting reports provide detailed data and information pertinent to the preliminary design.

Supporting Report A	:	Geological Investigation
Supporting Report B	:	Water and Sludge Investigation
Supporting Report C	:	Existing Sanitary Services
Supporting Report D	:	Sewage Generation Analysis
Supporting Report F	:	Effluent Water Quality Standards
Supporting Report G	:	Alternative Study on Sewage Treatment Works

In performing the preliminary design, particular reference is made to the following :

- Design Manual for East Africa, Overseas Development Administration (UK), Lagoon Technology International, 1992

- Lagoon Performance and the state of Lagoon Technology, From Office of Research and Monitoring, US Environmental Protection Agency

- Sectoral Study and National Programme for Community and Rural Water Supply, Sewerage and Water Pollution Control, Report No. 9, Selection and Design Criteria for Sewage Projects, WHO, May 1973

- Waste Water Engineering, Treatment, Disposal, Reuse, McGraw - Hill International Editions

- Design Criteria for Sewerage Facilities, Japan Sewerage Association

Valuable advises have been extended by the Kenyan counterpart team members in performing the preliminary design, for which the JICA Study Team would like to express their appreciation.

I2. BASIC CONCEPTS AND DESIGN CRITERIA FOR PRELIMINARY DESIGN OF SEWERAGE SYSTEM

I2.1 Basic Concepts for Rehabilitation and Expansion of Sewage Treatment Works

The physical condition and operational functions of the existing sewage treatment works have been investigated and needs for rehabilitation have been identified as reported in Supporting Report C. The sewage generation and institutional support system have been studied as presented in Supporting Reports D and K respectively. Through these elaboration, basic strategies have been set forth for rehabilitation and expansion of existing sewage works as summarized below:

Njoro STW :

- Treatment capacity: 9,600 m^3/day, composing of existing 3,600 m^3/day line and Nakuru Sewerage Project with 6,000 m^3/day
- Remodeling of the existing facilities for better treatment process
- Construction of additional treatment facilities such as rock filters and grass plots
- Construction of additional staff housing

Town STW :

- Treatment capacity: 6,600 m^3/day, composing of existing 3,400 m^3/day line and a new 3,200 m^3/day line
- Construction of a new sewage works with a treatment capacity of 3,200 m^3/day with a waste stabilization ponds process and additional treatment facilities such as rock a filters and grass plots
- Construction of additional treatment facilities such as rock filters and grass plot to be connected to the existing 3,400 m^3/day line
- Construction of a control office, workshop and staff houses
- Renovation of mechanical and electrical components of the existing 3,400 m^3/day line

Mwariki Pumping Station :

- Construction of a new pumping station
- Replacement of existing pumping facilities with new ones

A comparative study on sewage treatment process has been deliberated as given in Supporting Report H. It is concluded that a waste stabilization pond treatment process is the most technically and economically feasible for the project. The proposed new sewage works at Town STW and remodeling of existing sewage works at Njoro STW are therefore to be designated by the selected treatment process

I2.2 Design Criteria

For the purposes of design of various project components, the following design parameters are applied:

(1) General design parameters

(a) Amount of sewage

- Dry weather flow : 16,137 m^3/day
- Daily maximum factor : Ave. daily : Max. daily = 0.75 : 1.00
- Hourly peak factor : Ave. daily : Hourly peak = 1.00 : 2.00

(b) Design discharge for trunk sewer

- Njoro trunk sewer : 0.222 m^3/s, hourly peak
- Town trunk sewer : 0.153 m^3/s, hourly peak

(c) Design inflow into sewage works

	Sewage (m^3/day)			
	Average daily	Maximum daily	Hourly peak	Rainwater (m^3/day)
(c.1) Njoro STW				
- Existing	3,600	4,800	7,200	-
- Nakuru Sewerage Project	6,000	8,000	12,000	-
Total	9,600	12,800	19,200	1,900
(c.2) Town STW				
- Existing	3,400	4,500	6,800	-
- New expansion works	3,200	4,300	6,400	-
Total	6,600	8,800	13,200	1,400

(d) Design influent and effluent qualities

"Wastewater Standards for Discharge into Nakuru Nakuru" was discussed from the viewpoint of the sewage treatment technology and in the light of the standards in other countries. The following is the main issues:

BOD: Both the Kenya and Japanese teams reached conclusions through a number of discussions that (1) it is not possible to attain the BOD value 10 mg/L set forth in the above standards only by generally acceptable sewage treatment technology and (2) it is absolutely important to implement/enforce adequate non-structural measures such as pre-treatment of industrial wastewater in harmony with rehabilitation and expansion of existing sewage treatment works.

The Project is recognized to be implemented as earlier as possible, whereas it is apparent that it takes a long period to control/regulate the quality of the industrial wastewater flowing into the public sewer. It is therefore essential to establish a realistic pollution control plan adaptable to circumstances prevailing at the Study Area. As initial step, it is proposed to rehabilitate and expand the existing sewage treatment works to properly treat the increasing sewage and reduce the BOD concentration from 800 mg/L in influent to 15 mg/L in effluent. In subsequent step, the standard value of BOD concentration could be achieved with implementation/enforcement of the Trade Effluent BY-laws, which is being prepared by NMC to control harmful industrial wastes and limit the BOD concentration to 700 mg/L when discharging into public sewers.

The BOD_5 concentration is supposed to be decreased to around 400 - 500 mg/L if the above-said By-laws are successfully brought into effect. It is therefore expected that the effluent could consequently be upgraded to the level of the standard value.

SS: With effect of the rock filter and grass plot a target value is set at 15 mg/L.

COD: It is not possible to attain the value specified in the standards, less than 30 mg/L as reported in detail in Supporting Report F.

Nitrogen & Phosphate: Removal of the nutrients are expected to some extent but is difficult to assess quantitatively.

Heavy metals: Heavy metals and others are non-biodegradable substances. Heavy metals interfere with the biological processes and settle and accumulate in the waste stabilization ponds because of the physico-chemical conditions within the waste stabilization ponds. Excessive accumulation will result in problems for sludge disposal. Therefore, source control is important and shall be exercised to control these pollutants at their sources.

The target values of effluent are accordingly set out as given below:

	Influent	Effluent (Target values)
- BOD_5	800 mg/L	15 mg/L
- SS	700 mg/L	15 mg/L
- Fecal Coliform	10^8/100 mL	10^3/100 mL
- Air temperature at coldest month	16°C	16°C

(2) Proposed sewage treatment process

(a) Njoro STW

- Existing 3,600 m³/day line	:	Waste stabilization ponds with rock filters and grass plots
- 6,000 m³/day line	:	Same as above

(b) Town STW

- Existing 3,400 m³/day line	:	Conventional type, consisting of primary and secondary clarifiers, and trickling filter. To be improved with additional treatment facilities by the project
- New 3,200 m³/day line	:	Waste stabilization ponds with rock filters and grass plots

(c) Sludge treatment method : Sludge dry bed

(3) Design criteria for waste stabilization ponds

The design of the waste stabilization ponds has referred to "Design Manual for East Africa, Overseas Development Administration (UK), Lagoon Technology International, 1992" (the ODA Manual).

(a) Anaerobic Ponds (AP)

(i) Volumetric loading rate

$\lambda v = 20T - 100$

where, λv = Volumetric loading rate, $g/m^3/day$

T = Mean air temperature of coldest month, °C

(ii) BOD_5 removal = 2T + 20

(iii) Desludging frequency: Twice per year

(b) Facultative Ponds (FP)

(i) Surface loading

$\lambda s = 350 (1.107 - 0.002T)^{T-25}$

where, λs = Surface loading rate, kg/ha/day

T = Mean air temperature of coldest month, °C

(ii) Maximum surface loading

$\lambda sm = 60 (1.099)^T$

where, λsm : Maximum surface loading, kg/ha/day

(iii) BOD_5 concentration of effluent

$Le = (Lo)/(1 + Kt \times t)$

where, Le = Effluent BOD_5, mg/L

Lo = Influent BOD_5, mg/L

t = Retention time, days

K_T = Breakdown rate per day of sewage organic

= $0.3 \times (1.05)^{T-20}$ (d^{-1})

(c) 1st Maturation Pond (FMP)

(i) Maximum permissible BOD loading (λs)

λs = 75 percent of that into the preceding facultative pond

(ii) Influent BOD_5 (Lo)

Lo = 30 percent of that into the preceding facultative pond

(d) Second and Third Maturation Ponds (SMP and TMP)

(i) Effluent fecal coliforms

$$Ne = \frac{Ni}{(1+K_T ta)(1+K_T tf)(1+K_T tm_1)(1+K_T tm_s)^n}$$

where, Ne = Fecal coliforms of effluent number per 100 mL

Ni = Raw sewage fecal coliforms, number per 100 mL

ta = Retention time in AP , day

tf = Retention time in FP, day

tm_1 = Retention time in first maturation pond, day

tm_s = Retention time in SMP and TMP, day

n = Number of SMP and TMP, nos.

K_T = First order rate constant for FC removal per day $= 2.6 \times (1.19)^{T-20}$

(4) Design criteria for inlet and pond connection pipes

(a) Design discharge : Hourly peak discharge

(b) Velocity through pipe : 0.6 m/sec

(5) Design criteria for rock filer and grass plot

The rock filters and grass plots are to be connected to the waste stabilization ponds as additional treatment facilities. Reference is made to the following literatures in establishment of design loadings on rock filters and grass plots:

Rock filters :
- The ODA Manual
- State of Illinois, U.S.A., Rock Filer Design Standards

Grass plots :
- The ODA Manual
- Waste Water Engineering, McGraw-Hill International Edition

	Unit	Loading Rate: ODA Manual	Illinois State Standard	Waste Water Engineering	Adopted
(a) Rock filters	m^3/rock·m^3/day	1.0	0.8	-	0.5
(b) Grass plots	m^3/ha/day	2,000 - 5,000	-	208 - 1,560	1,000

The design values are determined conservatively in order to achieve as much higher water quality as possible.

(6) Design criteria for sludge drying bed

(a) Settlement sludge

$Mr = f \times Q \times SS$

$Md = a \times Mro + Mri$

Where,
- Mr : raw sludge solid (settlement)
- Mro : organic portion of Mr, ($Mro = 0.7 \times Mr$)
- Mri : inorganic portion of Mr, ($Mri = 0.3 \times Mr$)
- Md : digested sludge solid
- f : fraction of SS removed, 0.5
- a : decrease rate on digestion process, 0.5
- SS : suspended solids, mg/L
- Q : average daily flow , m^3/day

(b) Biological sludge solids

$Ms = Y \times BOD \times Q$

where,
- Ms : biological sludge solids, g
- Y : field coefficient, 0.2 mg/mg
- BOD : BOD reduced in pond, mg/L

(c) Sludge from APs

Water content : 90%

Unit weight : 1.0 ton/m^3

(d) Dried sludge

Water content : 50%

Unit weight : 1.25 ton/m^3

I3. PRELIMINARY DESIGN OF MWARIKI PUMPING STATION

I3.1 Pumping Station

The existing pumping station is inclined due to differential settlement of its foundation. It is therefore proposed to build a new station at site opposite to the existing one.

The new pumping station is 30.0 m^2 in floor area and is composed of a resting room for operator, a lavatory and a generator room. The preliminary design is given in DWG. B-1.

I3.2 Mechanical and Electrical Works

The following mechanical and electrical works are required:

(1) Re-setting of a diesel generator at the new pumping station

(2) Replacement of three existing submergible pumps with the new ones. Each pump shall be of cutter model, 7.5 kW, 240 V and 0.75 m^3/min capacity.

(3) Installation of mercury level switch for stirrers.

(4) Installation of an integrated control cabinet for operation of pumps and stirres, including a changeover switch between KPLC electric power supply and the diesel generator.

A single line diagram for electrical works is given in DWG. M-1.

I4. PRELIMINARY DESIGN OF NJORO STW

I4.1 Proposed Treatment Process

As noted in the preceding section I2.1, the existing 3,600 m^3/day line is proposed to be rehabilitated aiming at achieving more higher treatment efficiency by means of remodeling of waste stabilization ponds and provision of the additional treatment facilities composing of rock filters and grass plots. Fig. I-1 illustrates a schematic diagramme of treatment process.

I4.2 Sewage Treatment Process Design

I4.2.1 Existing 3,600 m^3/day Line

In accordance with the recommendation set forth in Supporting Report C, it is proposed to remodel the existing waste stabilization pond in order to ensure the targeted effluent water quality. It could be reiterated here that the existing facultative ponds are required to be enlarged in order to reduce the load as required. Due attention is also paid to make the operation and maintenance simpler as possible, and as a result it is proposed to remodel the existing ponds according to the criteria set forth in the ODA Manual and adjust the existing three lines into two lines.

General layout and hydraulic profile of the line are presented in DWGs. N-1 and N-2 respectively.

(1) Anaerobic Ponds (AP)

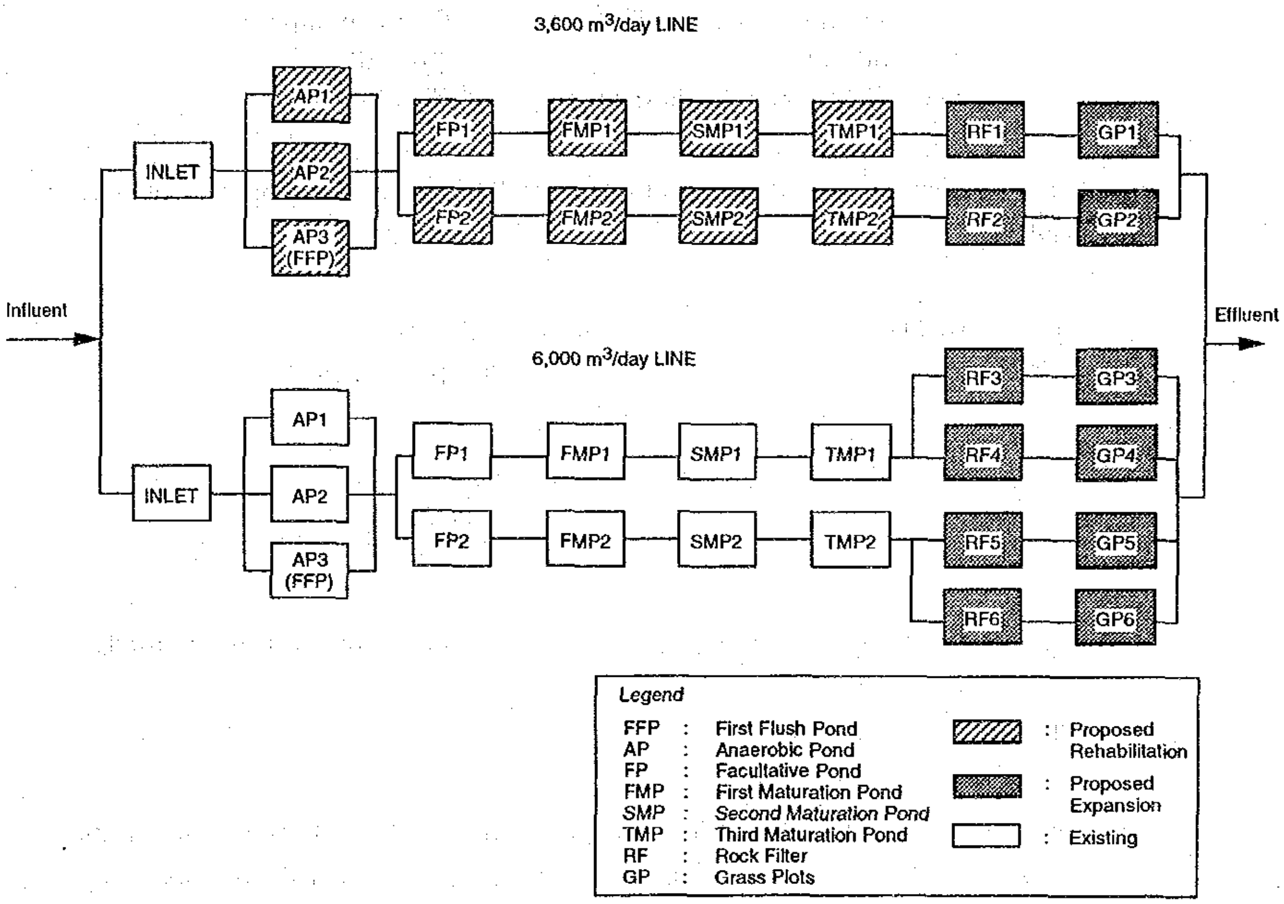
Design calculations are given hereunder.

(a) Volumetric loading rate $\lambda v = 20T - 100$

$$= 20 \times 16 - 100 = 220 \text{ g/m}^3\text{/d}$$

(b) Required pond volume $v = \frac{Liq}{\lambda v}$

$$= \frac{800 \times 3,600}{220} = 13,091 \text{ m}^3$$



THE REPUBLIC OF KENYA MINISTRY OF LOCAL GOVERNMENT	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY	TITLE SCHEMATIC DIAGRAMME OF TREATMENT PROCESS FOR NJORO STW

The effective depth is selected at 3.0 m in accordance with the ODA Manual. The AP is finally designed with the following features:

Number of ponds	:	2
Effective volume of each pond	:	6,777 m^3
Cross-sectional shape	:	Trapezoidal
Dimension of each pond		
Bottom area	:	1,368 m^2, 24 m x 57 m
Surface area at NOL	:	3,150 m^2, 42 m x 75 m
Effective water depth	:	3.0 m
Minimum free board	:	0.5 m, minimum
Side slope	:	1.0 : 3.0
Normal Operation Level (NOL)	:	El. 1,784.0 m

Based on the above figures, retention period and BOD_5 concentration of effluent were calculated as given below:

(c) BOD removal

$$R = 2T + 20 = 2 \times 16 + 20 = 52\%$$

(d) Retention time

$$t = \frac{V}{Q} = \frac{13,554}{3,600} = 3.7 \text{ days}$$

(e) BOD_5 concentration of effluent $Le = 0.48 \times 800 = 384$ mg/L

(2) First Flush Pond (FFP)

FFP is to absorb the rainwater. Since sludge accumulated on the sewer invert are flushed by the rainwater into the sewage treatment works, it is considered necessary to design the FFP with a similar function as the AP. Moreover it could be used as a stand-by anaerobic pond to allow a periodical maintenance and desludging of the APs. Thus it is proposed to designed with the same dimensions with those of the AP.

(3) Facultative Ponds (FP)

Design calculation of the FP is as follows:

(a) Organic loading per hectare $\lambda s = 350 \times (1.107 - 0.002T)^{T-25}$

$= 350 \times (1.107 - 0.002 \times 16)^{16-25}$

$= 182.6$ kg/ha/day

(b) Influent BOD load to each pond $= 384 \times 1{,}800 \times 10^{-3} = 691$ kg/day

(c) Required surface area $= \frac{691}{182.6} = 3.78 \text{ ha} = 37{,}800 \text{ m}^2$

The FP was finally designed with the following features. The effective depth is selected at 2.0 m according to the ODA Manual.

Number of ponds	:	2
Effective volume of each pond	:	74,602 m^3
Cross-sectional shape	:	Trapezoidal
Dimensions of each pond		
Bottom area	:	34,889 m^2, 139 m x 251 m
Surface area at NOL	:	39,713 m^2, 151 m x 263 m
Effective water depth	:	2.0 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 : 3.0
Normal Operation Level (NOL)	:	El. 1,783.0 m at FP1 El. 1,781.0 m at FP2

Based on the above figures, retention time and BOD_5 concentration of effluent were calculated as given below:

(d) Retention time

$$t = \frac{V}{Q} = \frac{74{,}602}{1{,}800} = 41.4 \text{ days}$$

(e) BOD_5 concentration of effluent

$$Le = \frac{384}{(1 + 0.25 \times 41.4)} = 33.8 \text{ mg/L}$$

where, $K_T = 0.3 \times (1.05)^{T-20} = 0.3 \times (1.05)^{16-20} = 0.25$

(4) 1st Maturation Pond (FMP)

Design of the FMP was made as calculated below.

(a) Organic loading per hectare $\lambda s = 0.75 \times 182.6$

$= 137$ kg/ha/day

(b) Required surface area

$$As = \frac{10 \times (0.3) \times Li \times Q}{\lambda}$$

$$= \frac{10 \times 0.3 \times 384 \times 1{,}800}{137}$$

$$= 15{,}136 \text{ m}^2$$

According to the ODA Manual, effective water depth is taken at 1.5 m. The FMP was designed with the following features:

Number of ponds	:	2
Effective volume of each pond	:	22,577 m^3
Cross-sectional shape	:	Trapezoidal
Dimensions of each pond		
Bottom area	:	13,904 m^2, 88 m x 158 m
Surface area at NOL	:	16,199 m^2, 97 m x 167 m
Effective water depth	:	1.5 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 : 3.0
Normal Operation Level (NOL)	:	El. 1,778.0 m at FMP1
	:	EL. 1,779.0 m at FMP2

Retention period is calculated at 12.5 days as given below based on the above figures.

(c) Retention time, $t = V/Q = \frac{22{,}577}{1{,}800} = 12.5$ days

(5) Second and Third Maturation Ponds (SMP and TMP)

Retention time

$$\theta m = \{[\frac{Ni}{Ne(1+K_T\theta a)(1+K_T\theta f)(1+K_T\theta_M)}]^{1/n}-1\} \times \frac{1}{K_T}$$

where,

θm	=	Retention time in SMP, day
Ni	=	Influent fecal coliforms, 10^8
Ne	=	Effluent fecal coliforms, 10^3
Kt	=	Die off coefficient
θa	=	Retention time in AP, 3.7 days
θf	=	Retention time in FP, 41.4 days
θ_M	=	Retention time in FMP, 12.5 days
n	=	Number of SMP, 2

$$\theta m = \{[\frac{10^8}{10^3(1+1.3x3.7)(1+1.3x41.4)(1+1.3x12.5)}]^{1/2}-1\} \times \frac{1}{K_T}$$

$$= (18.4^{1/2} - 1)/1.30 = 2.5 \text{ days}$$

It is proposed to use a retention period of 3 days.

The SMP are designed with the following principal features:

		SMP	TMP
Number of ponds	:	2	2
Effective volume of each pond	:	5,514 m^3	5,514 m^3
Cross-sectional shape	:	Trapezoidal	Trapezoidal
Dimension of each pond			
Bottom area	:	2,844 m^2, 18 m x 158 m	2,844 m^2, 18 m x 158 m
Surface area at NOL	:	4,509 m^2, 27 m x 167 m	4,509 m^2, 27 m x 167 m
Effective water depth	:	1.5 m	1.5 m
Minimum freeboard	:	0.5 m	0.5 m
Side slope	:	1.0 to 3.0	1.0 to 3.0
Normal Operation Level (NOL)	:	El. 1,777.5 m at SMP1 El. 1,778.5 m at SMP2	El. 1,777.0 m at TMP1 El. 1,778.0 m at TMP2

The total retention time through the AP down to the MP (2) is 63.6 days.

(b) BOD_5 concentration of effluent

$$Le = 0.75\,Lo = 0.75 \times 33.8 = 25.4 \text{ mg/L} \doteqdot 30 \text{ mg/L}$$

where, Le = BOD_5 of pond effluent (mg/L)

Lo = BOD_5 of pond influent (mg/L)

(6) Rock Filter (RF)

Design calculations are as given below. In accordance with the design loading rate of 0.5 m^3/rock m^3/day, required volume is calculated at 7,200 m^3 as follows:

$$\text{Required volume} \quad V = \frac{3{,}600}{0.5} = 7{,}200 \text{ m}^3$$

The RF is designed with the following principal features:

Number of RF	:	2
Effective volume of each RF	:	3,667 m^3
Cross-sectional shape	:	Trapezoidal
Dimension of each RF		
Bottom area	:	1,695 m^2, 17.4 m x 97.4 m
Surface area at NOL	:	2,889 m^2, 27.0 m x 107.0 m
Effective rock height	:	1.6 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 to 3.0
Normal Operation Level	:	El. 1,776.5 m at RF1
		El. 1,777.5 m at RF2

At the bottom of the RFs drain ditch will be provided in order to facilitate drainage of the water and sludge accumulated into the rock filter drain pit. Features of drain ditch are as follows:

Dimensions of drain ditch		
Width	:	0.30 m
Height	:	0.50 ~ 0.20 m
Length	:	97.4 m
Number	:	2 raws

(7) Grass Plots (GP)

Design calculations are given below:

Required area A = $\frac{3,600}{1,000}$ = 3.60 ha

The GP has the following principal features:

Number of GP	:	2
Net area of each GP	:	1.8 ha
Dimension of each GP	:	110 m x 165 m

It is expected that BOD_5 concentration of effluent should be around 15 mg/L.

I4.2.2 Additional Treatment Facilities for 6,000 m^3/day Line

The RF and GP are to be connected to the waste stabilization ponds constructed by the Nakuru Sewerage Project. The quantity of effluent from the waste stabilization ponds is 6,000 m^3/day. Design calculations were made by the same method as the design calculation of the 3,600 m^3/day line. General layout and hydraulic profile of this line are shown in DWGs. N-1 and N-2 respectively.

(1) Rock Filters (RF)

Required volume V = $\frac{6,000}{0.5}$ = 12,000 m^3

(2) Grass Plots (GP)

Area A = $\frac{6,000}{1,000}$ = 6.00 ha

The RFs and GPs are designed with the following principal features:

		RF	GP
Number of filters/plots	:	4	4
Effective volume/area of each filter/plot	:	3,027 m^3	1.5 ha
Cross-sectional shape	:	Trapezoidal	-
Dimension of each filter/plot	:		
Bottom area	:	1,381 m^2, 17.4 m x 79.4 m	1.5 ha, 92 m x 165 m
Surface area at NOL	:	3,493 m, 27.0 m x 89.0 m	- -
Effective rock height	:	1.6 m	-
Minimum freeboard	:	0.5 m	-
Side slope	:	1.0 : 3.0	-
Normal Operation Level (NOL)	:	El. 1,771.1 m	-

As the same as the RFs at the 3,600 m^3/day line, the RFs of the 6,000 m^3/day line will also be provided with drain ditch with the following featured:

Dimensions of drain ditch

Width	:	0.30 m
Height	:	0.50 ~ 0.20 m
Length	:	79.4 m
Number	:	2 raws

The waste stabilization ponds have been designed in accordance with the same design criteria as set forth herein. It is therefore assessed that BOD_5 concentration of influent into the RFs is 30 mg/L. Accordingly the BOD_5 concentration of effluent from the GPs is expected to be around 15 mg/L.

4.2.3 Rock Filter Drain Pit

The rock filter drain pit is to temporarily store water and sludge drained from the RFs. In order to avoid mechanical system, hydraulic flushing method is adopted so that the pit is set out lower than the RFs, the RFs are connected to the drain pit by drain pipes, which is linked to the drain ditch in RFs. The layouts of the drain pit and drain pipes are shown in DWG. N-1.

The volume of the drain pit is calculated as follows:

Gross volume of RFs	:	7,200 m^3 + 12,000 m^3 = 19,200 m^3
Net volume of RFs	:	19,200 m^3 x 0.5 = 9,600 m^3, assuming rock fragment volume at 50%.
Drainage operation	:	RFs in every treatment lines are in even number. Half of them will be drained in one operation.
Required volume of pit	:	9,600 m^3 x 0.5 = 4,800 m^3

The drain pit and pipe are deigned with the following features.

(1) Rock filter dain pit

Number of pit	:	1
Effective volume of pit	:	4,804 m^3
Cross-sectional shape	:	Trapezoidal
Dimension of pit		
Bottom area	:	3,515 m^2, 37 m x 95 m
Surface are of NOl	:	*4,517 m^2, 44.2 m x 102.2 m*
Effective depth	:	1.2 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 to 3.0
Normal Operation Level	:	El. 1,768.7 m

(2) Drain pipes

	RF (1) & (2) - RFDP	RF (3), (4), (5) & (6) - RFDP
Number of raws	2	2
Pipe material	Concrete, cast iron	Concrete, cast iron
Diameter	300, 450, 600 mm	300, 450, 600 mm
Length (total)	400 m	400 m

I4.3 Preliminary Design of Sewage Treatment Facilities

I4.3.1 Major Structural Components

Each of two sewage treatment lines is composed of the following major works:

(1) 3,600 m^3/day line

- (a) Inlet pipe between the existing split chamber and the APs
- (b) Pond connection pipes between ponds, including pond outlet and inlet and split chamber
- (c) Waste stabilization ponds, consisting of three APs, two FPs, two FMPs, two SMPs, and two TMPs
- (d) Two RFs and two GPs, including ancillary structures
- (e) Outlet works

(2) 6,000 m^3/day line

- (a) Inlet pipe between the TPMs and the new RFs
- (b) Four RFs and four GPs including ancillary structures
- (c) Outfall works

I4.3.2 Inlet Pipes

The inlet pipe connects the existing structure with the new structure to be constructed by the project and convey the raw sewage into the APs in case of the rehabilitation of 3,600 m^3/day line. It is designed with a gravity flow and has the following principal features:

		3,600 m^3/day line
Number of raws	:	1
Design discharge of each raw	:	0.083 m^3/s
Number of split chamber on each raw	:	1
Inlet water level	:	El. 1,785.6 m
Outlet water level	:	El. 1,784.0 m
Inlet pipe		
Pipe material	:	Concrete
Diameter	:	300 - 450 mm
Length (total)	:	315 m

The split chamber is to distribute the water into the receiving waterbody at a definite rate. There are two split chambers. The preliminary design of the inlet pipe is as shown in DWG. N-3.

I4.3.3 Pond Connection Pipes

The pond connection pipe is required between the successive ponds and is designed with a gravity flow taking the advantage of difference in height between the ponds under consideration. The pipe system is mainly composed of a pond outlet, a connection pipe and a pond inlet. Salient features of the pipes are as follows: Alignment of pond connection pipes and typical design of the pond outlet and inlet are shown in DWGs N-4 and C-1 respectively.

(1) 3,600 m^3/day line

The design discharge is 0.083 m^3/sec for the pond connection pipe between the APs and the FPs and 0.042 m^3/sec for the remaining pond connection pipes.

(a) APs - FPs

		APs - FP1	APs - FP2
Normal Operation Level at AP	:	El. 1,784.0 m	El. 1,784.0 m
Normal Operation Level at FP	:	El. 1,783.0 m	El. 1,781.0 m
Pipe			
Material	:	Concrete	Concrete
Diameter	:	300 - 450 mm	300 mm
Length	:	420 m	70 m
Pond outlet			
Type	:	Horizontal, with overflow weir	Horizontal, with overflow weir
Width	:	2.0 m	2.0 m
Pond inlet			
Type	:	Chuteway	Chuteway
Width	:	1.0 m	1.0 m
Height	:	1.80 m	1.80 m

(b) FPs - FMP s

		FP1 - FMP1	FP2 - FMP2
Normal Operation Level at FP	:	El. 1,783.0 m	El. 1,781.0 m
Normal Operation Level at FMP	:	El. 1,778.0 m	El. 1,779.0 m
Pipe			
Material	:	Concrete	Concrete
Diameter	:	300 mm	300 mm
Length	:	190 m	185 m
Pond outlet			
Type	:	Horizontal, with overflow weir	Horizontal, with overflow weir
Width	:	2.00 m	2.00 m
Pond inlet			
Type	:	Chuteway	Chuteway
Width	:	1.00 m	1.00 m
Height	:	1.30 m	1.30 m

(c) FMPs - SMPs

		FMP1 - SMP1	FMP2 - SMP2
Normal Operation Level at FMP	:	El. 1,778.0 m	El. 1,779.0 m
Normal Operation Level at SMP	:	El. 1,777.5 m	El. 1,778.5 m
Pipe			
Material	:	Concrete	Concrete
Diameter	:	300 mm	300 mm
Length	:	5 m	5 m
Pond outlet			
Type	:	Horizontal, with overflow weir	Horizontal, with overflow weir
Width	:	2.00 m	2.00 m
Pond inlet			
Type	:	Chuteway	Chuteway
Width	:	1.00 m	1.00 m
Height	:	1.30 m	1.30 m

(d) SMPs - TMPs

		SMP1 - FMP1	SMP2 - TMP2
Normal Operation Level at SMP	:	El. 1,777.5 m	El. 1,778.5 m
Normal Operation Level at TMP	:	El. 1,777.0 m	El. 1,778.0 m
Pipe			
Material	:	Concrete	Concrete
Diameter	:	300 mm	300 mm
Length	:	5 m	5 m
Pond outlet			
Type	:	Horizontal, with overflow weir	Horizontal, with overflow weir
Width	:	2.00 m	2.00 m
Pond inlet			
Type	:	Chuteway	Chuteway
Width	:	1.00 m	1.00 m
Height	:	1.30 m	1.30 m

(e) TMPs - RFs

		TMP1 - RF1	TMP2 - RF2
Normal Operation Level at TMP	:	El. 1,777.0 m	El. 1,778.0 m
Normal Operation Level at RF		El. 1,776.5 m	El. 1,777.5 m
Pipe	:		
Material	:	Concrete	Concrete
Diameter	:	300 mm	300 mm
Length	:	110 m	50 m

Typical design of the pond connection pipe between the TMP and the RF is presented in DWG. C-3.

(2) 6,000 m^3/day line

The design discharge is 0.069 m^3/s for all the pipes.

		TMP1 - RF (3) & (4)	TMP2 - RF (5) & (6)
Normal Operation Level at TMP	:	El. 1,772.1 m	El. 1,772.1 m
Normal Operation Level at RF	:	El. 1,771.6 m	El. 1,771.6 m
Pipe			
Material	:	Concrete	Concrete
Diameter	:	375 mm	375 mm
Length	:	300m	535 m

I4.3.4 Waste Stabilization Ponds, Rock Filters and Grass Plots

Earth works are substantial for constructions of the WSPs, FPs and GPs. Topographically the proposed sites in general slope towards Lake Nakuru. Taking advantage such topographic conditions, all the WSPs, FPs and GPs are lined up so that all the treatment process can be achieved by a gravity flow. The levels of the ponds are selected in due consideration of hydraulic and a balance between excavation and embankment volumes.

The embankment can be constructed earth materials available at sites. The bottoms of all the ponds are to be finished with sufficient density to ensure impermeability, excepting the GPs. The slopes of excavation and embankment are to be covered with sod facing to protect soil erosion and precast concrete slabs, each with a size of 0.75 m x 0.75 m, are to be placed along the perimeter of the pond as shown in DWG. N-5.

The RFs are to be filled up with rock fragments with a size of 10~20 cm and with a thickness of 1.6 m. At the downstream end of the RFs, an small open ditch with overflow weir will be installed to distribute the water evenly into the GPs.

The GPs are to be covered by Kikuyu grass for their entire area. It will be provided with treated water channel at its downstream and connected to the outlet works. The channel is 300 mm square.

The preliminary designs of the waste stabilization ponds, RFs and GPs are shown in DWGs N-4 through N-8 and C-3.

I4.3.5 Outlet Works

The treated water is to be discharged into the Njoro river through the outlet works, which comprises a conduit and an outfall at the left bank of the Njoro river.

The conduit is in principle open channel with a dimensions of 675 mm square but a concrete pipe is to be used at road-crossing as shown in DWG. N - 9. The outfall is of cascade type, having 0.675 m wide and 4.55 m high, in order to dissipate hydraulic energy when flowing into the river.

I4.4 Preliminary Design of Sludge Drying Bed

I4.4.1 Estimated Sludge Volume

In waste stabilization ponds most of the sludge is produced in the APs with a small fraction in the FPs. In the APs the main mode of sludge generation is through settlement while biomass formation predominates in the FPs. The sludge from the APs is digested and quite stable to handle.

The rate of sludge generation depends on efficiency of settlement of the suspended solids and amount of cells which organic solids convert. The former depends on the retention time, characteristics of the solids and degree of mixing while the later depends on the extent of BOD_5 removal in the pond. In anaerobic digestion about one-fifth of the BOD_5 removed is converted into new cells.

It is necessary to treat and dispose the sludge, which will be generated by the sewage amounting to 9,600 m^3/day. The volume of sewage is estimated through the following calculations:

(1) Settlement sludge

$$Mr = f \times Q \times SS = 0.5 \times 9{,}600 \times 700 \times 10^{-3} = 3{,}360 \text{ kg/day}$$
$$Md = a \times Mro + Mri = 0.5 \times 2{,}352 + 1{,}008 = 2{,}184 \text{ kg/day}$$

Where,

Mr	:	raw sludge solid (settlement), kg/day
Mro	:	organic portion of Mr, $Mro = 0.7 \times Mr$
Mri	:	inorganic portion of Mr, $Mri = 0.3 \times Mr$
Md	:	digested sludge solid, kg/day
f	:	fraction of SS removed, 0.5
a	:	decrease rate on digestion process, 0.5
SS	:	suspended solids, 700 mg/L
Q	:	average daily flow, 9,600 m^3/day

(2) Biological sludge solids

$$Ms = Y \times BOD \times Q = 0.2 \times (800 - 384) \times 9{,}600 \times 10^{-3} = 799 \text{ kg/day}$$

where, Ms : biological sludge solids, g
Y : field coefficient, 0.2 mg/mg
BOD : BOD reduced in pond, 800 - 384 mg/L
Q : flow, 9,600 m^3/day

(3) Volume of raw sludge

Total settleable solids	=	799 + 2,184 = 2,983 kg/day
Water content	=	90%
Density of dry solids	=	1,500 kg/m^3
Density of water	=	1,000 kg/m^3
Volume of raw sludge	=	$\frac{2{,}983}{0.1 \times 1{,}500} = 20 \text{ m}^3\text{/day}$

The daily sewage generation is estimated at 20 m^3/day for the entire Njoro STW.

14.4.2 Sludge Drying Bed

It is proposed to construct a sludge drying bed to treat the raw sludge generating from the APs. The desludging work is preferred to be carried out at intervals of 6 months by using mud pump. The sludge drying bed is designed as follows:

(1) Volume of raw sludge : 20 m^3/day × 180 day = 3,600 m^3
(2) Assumed raw sludge thickness : 30 cm
(3) Proposed depth of bed : 1.2 m
(4) Proposed dimensions of bed
Cross-sectional slope : Trapezoidal
Bottom area : 11,354 m^2, 74.8 m × 151.8 m
Surface area : 13,038 m^2, 82.0 m × 159.0 m
Slope of bed : 5%
Storage capacity : 14,635 m^3

The preliminary design is given in DWG. N-4.

Assuming the water content of the dried sludge at 50%, sludge thickness will be reduced one fifth, i.e., 6 cm. Thus sludge drying bed capacity corresponds to the dried sludge volume of about 10 years.

The digested sludge will be spread on the drying bed with a maximum gradient of 5% and it will be dewatered through evaporation and percolation. Since climate has a high effect on the rate of dewatering, desludging should be done preferably during the dry seasons.

I4.5 Preliminary Design of Building Works

It is proposed a build four Kenyan standard Type D houses at the Njoro STW to supplement the existing accommodation. Two houses are combined into one building structure. Each house has a floor area of about 35 m^2 and is composed of one bed room, one living room, one toilet, one shower room and one kitchen as shown in DWG. B-2.

I4.6 Land Requirement

As shown in DWG. N-1, it is unavoidable to site the new sewage treatment facilities beyond the boundaries of the existing sewage treatment works. With the implementation of the project, total area is expanded to 102.1 ha, of which 9.3 ha is assessed to be newly acquired.

I5. PRELIMINARY DESIGN OF TOWN STW

I5.1 Proposed Treatment Process

The existing conventional system with a treatment capacity is proposed to be added with waste stabilization ponds, RFs and GPs for upgrading the quality of effluent. The new waste stabilization pond line with a treatment capacity of 3,200 m^3/day is to be constructed adjacent to the existing conventional system in order to cope with the increasing sewage volume. Fig. I-2 gives schematically the treatment process of both the existing and new lines.

I5.2 Sewage Treatment Process Design

I5.2.1 Additional Facilities to Existing 3,400 m^3/day Line

The waste stabilization ponds system, which is to be newly connected to the existing system, is designed in compliance with the design criteria. According to the investigation of water quality and assessment of the existing conventional system, it is concluded that the existing system is capable of removing 65% of BOD_5. Accordingly the BOD_5 concentration of the effluent is 280 mg/L, which is taken as the BOD_5 concentration of influent into the new additional treatment facilities. General layout and hydraulic profile of the lines are as shown in DWGs. T - 1 and T - 2 respectively.

(1) Facultative Pond (FP)

(a) Volumetric loading rate : $\lambda s = 350 \times (1.107 - 0.002T)^{T-25}$

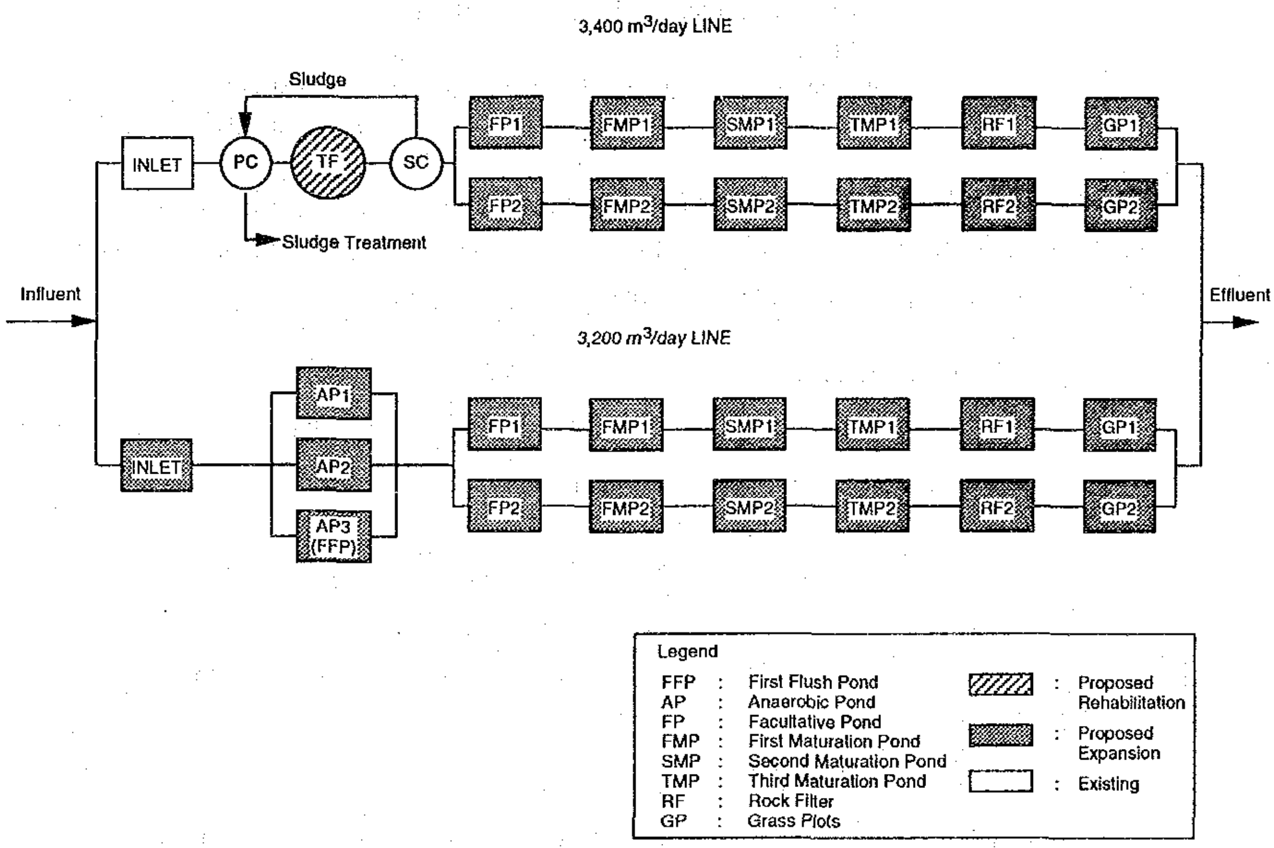
$= 350 \times (1.107 - 0.002 \times 16)^{16-25}$

$= 182.6$ kg/ha/day

(b) BOD of each pond : $= 280 \times 1{,}700 \times 10^{-3} = 476$ kg/day

(c) Required surface area of each pond : $= \frac{476}{182.6} = 26{,}100\ m^2$

Fig. I-2



THE REPUBLIC OF KENYA	THE STUDY ON THE NAKURU SEWAGE WORKS REHABILITATION AND EXPANSION PROJECT	TITLE
MINISTRY OF LOCAL GOVERNMENT	JAPAN INTERNATIONAL COOPERATION AGENCY	SCHEMATIC DIAGRAMME OF TREATMENT PROCESS FOR TOWN STW

According to the above calculations, the FP is designed with the following principal features:

Number of ponds	:	2
Effective volume of each pond	:	52,320 m^3
Cross-sectional shape	:	Trapezoidal
Dimensions of each pond		
Bottom area	:	23,790 m^2, 78 m x 305 m
Area at NOL	:	28,530 m^2, 90 m x 317 m
Net depth	:	2.0 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 : 3.0
Normal Operation Level (NOL)	:	El. 1,770.5 m at FP1
		El. 1,769.0 m at FP2

The net water depth is selected at 2.0 m, the same as that of the Njoro 3,600 m^3/day line, according to the ODA Manual. Based on the above features, retention time and BOD_5 concentration of effluent are calculated as given below:

(d) Retention time

$$t = V/Q = \frac{52{,}320}{1{,}700} = 30.7 \text{ days}$$

(e) BOD5 concentration of effluent

$$Le = \frac{280}{1 + 0.25 \times 30.7} = 32.3 \text{ mg/L}$$

where,

$$K_T = 0.3 \times (1.05)^{T-20}$$

$$= 0.3 \times (1.05)^{16-20} = 0.25$$

(2) 1st Maturation Pond (FMP)

The same design criteria as that of the FMP at Njoro STW is adopted. Design calculations are as given below:

(a) Organic loading per hectare

$$\lambda s = 0.75 \times 182.6 = 137 \text{ kg/ha/day}$$

(b) Required surface area (each pond)

$$As = \frac{10 \times (0.3) \times Li \times Q}{\lambda s}$$

$$= \frac{10 \times 0.3 \times 280 \times 1{,}700}{137} = 10{,}423 \text{ m}^2$$

In accordance with the above calculations, the FMP is designed with the following principal features:

Number of ponds	:	2
Effective volume of each pond	:	15,827 m^3
Dimensions of each pond		
Bottom area	:	9,512 m^2, 58 m x 164 m
Surface area at NOL	:	11,591 m^2, 67 m x 173 m
Effective water depth	:	1.5 m
Side slope	:	1.0 : 3.0
Normal operation level (NOL)	:	El. 1,768.0 m

The effective water depth is selected at 1.5 m in compliance to the ODA Manual. Based on the above figures, retention time is calculated as follows:

(c) Retention time

$$t = V/Q = \frac{15,827}{1,700} = 9.3 \text{ days}$$

(3) Second and Third Maturation Ponds (SMP and TMP)

(a) Retention time

The retention period is determined at 3 days, which is the same figure as adopted for the same ponds of the Njoro STW. Thus the SMPs are designed with the following principal features:

		SMP	TMP
Number of ponds	:	2	2
Effective volume of each pond	:	5,231 m^3	5,231 m^3
Dimension of each pond			
Bottom area	:	2,880 m^2, 30m x 96m	2,880 m^2, 30m x 96m
Surface area at NOL	:	4,095 m^2, 39m x 105m	4,095 m^2, 39m x 105m
Effective water depth	:	1.5 m	1.5 m
Side slope	:	1.0 : 3.0	1.0 : 3.0
Normal Operation Level (NOL)	:	El. 1,767.5 m	El. 1,767.0 m

(b) BOD_5 concentration of effluent

The BOD_5 concentration of the effluent from the TMP is calculated as follows:

$$Le = 0.75\ Lo = 0.75 \times 32.3 = 24.2\ mg/L$$

where, Le = Pond effluent BOD_5 (mg/l)
Lo = Pond influent BOD_5 (mg/l)

A retention period form the primary clarifier down to the TMP is calculated at 46.0 days.

(4) Rock Filter (RF)

Required volume $V = \frac{3,400}{0.5} = 6,800\ m^3$

According to the design criteria, effective depth is taken at 1.6 m. The RF is designed with the following principal features:

Number of ponds	:	2
Effective volume of each pond	:	3,453 m^3
Cross-sectional shape	:	Trapezoidal
Dimensions of each RF		
Bottom area	:	1,590 m^2, 17.4m x 91.4 m
Surface area at tope or rock	:	2,727 m^2, 27.0 m x 101.0 m
Effective depth	:	1.6 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 : 3.0
Normal Operation Level (NOL)	:	El. 1,766.0 m

The rock filter is provided with drain ditches with the following dimensions to facilitate hydraulic flushing of the water and sludge into the rock filter drain pit:

Dimensions of drain conduit

Width	:	0.3 m
Height	:	0.50 ~ 0.20 m
Length	:	91.4 m
Number	:	2 raws

(5) Grass Plots (GP)

The required area is calculated at 3.40 ha on the basis of the design inflow of 3,400 m^3/day and loading rate of 1,000 m^3/ha/day. Two GPs are to be provided, each with an area of 1.70 ha.

The BOD_5 concentration of effluent from the TMPs is conservatively taken at 30 mg/L, which is expected to be reduced to 15 mg/L through the process by the RFs and GPs.

(6) Rock filter drain pit

The rock filter drain pit and drain pipes are designed with the following features: the design principle and process are the same as those applied to that of the Njoro STW.

(a) Rock filter drain pit

Number	:	1
Cross sectional shape	:	Trapezoidal
Effective volume	:	1,600 m^3
Dimension of pit		
Bottom area	:	895 m^2, 6.6 m x 135. 6 m
Surface are of NOL	:	1,971 m^2, 13.8 m x 142.8 m
Effective depth	:	1.2 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 to 3.0
Normal Operation Level	:	El. 1,763.8 m

(b) Drain pipe

Number	:	6 raws
Pipe material	:	Cast iron
Diameter	:	300, 450 mm
Length (Total)	:	120 m

I5.2.2 New 3,200 m^3/day Line

The same design process as the Njoro 3,600 m^3/day line is adopted as described below: As shown in Fig. I-2, the proposed new line is composed of two treatment streams and its hydraulic profile is also shown in DWG. T - 2.

(1) Anaerobic Ponds (AP)

(a) Volumetric loading rate : Same as the Njoro 3,600 m^3/day line, 220 g/m^3/day

(b) Required pond volume

$$v = \frac{LiQ}{\lambda v} = \frac{800 \times 3{,}200}{220} = 11{,}636 \text{ m}^3$$

(c) BOD removal

$$R = 2T + 20 = 2 \times (16) + 20 = 52\%$$

There are two APs and effective depth of each pond is selected at 3.0 m, the same figure as that of the Njoro STW. The APs have the following features:

Number of ponds	:	2
Effective volume of each pond	:	6,099 m^3
Cross-sectional shape	:	Trapezoidal
Dimensions of each RF		
Bottom area	:	1,196 m^2, 23 m x 52 m
Surface area at NOL	:	2,870 m^2, 41 m x 70 m
Effective water depth	:	3.0 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 : 3.0
Normal Operation Level (NOL)	:	El. 1,775.0 m

Based on the above figures, retention time and BOD_5 concentration of effluent are calculated as given below:

(d) Retention time

$$t = V/Q = \frac{6{,}099}{1{,}600} = 3.8 \text{ days}$$

(e) BOD_5 concentration of effluent $Le = 0.48 \times 800 = 384$ mg/L

(2) First Flush Pond (FFP)

The same principle as that of the Njoro STW is introduced, i.e., the FFP will act as a stand-by unit of the AP. Therefore only one FFP is required, dimensions of which are quite the same with those of the APs.

(3) Facultative Ponds (FP)

(a) Organic loading per hectare

λs = 182.6 kg/ha/day, as calculated for the Njoro STW

(b) BOD volume of each pond = $384 \times 1{,}600 \times 10^{-3}$ = 614 kg/day

(c) Required surface area = $\frac{614}{182.6}$ = 3.36 ha = 33,600 m^2

The effective water depth is taken at 2.0 m, the same figure as that of the Njoro STW. The following is principal features of the FPs:

Number of ponds	:	2
Effective volume of each pond	:	67,276 m^3
Cross-sectional shape	:	Trapezoidal
Dimensions of each pond		
Bottom area	:	31,100 m^2, 100 m x 311 m
Surface area at NOL	:	36,176 m^2, 112 m x 323 m
Effective water depth	:	2.0 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 : 3.0
Normal Operation Level (NOL)	:	El. 1,774.0 m at FP1 El. 1,772.5 m at FP2

Retention time and BOD_5 concentration of effluent are calculated as given below, based on the above figures:

(d) Retention time

$$t = V/Q = \frac{67{,}276}{1{,}600} = 42.0 \text{ days}$$

(e) BOD_5 concentration of effluent

$$Le = \frac{384}{1 + 0.25 \times 42.0} = 33.4 \text{ mg/l}$$

where, $K_T = 0.3 \times (1.05)^{T-20} = 0.3 \times (1.05)^{16-20}$
$= 0.25$

(4) 1st Maturation Pond (FMP)

(a) Organic loading per hectare

$$\lambda s = 0.75 \times 182.6 = 137 \text{ kg/ha/day}$$

(b) Required surface area

$$As = \frac{10 \times 0.3 \times Li \times Q}{\lambda s}$$
$$= \frac{10 \times 0.3 \times 384 \times 1,600}{137} = 13,454 \text{ m}^2$$

The FMP is designed with the following principal features :

Number of ponds	:	2
Effective volume of each pond	:	20,256 m^3
Cross-sectional shape	:	Trapezoidal
Dimensions of each pond		
Bottom area	:	12,388 m^2, 76 m x 163 m
Surface area at NOL	:	14,620 m^2, 85 m x 172 m
Effective water depth	:	1.5 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 : 3.0
Normal Operation Level (NOL)	:	El. 1,770.5 m

The retention period is 12.6 days as calculated below:

(c) Retention time $t = V/Q$
$= 20,256/1600 = 12.6$ days

(5) Second and Third Maturation Ponds (SMP and TMP)

(a) Retention time

$$\theta m = \{[\frac{Ni}{Ne(1+K_T\theta a)(1+K_T\theta f)(1+K_T\theta_M)}]^{1/n} - 1\} \times \frac{1}{K_T}$$

where,	θm	=	Retention time in MP
	Ne	=	Effluent fecal coliforms
	Kt	=	Die off coefficient
	θa	=	Retention time in AP, 3.64 days
	θf	=	Retention time in FP, 42.0 days
	θ_M	=	Retention time in FMP, 12.6 days
	n	=	Number of successive maturation ponds, 2

$$\theta m = \{[\frac{10^8}{10^3(1+1.3x3.64)(1+1.3x42.0)(1+1.3x12.7)}]^{1/n} - 1\} \times \frac{1}{K_T}$$

$$= (17.9^{1/2} - 1)/1.30 = 2.5 \text{ days}$$

It is determined to use a retention period of 3 days.

The SMPs are designed with the following principal features respectively:

		SMP	TMP
Number of ponds	:	2	2
Effective volume of each pond	:	4,832 m^3	4,832 m^3
Cross-sectional shape	:	Trapezoidal	Trapezoidal
Dimension of each pond			
Bottom area	:	2,632 m^2, 28 m x 94 m	2,632 m^2, 28 m x 94 m
Surface area at NOL	:	3,811 m^2, 37 m x 103 m	3,811 m^2, 37 m x 103 m
Effective Water depth	:	1.5 m	1.5 m
Minimum freeboard	:	0.5 m	0.5 m
Side slope	:	1.0 to 3.0	1.0 to 3.0
Normal Operation Level (NOL)	:	El. 1,769.5 m	El. 1,768.5 m

BOD_5 concentration of effluent is conservatively estimated at 30 mg/L through the following calculation:

(b) BOD_5 concentration of effluent

Le	=	0.75 Lo
		where, Le = BOD_5 concentration of effluent (mg/L)
		Lo = BOD_5 concentration of influent (mg/L)
L3	=	0.75 x 33.4 = 25.1 mg/L ≑ 30 mg/L

Total retention period through the AD down to the SMP is 64.4 days.

(7) Rock filters (RF)

Rock filter requirement is calculated as follows:

Required volume $V = \frac{3,200}{0.5} = 6,400\ m^3$

Two RFs are to be constructed, each with effective depth of 1.6 m. The principal features of the RF are as follows:

Number of RFs	:	2
Effective volume of each RF	:	3,240 m^3
Cross-sectional shape	:	Trapezoidal
Dimension of each RF		
Bottom area	:	1,486 m^2, 17.4 m x 85.4 m
Surface area at top of rock	:	2,565 m^2, 27.0 m x 95.0 m
Effective depth	:	1.6 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 to 3.0
Normal Operation Level	:	El. 1,767.5 m

RFs are provided with drain ditches having the following features:

Dimensions of drain conduit		
Width	:	0.3 m
Height	:	0.50 ~ 0.20 m
Length	:	85.4 m
Number	:	2 raws

(8) Grass plots (GP)

The required area is calculated at 3.20 ha on the basis of the design inflow of 3,200 m^3/day and loading rate of 1,000 m^3/ha/day. Two GPs are to be provided, each with an area of 1.60 ha.

The BOD_5 concentration of effluent is estimated at 15 mg/L on the basis of BOD_5 concentration of 30 mg/L for effluent from the TMP and reduction rate of 50%.

(9) Rock filter drain pit

The rock filter drain pit and drain pipe between RFs and drain pit were designed by the same design principle and process as those of the Njoro STW.

(a) Rock filter drain pit

Number of pit	:	1
Effective volume of pit	:	1,606 m^3
Cross-sectional shape	:	Trapezoidal
Dimension of pit		
Bottom area	:	842 m^2, 6.6 m x 127. 6 m
Surface are of NOL	:	1,860 m^2, 13.8 m x 134.8 m
Effective depth	:	0.6 m
Minimum freeboard	:	0.5 m
Side slope	:	1.0 to 3.0
Normal Operation Level	:	El. 1,765.3 m

(b) Drain pipe (RF-RFDP)

Line	:	6 raws
Material	:	Cast iron
Diameter	:	300, 450 mm
Length (Total)	:	120 m

I5.3 Preliminary Design of Sewage Treatment Facilities

I5.3.1 Major Structural Components

The following major works will be undertaken at the respective sewage treatment works:

(1) 3,400 m^3/day line

- (a) Ventilation at trickling filter
- (b) Inlet pipe between the existing Secondary Clarifier and the FPs
- (c) Pond connection pipes between the ponds, including pond outlet and inlet and split chamber
- (d) Waste stabilization ponds, consisting of two FPs, two FMPs, two SMPs and two TMPs
- (e) Two RFs and two GPs, including ancillary structures

(2) New 3,200 m^3/day line

- (a) Inlet works, including of grit chamber and parshall flume
- (b) Pond connection pipes between the ponds, including pond outlet and inlet and split chamber
- (c) Waste stabilization ponds, consisting of three APs, two FPs, two FMPs, two SMPs and two TMPs
- (d) Two RFs and two GPs, including ancillary structures

I.5.3.2 Ventilation at Existing Trickling Filter

Through the evaluation of the function of the existing facilities, it is recommended to add three ventilations at the existing trickling filter in order to increase efficiency and keep its function properly. The proposed location of the ventilations is shown in DWG. T-11. The structural design can be made at the time of detailed design upon checking of existing structure through test pitting.

I5.3.3 Inlet Works

A new inlet work needs to be constructed to divert the raw sewage amounting to 3,200 m3/day to the new sewage works. The proposed layout of the works is shown schematically in Fig. I-3, and comprises inlet channel, constant velocity grit removal chambers, parshall flumes and inlet pipe. The inlet channel is equipped with two screens to remove trash and other foreign materials and also associated with a bypass to cope with overflowing owing to clogging of screens. Two grit chambers are proposed to be constructed. They will be used alternately to facilitate grit removal works. Each chamber connects a parshall flume at its downstream for sewage discharge monitoring.

The hydraulic design of the inlet work is given below:

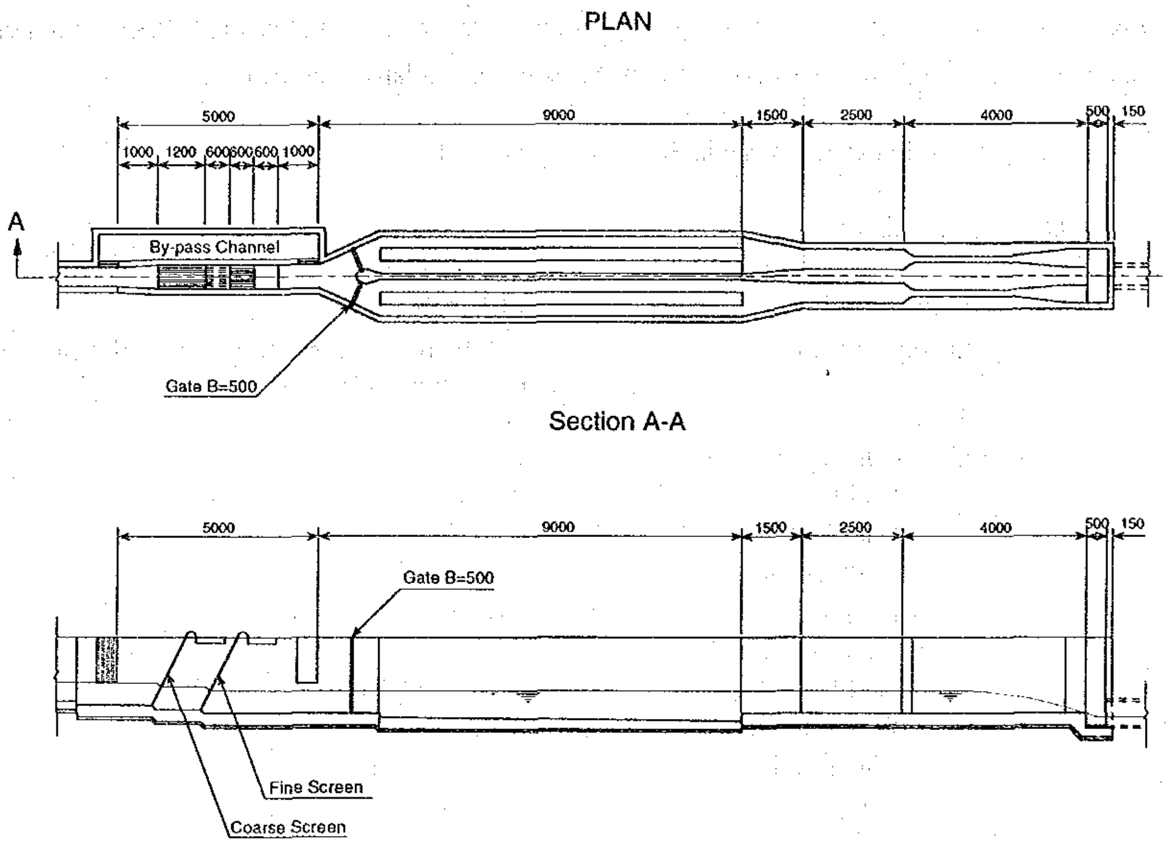
(1) Inlet channel

Inlet water level	:	El. 1,779.75 m
Design discharge	:	0.089 m^3/s, corresponding to the hourly maximum peak flow
Type	:	Open channel
Upstream channel		
Width	:	0.50 m
Water depth	:	0.50 m
Wall height	:	1.20 m
Length	:	3.60 m
Downstream channel		
Width	:	0.50 - 0.60 m
Water depth	:	0.50 m
Wall height	:	1.20 - 1.45 m
Length	:	6.15 m
Bypass channel		
Width	:	0.50 m
Overflow weir, width	:	1.00 m
crest	:	El. 1,779.60 m

Two screens are to be installed and their features are as follows:

		Coarse screen	Fine screen
Width	:	0.60 m	0.60 m
Height	:	1.20 m	1.35 m
Setting angle to horizontal	:	60°	60°
Bars			
Size	:	10 mm x 50 mm	10 mm x 50 mm
Spacing	:	50 mm	25 mm

Fig. I-3



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MINISTRY OF LOCAL GOVERNMENT	JAPAN INTERNATIONAL COOPERATION AGENCY	

(2) Constant velocity grit removal chamber

(a) Channel cross section

Design conditions are set as follows:

Design discharge	:	0.089 m^3/s
Allowable velocity	:	0.30 m/s
Water depth	:	0.50 m, same as the water depth at parshall flume

Cross-sectional shape of chamber is taken as illustrated below:

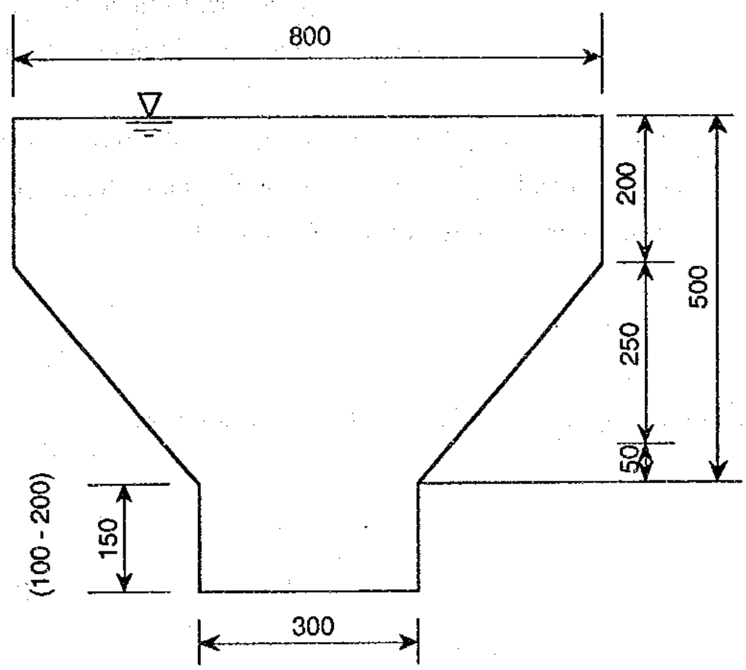

Fig. I-4 Section of Chamber

Assuming that cross-sectional shape is equivalent to a parabolic shape, the required water depth is given by the following calculation.

$$Q = 2/3 \cdot B \cdot H \cdot V = 2/3 \times 0.3 \times 0.50 \times B = 0.089$$

where,	Q	:	discharge, m3/s
	B	:	breath of water surface, m
	H	:	water depth, m

B is calculated at 0.89 m.

(b) Length of channel

The length of channel is dependent on settling velocity of grit retained by a 65-mesh sieve, which is taken at 0.02 m/s. Required retention time is set at 30 seconds at the minimum. The required channel length is calculated by the following equation:

$$Lo = \frac{H \times v}{Vs} = \frac{0.50 \times 0.30}{0.02} = 7.50 \text{ m}$$

where,
- Lo : length required, m
- V : velocity through chamber, m/s
- H : water depth in chamber, m
- Vs : settling velocity of grit, m/s

In order to satisfy the retention time of 30 seconds, the calculated value is not enough, resulting in only 25 seconds. Thus the length of the channel is set at 9.0 m to meet the retention requirement.

(3) Parshall flume

A schematic layout of parshall flume is given below:

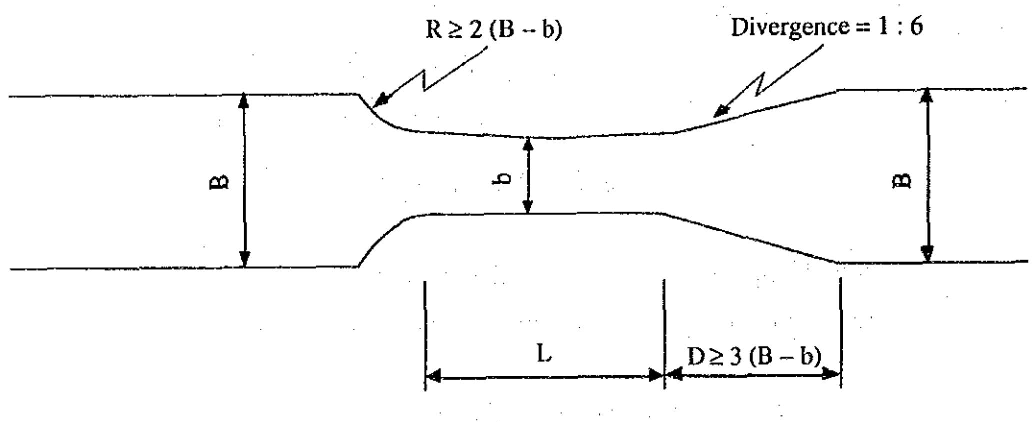

Fig. I-5 Schematic Layout of Parshall Flume

Discharge capacity of the parshall flume is given by the following equation:

$$Q = \left(\frac{2}{3}\right)^{3/2} \sqrt{gn} \times Cv \times Cd \times b \times h^{3/2}$$

where,	Q	:	discharge, m^3/sec
	gn	:	gravitational acceleration, 9.8 m/sec
	Cv	:	coefficient of approach velocity, m/sec
	b	:	width of flume throat, m
	h	:	gauged head, m
	Cd	:	coefficient of discharge, 1,064

The design discharge is 0.089 m^3/s and a throat width is selected at 0.15 m. The required water depth, "h" is accordingly given at 0.50 m.

(4) Inlet pipe

Inlet pipe are to be laid down between the parshall flume and the anaerobic ponds. They are concrete pipe with a diameter of 450 mm and a length of 190 m and a diameter of 300 mm with a length of 270 m.

The preliminary design of the inlet pipes are as shown in DWG. T - 3.

I5.3.4 Pond Connection Pipes

The function and components of the pond connection pipes are the same as those of the Njoro STW. Salient features are as summarized below: Alignment of pipes and typical design of the pond outlet and inlet are as shown in DWGs. T - 6 and C - 1 respectively.

(1) APs - FPs

	Existing 3,400 m^3/day Line		New 3,200 m^3/day Line	
	SC - FP1	SC - FP2	APs - FP1	APs - FP2
NOL at AP, SC	El. 1,774.69 m	El. 1,774.69 m	El. 1,775.0 m	El. 1,775.0 m
NOL at FP	El. 1,770.5 m	El. 1,769.0 m	El. 1,774.0 m	El. 1,772.5 m
Design discharge	0.079 m^3/sec	0.079 m^3/sec	0.074 m^3/sec	0.074 m^3/sec
Pipe				
Material	Concrete	Concrete	Concrete	Concrete
Diameter	300 - 450 mm	300 - 450 mm	300 - 450 mm	300 - 450 mm
Length	270 m	190 m	50 m	420 m
Pond outlet				
Type	-	-	Horizontal with overflow weir	Horizontal with overflow weir
Width	-	-	200 m	200 m
Pond inlet				
Type	Chuteway	Chuteway	Chuteway	Chuteway
Width	1.00 m	1.00 m	1.00 m	1.00 m
Height	1.80 m	1.80 m	1.80 m	1.80 m

(2) FPs - FMPs

	Existing 3,400 m^3/day Line		New 3,200 m^3/day Line	
	FP1 - FMP1	FP2 - FMP2	FP1 - FMP1	FP2 - FMP2
NOL at FP	El. 1,770.5 m	El. 1,769.0 m	El. 1,774.0 m	El. 1,772.5 m
NOL at MFP	El. 1,768.0 m	l. 1,768.0 m	El. 1,770.5 m	El. 1,770.5 m
Design discharge	0.040 m^3/sec	0.040 m^3/sec	0.037 m^3/sec	0.037 m^3/sec
Pipe				
Material	Concrete	Concrete	Concrete	Concrete
Diameter	300 mm	300 mm	300 mm	300 mm
Length	160 m	150 m	220 m	150 m
Pond outlet				
Type	Horizontal with overflow weir	Horizontal with overflow weir	Horizontal with overflow weir	Horizontal with overflow weir
Width	2.00 m	2.00 m	2.00 m	2.00 m
Pond inlet				
Type	Chuteway	Chuteway	Chuteway	Chuteway
Width	1.00 m	1.00 m	1.00 m	1.00 m
Height	1.30 m	1.30 m	1.30 m	1.30 m

(3) FMPs - SMPs

	Existing 3,400 m^3/day Line		New 3,200 m^3/day Line	
	FMP1 - SMP2	FMP2 - SMP2	FMP1 - SMP2	FMP2 - SMP2
NOL at FMP	El. 1,768.0 m	El. 1,768.0 m	El. 1,770.5 m	El. 1,770.5 m
NOL at SMP	El. 1,767.5 m	El. 1,767.5 m	El. 1,769.5 m	El. 1,769.5 m
Design discharge	0.040 m^3/sec	0.040 m^3/sec	0.037 m^3/sec	0.037 m^3/sec
Pipe				
Material	Concrete	Concrete	Concrete	Concrete
Diameter	300 mm	300 mm	300 mm	300 mm
Length	5 m	5 m	5 m	5 m
Pond outlet				
Type	Horizontal with overflow weir	Horizontal with overflow weir	Horizontal with overflow weir	Horizontal with overflow weir
Width	2.00 m	2.00 m	2.00 m	2.00 m
Pond inlet				
Type	Chuteway	Chuteway	Chuteway	Chuteway
Width	1.00 m	1.00 m	1.00 m	1.00 m
Height	1.30 m	1.30 m	1.30 m	1.30 m

(4) SMPs - TMPs

	Existing 3,400 m^3/day Line		New 3,200 m^3/day Line	
	SMP1 - TMP1	SMP2 - TMP2	SMP1 - TMP1	SMP2 - TMP2
NOL at SMP2	El. 1,767.5 m	El. 1,767.5 m	El. 1,769.5m	El. 1,769.5 m
NOL at TMP	El. 1,767.0 m	El. 1,767.0 m	El. 1,768.5 m	El. 1,768.5 m
Design discharge	0.040 m^3/sec	0.040 m^3/sec	0.037 m^3/sec	0.037 m^3/sec
Pipe				
Material	Concrete	Concrete	Concrete	Concrete
Diameter	300 mm	300 mm	300 mm	300 mm
Length	5 m	5 m	5 m	5 m
Pond outlet				
Type	Horizontal with overflow weir	Horizontal with overflow weir	Horizontal with overflow weir	Horizontal with overflow weir
Width	2.0 m	2.00 m	2.00 m	2.00 m
Pond inlet		m		
Type	Chuteway	Chuteway	Chuteway	Chuteway
Width				
Height	1.30 m	1.30 m	1.30 m	1.30 m

(5) TMPs - RF2

	Existing 3,400 m^3/day Line		New 3,200 m^3/day Line	
	TMP1 - RF1	TMP2 - RF2	TMP1 - RF1	TMP2 - RF2
NOL at TMP	El. 1,767.0 m	El. 1,767.0 m	El. 1,768.5 m	El. 1,768.5 m
NOL at RF	El. 1,766.0 m	El. 1,766.0 m	El. 1,767.5 m	El. 1,767.5 m
Design discharge	0.040 m^3/sec	0.040 m^3/sec	0.037 m^3/sec	0.037 m^3/sec
Pipe				
Material	Concrete	Concrete	Concrete	Concrete
Diameter	300 mm	300 mm	300 mm	300 mm
Length	80 m	15 m	45 m	5 m

The pond outlet into the RFs is designed as shown in DWG. C - 3.

I5.3.5 Waste Stabilization Ponds, Rock Filters and Grass Plots

The same designs as stated in the preceding Sub-section I4.3.4 are applied for the designs of the waste stabilization ponds, rock filters and grass plots in the Town STW. The preliminary design of the WSP, RFs and GPs are as shown in DWGs. T - 6 through T - 10 and C - 3.

I5.3.6 Outlet Works

The grass plots are provided with the treated water channel at their downstream end, which is directly connected to the storm water drainage channel. Thus the treated water is discharged into Lake Nakuru through the storm water drainage channel. The profile and typical cross section of the stormwater drainage are shown in DWG. S - 1.

I5.4 Preliminary Design of Sludge Drying Bed

I5.4.1 Estimated Sludge Volume

In the Town STW, sludge comes out both the existing 3,400 m^3/day and new 3,200 m^3/day lines. The former line is provided with a digester tank and sludge drying beds and such facilities are evaluated to be appropriated to treat the generating sludge. For the later it is proposed to construct a sludge drying bed same as the Njoro STW.

The sludge volume is estimated for the new 3,200 m^3/day line as given below :

(1) Settlement sludge

$$Mr = f \times Q \times SS = 0.5 \times 3{,}200 \times 700 \times 10^{-3} = 1{,}120 \text{ kg/day}$$
$$Md = a \times Mro + Mri = 0.5 \times 784 + 336 = 728 \text{ kg/day}$$

Where,	Mr	:	raw sludge solid (settlement), kg/day
	Mro	:	organic portion of Mr, $Mro = 0.7 \times Mr$
	Mri	:	inorganic portion of Mr, $Mri = 0.3 \times Mr$
	Md	:	digested sludge solid, kg/day
	f	:	fraction of SS removed, 0.5
	a	:	decrease rate on digestion process, 0.5
	SS	:	suspended solids, 700 mg/L
	Q	:	average daily flow, 3,200 m^3/day

(2) Biological sludge solids

$$Ms = Y \times BOD \times Q = 0.2 \times (800 - 384) \times 3{,}200 \times 10^{-3} = 266 \text{ kg/day}$$

where,	Ms	:	biological sludge solids, g
	Y	:	yield coefficient, 0.2 mg/mg
	BOD	:	BOD reduced in pond, 800 - 384 mg/L
	Q	:	flow, 3,200 m^3/day

(3) Volume of raw sludge

Total settleable solids	=	266 + 728 = 994 kg/day
Water content	=	90%
Density of dry solids	=	1,500 kg/m^3
Density of water	=	1,000 kg/m^3
Volume of raw sludge	=	$\frac{994}{0.1 \times 1{,}500} = 6.6$ m^3/day

The daily sewage generation volume is estimated at 6.6 m^3/day.