- Gravity thickening
- Centrifugal thickening
- Flotation thickening

Gravity thickening is usually adopted for primary sludge and combined sludge of primary and secondary sludge. Centrifugal thickening and Flotation thickening are adopted to concentrate the secondary sludge as the secondary sludge is difficult to be concentrated by gravity thickening. Centrifugal thickening process can achieve the solid concentration of ranging from 3% to 10% with an average of 6 % whereas the flotation thickening can achieve from 3% to 6% with an average of 4%. Hence the required capacity of anaerobic digestion tank subsequent to the centrifugal thickener would be about 67% of that of subsequent to the flotation thickener. Hence Centrifugal thickener is recommended for thickening of secondary sludge.

From the above discussion two (2) alternatives of sludge thickening are possible;

1) Separate thickening in which primary sludge is to be thickened by Gravity thickener and secondary sludge to be thickened by Centrifugal thickener
2) Combined thickening in which primary and secondary sludge are mixed together and thickened in Gravity thickener.

4.3 Sludge Stabilization

In this project, following three (3) sludge stabilization processes are studied:

- Anaerobic digestion
- Aerobic digestion
- Lime stabilization

(1) Anaerobic Digestion

Anaerobic digestion has been and continues to be one of the most widely used processes for the stabilization of wastewater treatment sludge, and has the following advantages:

- Required energy for operation is just limited for mixing the anaerobic digestion tank
- High rate of pathogens destruction
- Production of electric power by methane can cover from 20% to 30% of electric consumption at the treatment plant

- Reduction of 30% to 40% of sludge volume requiring ultimate disposal.
- Sludge is suitable for land disposal

The required retention time of anaerobic digestion tank is more than 20 days under the temperature of 30°C to 35°C. And biogas produced from the anaerobic processing of sludge should be collected either for use or for burning to avoid odor. This digester gas handling system requires intricate devices. These complications lead to the following disadvantages:

- Requires skilled operators
- High initial cost requirement
- Supernatant strong in BOD, COD, SS, and NH_3

And for treating chemically precipitated primary sludge, anaerobic digestion is not recommmended because it may lead to process failure (Acid Digestor) of anaerobic digestion process.

(2) Aerobic Digestion

Aerobic digestion is the process which is used for stabilization of sludge in small plants. Usually this process is used to stabilize sludge from extended aeration or nitrification systems where sludge has already longer SRT of the order of 20 days. The primary sludge which has comparatively smaller SRT may not be fully stabilized by aerobic digestion process. Hence for primary sludge aerobic digestion process is not recommended.

The advantages of aerobic digestion compared to anaerobic digestion process are listed below:

- Lower initial cost requirement
- Lower BOD concentrations in supernatant
- Operation is relatively easy

Disadvantages of aerobic digestion are as follows:

- Higher power cost requirement for association with supplying the required oxygen
- Digested sludge is produced with poor mechanical dewatering characteristics

(3) Lime Stabilization

In the lime stabilization process, lime is added to untreated sludge in sufficient quantity to raise the pH to 12 or higher. The high pH creates an environment that is not conducive to the survival of microorganisms. Consequently, the sludge will not putrefy, create odor, or pose a health hazard, so long as the pH is maintained at this level. This process has not been used so frequently as other two (2) stabilization process because of the lower efficiency of sludge stabilization. Incineration or sanitary landfill is required as the ultimate disposal for the lime stabilized sludge.

Stacked lime of more than 2 million m^3 is available at the treatment plant site. If the stacked lime is in useable condition, lime stabilization process can be operated by using this stacked lime for more than 50 years.

Hence JICA Study Team requested Central Laboratory to analyze the quality of that stacked lime. Based on the laboratory analysis, the stacked lime has been already effloresced.

From the above discussions, the main conclusions relevant to this study are as follows:

- Aerobic digestion is not recommended for primary sludge
- The stacked lime at the proposed treatment site has been already effloresced, hence lime stabilization process is neglected from the alternatives of stabilization process

4.4 Dewatering

Natural and mechanical dewatering processes are employed for dewatering sludge discharged from wastewater treatment plant. Sand drying beds and drying lagoon are main systems of natural dewatering process. Sludge lagoon is not recommended for unstabilized sludge. Belt filter press is the most commonly used mechanical dewatering process. In this study, these three (3) dewatering systems are compared.

4.5 Ultimate Disposal

Land Disposal has been considered as the ultimate disposal, thus it is necessary to stabilize the sludge before disposal so as to reduce pathogens and odor. In case sludge is not stabilized Sanitary Landfill is recommended as ultimate disposal.

4.6 Alternatives of Sludge Treatment Process

According to the above discussions, alternative process at each step of sludge treatment has been considered for the study;

Thickening process

- Separate thickening
- Combined thickening

Stabilization process

- Anaerobic digestion
- Aerobic digestion

Dewatering process

- Belt Filter Press
- Drying bed
- Drying Lagoon

Disposal process

- Land disposal
- Sanitary Landfill

These processes are considered in each alternative of wastewater treatment for the Final Project (year 2015) and appropriate modification will be done for the Urgent Project.

4.7 Design Criteria Considered for Alternative Process

The Standard Design Manuals being used as references are as follows:

- Wastewater Engineering (Metcalf / Eddy) (W/E)
- WEF Manual of Practice No.8 & ASCE Manual and Report on Engineering Practice No.76 (WEF)
- Japanese Design Manual on Wastewater Treatment (JDM)

The results of the comparative study of design criteria are summarized in Table F.2. Based on the comparative study, design criteria used in the evaluation of the alternatives was selected. These design criteria are described below:

(1) Gravity Thickener

Depending upon the sludge characteristics, solid loading and thickened sludge concentration are determined based on the design criteria of W/E and WEF as shown below.

Sludge Type	Item	Design Criteria
Primary Sludge	Raw Sludge Concentration	3.0%
	Thickened Sludge Concentration	6.0%
	Solid Loading	110 kg/m^2•d
Chemically Precipitated Sludge	Raw Sludge Concentration	2.0 %
	Thickened Sludge Concentration	6.0 %
	Solid Loading	30 kg /.m^2•d
Primary & Activated Sludge	Raw Sludge Concentration	Primary = 3.0 % Activated = 0.8 %
	Thickened Sludge Concentration	3.0 %
	Solid Loading	50 kg / m^2•d
Primary & Biofilter Sludge	Raw Sludge Concentration	Primary = 3.0 % Biofilter = 2.0 %
	Thickened Sludge Concentration	5.0 %
	Solid Loading	75 kg / m^2•d

(2) Centrifugal Thickener

Centrifugal thickener is used for thickening activated sludge only. Raw sludge and thickened sludge concentration are reported as 0.8% and 6.0% respectively. The operation time recommended is 24 hrs/day and 80% of operation efficiency is expected.

(3) Anaerobic Digestion

Design retention time of anaerobic digestion tank of 20 days has been recommended by WEF.

(4) Aerobic Digestion

Design criteria for aerobic digestors, as recommended by W/E, are as follows:

Retention time 15 - 20 days
Solids loading 1.6 - 4.8 Kg volatile solids/m^3•d

Expected reduction in volatile suspended solids: 40-50 %

(5) Mechanical Dewatering (Belt Filter Press Type)

Belt filter press type is employed as a mechanical dewatering system. Dewatering capacity and solid concentration of dewatered sludge cake depends on the sludge characteristics as shown below:

Sludge Type	Item	Design Criteria
Anaerobic Digested Sludge (PRI + AS)	Sludge Loading per Belt Width	250 kg / hr.•m
	Dozing Rate of Dry Polymer	5 g/kg DS
	Solid Concentration of Dewatered Sludge Cake	22 %
Anaerobic Digested Sludge (AS)	Sludge Loading per Belt Width	90 kg / hr.•m
	Dozing Rate of Dry Polymer	7 g / kg•DS
	Solid Concentration of Dewatered Sludge Cake	15 %
Anaerobic Digested Sludge (PRI + BF)	Sludge Loading per Belt Width	250 kg / hr.•m
	Dozing Rate of Dry Polymer	5 g / kg•DS
	Solid Concentration of Dewatered Sludge Cake	22 %
Chemically Precipitated Sludge (Without Stabilization)	Sludge Loading per Belt Width	200 kg / hr.•m
	Dozing Rate of Dry Polymer	3 g / kg DS
	Solid Concentration of Dewatered Sludge Cake	22 %
Aerobic Digested Sludge (PRI + AS)	Sludge Loading per Belt Width	180 Kg /hr.•m
	Dozing Rate of Dry Polymer	5 g / kg•DS
	Solids Concentration of Dewatered Sludge Cake	18 %
Aerobic Digested Sludge (PRI + BF)	Sludge Loading per Belt Width	180 Kg /hr.•m
	Dozing Rate of Dry Polymer	5 g / kg•DS
	Solids Concentration of Dewatered Sludge Cake	18 %

Note : PRI means primary sludge, AS means activated sludge, BF means biofilter sludge and DS means dry solid.

Operation time and operation efficiency are determined as 12 hrs per day and 80% respectively.

(6) Sand Drying Beds

Solids Surface Loading : 73 $kg/m^2/year$ (WEF)

(7) Drying Lagoon

Solid Volumetric Loading : 36 $kg/m^3/year$ (W/E)

Cycle Time : 2 years

Effective Lagoon Depth : 1.25 m

Table F.3 show the design criteria of each facility by alternative case.

5. Comparative Evaluation

5.1 General

As discussed in Appendix F, section 4, three (3) alternatives of wastewater treatment have been proposed and alternatives of sludge treatment process at each step of sludge treatment system also have been proposed. These alternatives are financially evaluated to find optimum Wastewater and Sludge Treatment System.

The proposed Texcoco wastewater treatment plant with the capacity of 40 m^3/sec. is designed to have eight (8) units, each having capacity of 5 m^3/sec. Sludge treatment system is also supossed to consist of eight (8) units and each unit treats the sludge discharged from one (1) unit of wastewater treatment plant with a capacity of 5 m^3/sec. Initially, Cost estimation has been done for one (1) unit of wastewater and sludge treatment system and then total cost is estimated by multiplying with eight (8). There are two (2) major components of the cost involved in the cost estimation

- Construction Cost
- Operation and Maintenance Cost (O/M Cost)

The Construction Cost and O/M Cost involved in the general items such as receiving tank, distribution tank, chlorination tank, control building, discharge channel, access roads etc. are not much different for each alternative and hence these costs are not considered in the evaluation stage. Whereas the cost of pile foundation (for supporting structure) has been considered in the evaluation. Construction cost of concrete pile having 0.6 m diameter, 30 m length and 3 m pitch has been included

All costs are estimated in Nuevos Peso with May 1994 prices as the basis.

5.2 Wastewater Treatment System

Structural design, Construction Costs and O/M Costs have been computed for each alternative and as mentioned above common units such as receiving unit, chlorination tanks etc. are neglected at this step.

5.2.1 Alternative I

(1) Structural Design

Alternative I is the conventional activated sludge process. The Schematic diagram of the process is shown below.

P/S : Primary sedimentation tank
A/T : Aeration tank
S/S : Secondary sedimentation tank
CL : Chlorination

The required dimensions of the facility for the one (1) unit are as follows:

- Primary Sedimentation Basin : 10 m (w) x 39 m (l) x 3.0 m (d) x 32 tanks
- Aeration Tank : 10.3 m (w) x 89 m (l) x 6.0 m (d) x 32 tanks
- Secondary Sedimentation Basin : 10 m (w) x 54 m (l) x 3.5 m (d) x 32 tanks

(2) Construction Cost

Construction Cost of the facility for one (1) unit is:

- Primary Sedimentation Basin	Civil	:	N$	32.10 million
	M/E	:	N$	20.83 million
	Total	:	N$	52.93 million
- Aeration Tank	Civil	:	N$	67.10 million
	M/E	:	N$	47.90 million
	Total	:	N$	115.00 million
- Secondary Sedimentation Basin	Civil	:	N$	43.90 million
	M/E	:	N$	28.50 million
	Total	:	N$	72.40 million

The total construction cost of one (1) unit is N$ 240.33 million. Hence the total construction cost of eight (8) units for the Alternative I is N$ 1922.6 million.

(3) O/M Cost

Electrical expenditure of Blower and Repairing cost is considered as the major O/M cost involved in the Alternative I.

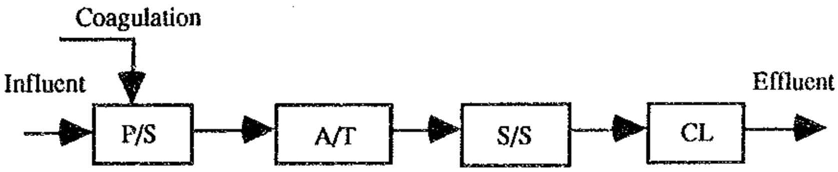
Annual Electrical Expenditure of one (1) unit	: N$ 5.35 million
Repairing cost of one (1) unit	: N$ 5.83 million

Hence total annual O/M cost of eight (8) units for the Alternative I is N$ 89.4 million.

5.2.2 Alternative II

(1) Structural Design

Alternative II is the activated sludge process with coagulation in primary sedimentation basin. The schematic diagram of the process is shown below.



P/S : Primary sedimentation tank
A/T : Aeration tank
S/S : Secondary sedimentation tank
CL : Chlorination

The required dimensions of the facility for one (1) unit are as follows:

- Primary Sedimentation Basin	:	10 m (w) x 39 m (l) x 3.0 m (d) x 32 tanks
- Aeration Tank	:	10.3 m (w) x 81 m (l) x 6.0 m (d) x 32 tanks
- Secondary Sedimentation Basin	:	10 m (w) x 54 m (l) x 3.5 m (d) x 32 tanks

(2) Construction Cost

Construction Cost of the facility for one (1) unit is:

- Primary Sedimentation Basin	Civil	:	N$	41.30 million

(including mixing and flocculation	M/E	:	N$	21.60 million
unit)	Total	:	N$	62.90 million
- Aeration Tank	Civil	:	N$	62.00 million
	M/E	:	N$	43.10 million
	Total	:	N$	105.10 million
- Secondary Sedimentation Basin	Civil	:	N$	43.90 million
	M/E	:	N$	28.50 million
	Total	:	N$	72.40 million

The total construction cost of one (1) unit is N$ 240.40 million. Hence the total construction cost of eight (8) units for the Alternative II is N$ 1923.2 million.

(3) O/M Cost

Electrical expenditure, Repairing cost and chemical cost are considered as the major O/M cost involved in the Alternative II.

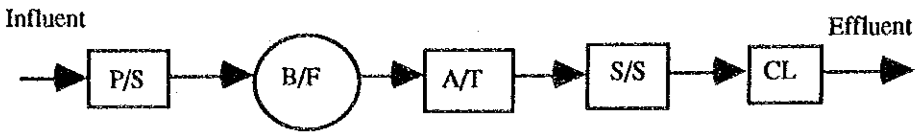
Annual Electrical Expenditure of one (1) unit	:	N$ 4.70 million
Annual Chemical Cost of one (1) unit	:	N$14.50 million
Repairing cost of one (1) unit	:	N$ 5.59 million

Hence total annual O/M cost of eight (8) units for the Alternative II is N$ 198.32 million.

5.2.3 Alternative III

(1) Structural Design

Alternative III is the dual process, i.e., biofilter followed by conventional activated sludge process. The schematic diagram of the process is shown below.



P/S : Primary sedimentation tank
B/F : Biofilter
A/T : Aeration tank
S/S : Secondary sedimentation tank
CL : Chlorination

The required dimensions of the facility for the one (1) unit are as follows:

- Primary Sedimentation Tank	:	10 m (w) x 39 m (l) x 3.0 m (d) x 32 tanks
- Biofilter	:	Diameter 27 m x 3.5 m (d) x 8 tanks
- Aeration Tank	:	10.3 m (w) x 55 m (l) x 6.0 m (d) x 32 tanks
- Secondary Sedimentation Tank	:	10 m (w) x 54 m (l) x 3.5 m (d) x 32 tanks

(2) Construction Cost

Construction cost of the facility for one (1) unit is:

- Primary Sedimentation Tank	Civil	:	N$	32.10 million
	M/E	:	N$	20.83 million
	Total	:	N$	52.93 million
- Pumping Station	Civil	:	N$	5.20 million
	M/E	:	N$	19.30 million
	Total	:	N$	24.50 million
- Biofilter	Civil	:	N$	65.50 million
	M/E	:	N$	4.80 million
	Total	:	N$	70.30 million
- Aeration Tank	Civil	:	N$	44.00 million
	M/E	:	N$	30.40 million
	Total	:	N$	74.40 million
- Secondary Sedimentation Tank	Civil	:	N$	43.90 million
	M/E	:	N$	28.50 million
	Total	:	N$	72.40 million

The total construction cost of one (1) unit is N$ 294.53 million. Hence the total construction cost of eight (8) units for the Alternative III is N$ 2,356.2 million.

(3) O/M Cost

For Alternative III also, Electrical expenditure and Repairing cost is considered as the major O/M cost involved.

Annual Electrical Expenditure of one (1) unit	:	N$ 4.18 million
Repairing cost of one (1) unit	:	N$ 6.23 million

Hence total annual O/M cost of eight (8) units for the Alternative III is N$ 83.3 million.

5.3 Selection of Appropriate Sludge Treatment System

As described in the previous section, alternative process at each step of sludge treatment has been decided. These alternative processes are financially compared to find appropriate process at each step and hence appropriate sludge treatment system has been selected.

For financially comparing different processes, calculations have been done for Alternative I and appropriate sludge treatment process has been selected. The effect of solids getting washoutout in each step of sludge treatment system has been neglected. In other words 100% solid capture at each step has been assumed.

Keeping the same financial comparison as the basis, appropriate sludge treatment system for Alternative II and Alternative III have been selected with proper modifications, which is further discussed in the subsequent sections.

For evaluating various alternative processes, structural design, construction costs and O/M costs have been computed for each process.

5.3.1 Thickening Process

Separate Thickening (primary sludge to be thickened by Gravity Thickener and secondary sludge to be thickened by Centrifugal Thickener) and Combined Thickening (primary and secondary sludge to be thickened together by Gravity Thickener) have been selected as two (2) alternative processes in Appendix F, section 4.2.

Thickening process has major effect on the subsequent stabilization process. For comparison, Anaerobic Digestion is selected as the stabilization process.

A) Separate Thickening

(1) Structural Design

The details of the sludge characteristics obtained, employing Separate thickening system are mentioned for one (1) unit.

Characteristics of sludge	Primary Sludge		Secondary Sludge	
	Unthickened Sludge	Thickened Sludge	Unthickened Sludge	Thickened Sludge
Quantity (m^3/d)	1,500	750	6,800	910
Solid Content (%)	3	6	0.8	6

Required capacity of anaerobic digestion tank for one (1) unit: 33,200 m^3.

The calculation chart is shown in Fig. F.6.

The required dimensions of the facility for one (1) unit are as follows:

- Gravity Thickener : Diameter 16.0m x 4.0 m (h) x 2 tanks (solid loading = 110 $kg/m^2 \cdot d$)
- Centrifugal Thickener : 180 m^3/hr. x 2 sets
- Anaerobic Digestion Tank : Diameter 24.0 m x 12.5 m (h) x 6 tanks

(2) Construction Cost

The direct construction cost for one (1) unit is estimated to be N$ 48.6 million at 1994 price with the following breakdown.

(Unit : million N$)

Work Item	Const. Cost
Gravity Thickener	4.00
Centrifugal Thickener	8.00
Anaerobic Digestion Tank	36.60
Total	48.60

Hence the total direct construction cost of eight (8) units for Separate Thickening is N$ 388.80 million.

(3) O/M Cost

Electrical expenditure is considered as the major O/M cost involved. Annual electrical expenditure for one (1) unit is estimated as N$ 0.568 million at 1994 price. Breakdown is shown below.

Electrical Power Consumption for

- Gravity Thickener	: 1,500 m^3/d x 0.03 kwH/m^3= 45 kwH
- Centrifugal Thickening	: 6,800 m^3/d x 1.0 kwH/m^3= 6,800 kwH
- Anaerobic Digestion Tank	: 6 tanks x 15 kw x 24 h = 2,160 kwH

Total Electrical Power Consumption : 9,005 kwH

Monthly basic charge (N$ 24/kw/month)

- 9,005 kwH/day /24 h x 24 x 12 months = N$ 0.108 million

Electrical charge (N$ 0.14/kwH)

- 9,005 kwH/day x 365 d x 0.14 = N$ 0.460 million

Total Electrical Expenditure : N$ 0.568 million

Hence total annual O/M cost for eight (8) units for Separate Thickening is N$ 4.54 million.

B) Combined Thickening

(1) Structural Design

Mixed sludge (Primary sludge and Secondary Sludge) from one (1) unit

- Quantity produced : 8,300 m^3/day
- Solid content : 1.2 %

Thickened sludge (Gravity Thickener)

- Quantity produced : 3,310 m^3/day
- Solid Content : 3 %

Required capacity of anaerobic digestion tank for one (1) unit: 66,200 m^3.

The calculation chart is shown in Fig. F.6.

The required dimensions of the facility for one (1) unit are as follows:

- Gravity Thickener : Diameter 21.0m x 4.0 m (h) x 6 tanks (solid loading = 50 kg/m^2•d)
- Anaerobic Digestion Tank : Diameter 28.0 m x 14 m (h) x 8 tanks

(2) Construction Cost

The direct construction cost for one (1) unit of wastewater treatment system is estimated to be N$ 89.70 million at 1994 price with the following breakdown.

(Unit : million N$)

Work Item	Const. Cost
Gravity Thickener	18.5
Anaerobic Digestion Tank	71.2
Total	89.7

Hence the total direct construction cost of eight (8) units for Combined Thickening is N$ 717.6 million.

(3) O/M Cost

Electrical expenditure is considered as the major O/M cost involved. Annual electrical expenditure for one (1) unit is estimated as N$ 0.20 million at 1994 price. Breakdown is shown below.

Electric Power consumption for

- Gravity Thickener :
  8,300 m3/d x 0.03 kwH/m^3 = 249 kwH

- Anaerobic Digestion Tank :
  8 tanks x 15 kw x 24 h x 8 = 2,880 kwH

Total Electric Power Consumption : 3,129 kwH

- Monthly basic charge (N$ 24/kw/month)

3,129 kwH/day /24 h x 24 x 12 months = N$ 0.04 million

- Electrical charge (N$ 0.14/kwH)
  3,129 kwH/day x 365 d x 0.14 = N$ 0.16 million

Total Electrical Expenditure : N$ 0.20 million

Hence total annual O/M cost for eight (8) units for Separate Thickening is 1.60 million N$.

C) Financial Evaluation of Separate and Combined Thickening

Both Separate Thickening and Combined Thickening systems are compared in terms of required construction cost and O/M cost as described below:

	Construction Cost (N$ billion)	Annual Electrical Expenditure (N$ million / annum.)
Separate Thickening	388.8	4.54
Combined Thickening	717.6	1.60

As evident from the above table, Separate Thickening is more economical than Combined Thickening.

Hence Separate Thickening is selected as the appropriate thickening process atleast when anaerobic digestion is adopted as subsequent stabilization process.

5.3.2 Stabilization Process

As described in Appendix F, section 4.3, anaerobic digestion and aerobic digestion have been selected as two (2) alternative processes. These processes are financially evaluated to select the appropriate stabilization process.

As described in the previous section, Separate Thickening is the appropriate thickening process. The details of thickened sludge are mentioned below.

- Thickened primary sludge for one (1) unit

Volume	:	750 m^3/d
Solid weight	:	44.928 ton/d
Solid content	:	6.0 %

- Thickened secondary sludge from centrifugal thickener for one (1) unit

Volume	:	910 m^3/d
Solid weight	:	54.432 ton/d
Solid content	:	6.0 %

A) Anaerobic Digestion

(1) Structural Design

Required capacity of anaerobic digestion tank for one (1) unit of wastewater treatment plant is 33,200 m^3.

- Dimensions of Anaerobic Digestion Tank
  : Diameter 24 m x 12.5 m (h) x 6 tanks

(2) Construction Cost

The direct construction cost for one (1) unit is estimated to be N$ 36.6 million at 1994 price. The breakdown is shown below.

(Unit : million N$)

Work Item	Const. Cost
Anaerobic Digestion Tank	29.40
Mechanical & Electrical Works	7.20
Total	36.60

Total direct construction cost for eight (8) units is estimated to be N$ 292.8 million.

(3) O/M Cost

Electrical expenditure is considered as the major O/M cost involved. Electricity generation by digestor gas has been considered as energy recovery.

Total annual electrical expenditure for eight (8) units is estimated as N$ 1.09 million. The breakdown is shown below.

- Monthly basic charge (N$ 24 / kW/month)
  90 kW/d x 24 N$ /m x 12 months x 8 units
  = N$ 0.21 million / annum.

- Electrical charge (N$ 0.14 / kWH)

90 kW/d x 24 h x 365 d x 0.14 N$ x 8 units
= N$ 0.88 million / annum.

Total Electrical Expenditure : N$ 1.09 million / annum.

Electrical Generation by Digester Gas:

Digester gas may be used as fuel for boiler and internal combustion engines, which are in turn used for generating electricity. In large scale wastewater treatment plant, about 20% of total consumption of electricity can be afforded by the generated electricity by digester gas.

Electrical consumption = 432,000 x 0.3 KWH = 129,600 KWH/d
= 129,600 x 24 x 0.2 = 1,080 KW/unit
= 1,080 x 24 x 365 x 8 unit = 75,700 MWH

Hence the total energy recovery amounts to about 75,700 MWH per annum.

The above mentioned produced energy in terms of cost is estimated as N$ 13.09 million. The details are shown below.

- Monthly basic charge (N$ 24 / KW/month)
  1,080 KW/d x 24 N$ /m x 12 months x 8 units
  = N$ 2.49 million / annum.
- Electrical charge (N$ 0.14 / KWH)
  1,080 KW/d x 24 h x 365 d x 0.14 N$ x 8 units
  = N$ 10.60 million / annum.

Total N$ 13.09 million / annum.

B) Aerobic Digestion

(1) Structural Design

Required capacity of aerobic digestion tank for one (1) unit of wastewater treatment plant with is 24,900 m^3.

- Dimensions of Aerobic Digestion Tank
  : 20 m (l)x 20 m (w) x 5 m (h) x 13 tanks

(2) Construction Cost

The direct construction cost for one (1) unit is estimated to be N$ 23.60 million at 1994 price. The breakdown is shown below.

(Unit : million N$)

Work Item	Const. Cost
Aerobic Digestion Tank	13.20
Mechanical & Electrical Works	10.40
Total	23.60

Total direct construction cost for eight (8) units is estimated to be N$ 188.80 million.

(3) O/M Cost

Electrical expenditure is considered as major O/M cost involved.

Total Annual electrical expenditure for eight (8) units is estimated as N$ 10.90 million. The breakdown is shown below.

Electrical power consumption for one (1) unit : 900 kW/d

- Monthly basic charge (N$ 24 / KW/month)
  900 kW/d x 24 N$ /m x 12 months x 8 units
  = N$ 2.07 million / annum.
- Electrical charge (N$ 0.14 / kWH)
  900 kW/d x 24 h x 365 d x 0.14 N$ x 8 units
  = N$ 8.83 million / annum.

Total N$ 10.90 million / annum.

C) Financial Evaluation of Anaerobic Digestion and Aerobic Digestion

Both Anaerobic Digestion and Aerobic Digestion processes, for total wastewater treatment plant with a capacity of 40 m^3/sec., are compared in terms of required construction cost and annual electrical expenditure, as described below:

	Construction Cost (N$ billion)	Annual Electrical Expenditure (N$ million / annum.)
Anaerobic Digestion	292.8	(1.09 - 13.09) = - 12.00
Aerobic Digestion	188.8	10.90

Construction cost of Aerobic Digestion process is about 64% of that of Anaerobic Digestion process. Whereas Aerobic Digestion process requires the annual electricity charge of N$ 22.9 million more than that of Anaerobic Digestion process.

Construction cost and O/M cost of these two (2) digestion processes, for the project life time are compared, in terms of present values, estimated based on the following assumptions.

- Discount rate is 10% per annum.
- O/M period (effective project life time) is up to 30 years after the completion of the construction of treatment plant.

The construction cost and O/M cost of two (2) digestion processes are compared in terms of present values as shown below:

(Unit : million N$)

	Construction	O/M	Total
Anaerobic Digestion	280	-113	167
Aerobic Digestion	192	103	295

As evident from the above table, Anaerobic Digestion process is more economical than Aerobic Digestion process.

Hence Anaerobic Digestion is selected as appropriate stabilization process.

5.3.3 Dewatering Process

Sand Drying Beds, Drying Lagoon and Belt Filter Press have been selected as alternative processes in Appendix F, section 4.4. These processes are financially compared to select the appropriate drying process under following conditions

Total flow rate	:	40 m^3/sec
Influent SS	:	260 mg/l
Effluent SS	:	30 mg/l
Solids removed in digestion	:	33.33 %

The total solids which will be removed per day from all the eight (8) units are described below.

Solids removed : 40 m^3/sec. x 86,400 sec x (260 - 30) mg/l x 10^{-6} x (1-1/3)
= 529.92 ton/d

A) Sand Drying Beds

(1) Structural Design

Gross area required for Sand Drying Beds having solids surface loading of 73 $kg/m^2/year$ (ref. Appendix F, section 4.7) is estimated as follows:

$529.92 \text{ ton/d} \times 10^3 \times 365 \text{ d} / 73 = 264.96 \times 10^4 \text{ m}^2 = 265 \text{ ha}$

Then net area of sand drying beds system is assumed to be 345 ha which is about 30% larger than this gross required area for maintenance road and buffer zone.

(2) Construction Cost

Total direct construction cost is estimated to be N$ 150 million at 1994 price.

(3) O/M Cost

Only electrical expenditure is considered as the major O/M cost. Annual O/M cost is estimated as N$ 0.01 million.

B) Drying Lagoon

(1) Structural Design

Required Drying Lagoon area having solid volumetric loading of 36 $kg/m^3/year$, cycle time of 2 years and effective lagoon depth of 1.25 m (ref. Appendix F, section 4.7) is estimated as follows:

$529.92 \times 10^3 \times 365 \text{ d} \times 2 \text{ years} / 36 / 1.25 = 8{,}596{,}480 \text{ m}^2 = 860 \text{ ha}$

(2) Construction Cost

Direct construction cost is estimated to be N$ 175 million at 1994 price.

(3) O/M Cost

Electical expenditure is considered as the major O/M cost. Annual O/M cost is estimated to be N$ 0.01 million.

C) Belt Filter Press

(1) Structural Design

Daily dewatering capacity of one (1) unit of Belt Filter Press having sludge loading per belt width of 250 kg/hr.•m, operation time of 12 hrs, efficiency of 80% and belt width of 3 m (ref Appendix F, section 4.7) is calculated as follows:

250 kg/hr x 12 hrs. x 80 % x 3.0 m = 7,200 kg/set

Required number of units are;

66.24 ton/d x 10^3 / 7,200 = 9.2 = 10 set / unit

(2) Construction Cost

Direct construction cost is estimated to be N$ 125.6 million.

(3) O/M Cost

Annual O/M cost is estimated to be N$ 2.34 million.

D) Financial Evaluation of Sand Drying Beds, Drying Lagoon and Belt Filter Press

Above mentioned three (3) dewatering systems are evaluated in terms of construction cost and land acquisition cost as described below:

(Unit : million N$)

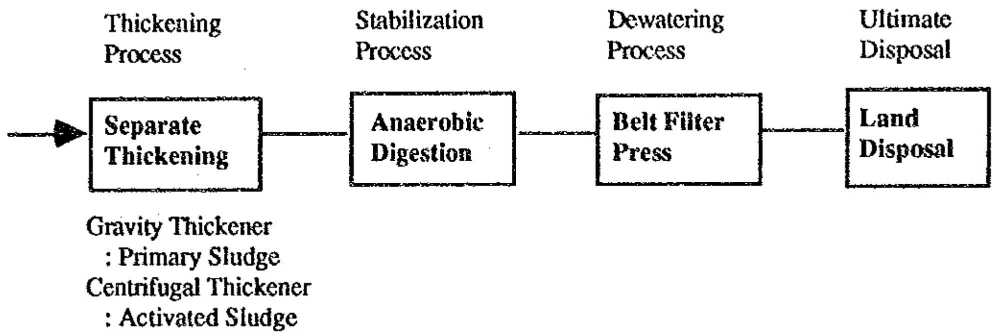
Cost	Sand Drying Beds	Drying Lagoon	Belt Filter Press
Construction Cost	150.0	175.0	125.6
Land Acquisition Cost	207.0 (345 ha)	516.0 (860 ha)	1.0 (2 ha)
Total Cost	357.0	691.0	126.6
Annual O/M Cost	0.01	0.01	2.34

As evidence from the above table, Belt Filter Press process is the most economical one.

Hence Belt Filter Press process is selected as appropriate dewatering process.

5.3.4 Appropriate Sludge Treatment System for Alternative I of Wastewater Treatment System

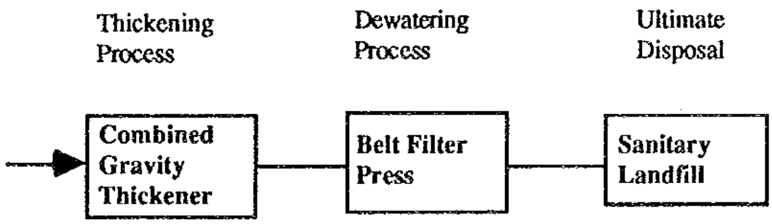
According to the above discussions for the conventional activated sludge, the following system is recommendable as sludge treatment system.



For the designing of sludge treatment system, method of ultimate disposal plays very important role specially on the stabilization process required. In the above mentioned appropriate sludge treatment system, land disposal is considered as the ultimate disposal after stabilizing the sludge.

However stabilization can be avoided if the sludge is disposed as sanitary landfill. This sludge treatment system without stabilization is financially compared with the above mentioned recommendable system.

The schematic diagram of the system without stabilization is shown below:



1) Structure Design

(a) Gravity Thickener

- Mixed sludge (Primary sludge and Secondary Sludge) from one (1) unit

  Quantity produced : 8,300 m^3/day

  Solid content : 1.2 %

- Thickened sludge (Gravity Thickener)

  Quantity produced : 3,310 m^3/day

Solid Content : 3 %

The required dimensions of the facility for one (1) unit are as follows:

Gravity Thickener : Diameter 21.0m x 4.0 m (h) x 6 tanks x 8 units (solid loading = 50 kg/m^2•d)

(b) Belt Filter Press

Daily dewatering capacity of one (1) unit of Belt Filter press having sludge loading per belt width of 250 kg/hr.m, operation time of 12 hrs, efficiency of 80 % and belt width of 3 m (ref Appendix F, section 4.7) is calculated as follows:

250 kg/hr x 12 hrs x 80 % x 3.0 m = 7,200 kg/set

Total sludge produced from one (1) unit	:	8,300 m^3/day (99.36 ton/day)
Sludge produced from eight (8) units	:	794.88 ton/day
Required units of belt filter press	:	14 sets for one (1) unit (capacity=7,200 kg/unit/d) 112 sets for eight (8) units
Dewatered sludge volume	:	3,600 m^3/d (solid content=22%)

(c) Sanitary Landfill

Sludge Volume to be disposed : 3,600 m^3/d

- Thickness of one layer dewatered sludge : 0.4 m
- Thickness of each covering soil layer : 0.3 m
- Total thickness of landfill : 7.0 m
- Disposal capacity per unit area : 4.0 m^3/m^2

Annual required land space for sanitary landfill is estimated as mentioned below:

3,600 m^3/d x 365 d / (4 m^3/m^2) = 32,8500 m^2 = 32.9 ha

2) Construction Cost

Direct construction cost of Gravity Thickener and Belt Filter Press systems are estimated at N$ 323.8 million at 1994 price.

Work Item	Const. Cost
Gravity Thickener	148.0
Belt Filter Press	175.8
Total	323.8

(Unit : million N$)

The construction cost for Sanitary landfill is included in the O/M cost for Sanitary Landfill.

3) O/M Cost

Annual O/M cost for Sanitary Landfill : N$ 85.4 million.

Annual O/M cost (Electrical expenditure) for Belt filter press : N$ 3.0 million.

Annual O/M cost (Electrical expenditure) for Gravity thickener : N$ 0.12 million.

Repairing cost : N$ 11.19 million

Total Annual O/M cost for sludge treatment system without stabilization is estimated to be N$ 99.7 million.

The total cost for the sludge treatment system without stabilization has been compared with the recommendable sludge treatment system (with stabilization). The details are shown below:

Facility Cost	Recommendable Process	Without Stabilization Process
Construction Cost (N$ million)		
Gravity & Centrifugal Thickener	96.00	-
Gravity Thickener	-	148.00
Anaerobic Digester	292.80	-
Belt Filter Press	125.60	175.80
Total Const. Cost	514.40	323.80
O/M Cost (N$ million / annum.)	38.40	99.70

Note : Details of cost estimation for recommendable process has been mentioned in previous sections. O/M cost includes Repairing cost and O/M cost for Land disposal.

Construction cost of recommendable sludge treatment process is 1.6 times higher than that of without stabilization process. While annual O/M cost of N$ 38.4 million for recommendable process is much cheaper than that of without stabilization process of N$ 99.7 million.

Construction and O/M costs of these two (2) systems for the project life time are compared in terms of present values estimated based on the same conditions as mentioned in Appendix F, section 5.3.2.

(Unit : million N$)

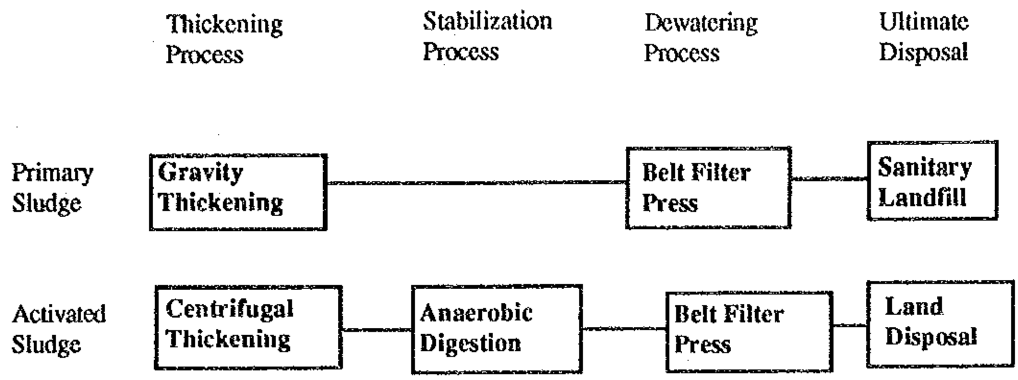
	Construction	O/M	Total
Recommendable One	546	362	908
Without Stabilization	348	939	1287

Hence Recommendable sludge treatment system mentioned in the beginning of this section i.e. consisting of Separate thickening, Anaerobic Digestion, Belt Filter Press and Land Disposal is the most appropriate sludge treatment system for Alternative I of wastewater treatment system.

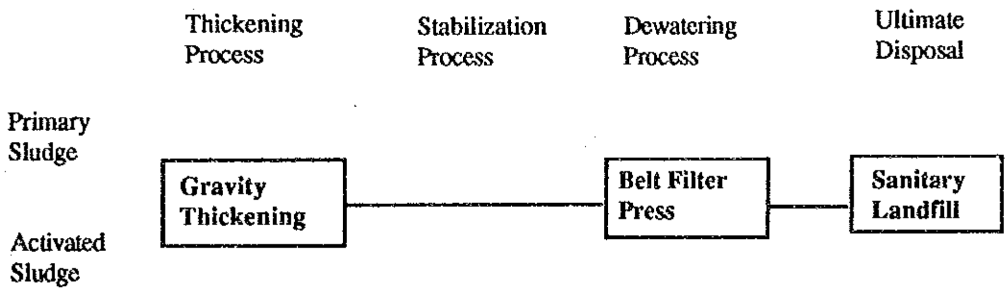
5.3.5 Appropriate Sludge Treatment System for Alternative II of Wastewater Treatment System

The appropriate sludge treatment system for Alternative II has been determined with the same basis as for Alternative I, with proper modifications. Alternative II employs chemical dosing in Primary Sedimentation Tank. As mentioned in Appendix F, section 4.3 Anaerobic Digestion and Aerobic Digestion is not recommended for chemically precipitated sludge, hence two (2) cases of sludge treatment are possible, which are described below:

Case 1



Case 2



Financial evaluation in terms of construction cost and O/M cost for these two (2) cases is carried out to find appropriate sludge treatment system for Alternative II.

A) Case 1 of Sludge Treatment System

1) Structural Design

The required dimensions of the facility are as follows:

- Gravity Thickener : Diameter 22 m x 4.0 m (d) x 8 tanks for one (1) unit
- Centrifugal Thickener : 30 m^3/hr x 2 sets for one (1) unit
- Anaerobic Digestion : Diameter 16 m x 8 m (d) x 2 tanks for one (1) unit
- Belt Filter Press : 3.0 m (belt width) x 18 sets for one (1) unit
- Sanitary Landfill : 1,197,200 m^3 / anumn for eight (8) units
- Land Disposal : 116,800 m^3/anumn for eight (8) units

2) Construction Cost

Direct construction cost of sludge treatment system for all the eight (8) units of Case 1 is estimated as N$ 488.5 million at 1994 price and breakdown of cost is shown below.

(Unit : N$ million)

Facility	Construction Cost
Gravity Thickener	211.2
Centrifugal Thickener	12.8
Anaerobic Digestion Tank	38.4
Belt Filter Press	226.1
Total	488.5

3) O/M Cost

Annual O/M cost for all the eight (8) units is estimated to be N$ 103.8 million. The breakdown is as follows :

(Unit : N$ million)

Facility	Construction Cost
Sanitary Landfill	77.8
Land Disposal	3.9
Electrical expenditure for (Gravity thickener, Centrifugal Thickener, Anaerobic digestion and Belt Filter Press)	2.8
Repairing cost	19.3
Total	103.8

B) Case 2 of Sludge Treatment System

1) Structural Design

The required dimensions of the facility are as follows:

- Gravity Thickener : Diameter 23 m x 4.0 m (d) x 8 tanks for one (1) unit
- Belt Filter Press : 3.0 m (belt width) x 17 sets for one (1) unit
- Sanitary Landfill : 1314000 m^3/anumn for eight (8) units

2) Construction Cost

Direct construction cost of sludge treatment system for all the eight (8) units of Case 2 is estimated as N$ 443.9 million at 1994 and breakdown of cost is shown below.

(Unit : N$ million)

Facility	Construction Cost
Gravity Thickener	230.4
Belt Filter Press	213.5
Total	443.9

3) O/M Cost

Annual O/M cost for all the eight (8) units is estimated to be N$ 106.4 million. The breakdown is as follows :

(Unit : N$ million)

Facility	Construction Cost
Sanitary Landfill	85.4
Electrical Expenditure for Gravity Thickener and Belt Filter Press	3.6
Repairing cost	17.4
Total	106.4

(3) Comparison of Case 1 and Case 2

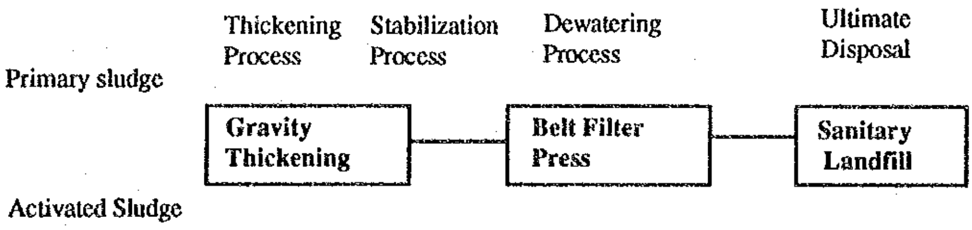
The total construction cost and O/M cost for Case 1 are N$ 488.5 million and N$ 103.8 million respectively whereas total construction cost and O/M cost for Case 2 are N$ 443.9 million and 106.4 million.

Construction and O/M costs of these two (2) cases for the project life time are compared in terms of present values estimated based on the same conditions as mentioned in Appendix F, section 5.3.2.

(Unit : N$ million)

	Construction Cost	O/M Cost	Total Cost
Case 1	521	980	1,501
Case 2	473	1,003	1,476

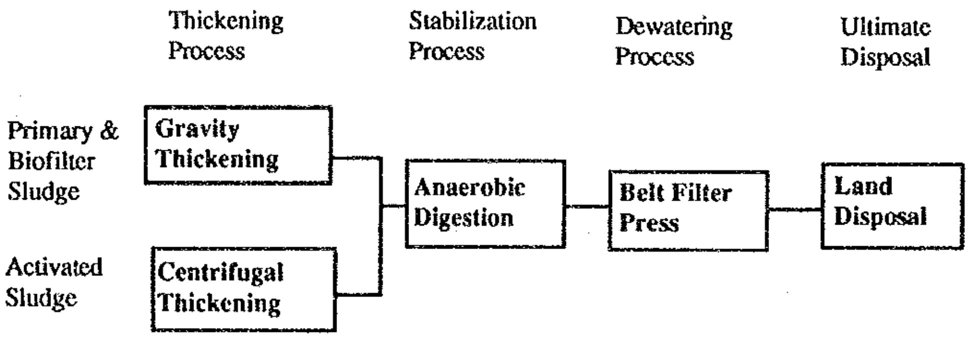
The above discussion indicate that Case 2 is cheaper than Case 1 and hence is the most Appropriate sludge treatment system for Alternative II of Wastewater treatment. The flow diagram of most Appropriate sludge treatment is shown below:



5.3.6 Appropriate Sludge Treatment System for Alternative III of Wastewater Treatment System

The appropriate sludge treatment system for Alternative III has been determined with the same basis as for Alternative I. Alternative III is a dual process, i.e., Biofilter followed by activated sludge process. The characteristics of sludge produced are not much different from Alternative I and hence the appropriate sludge treatment system has the same process.

The Schematic diagram of appropriate sludge treatment system for Alternative III is shown below.



The structural design, construction cost and O/M cost for the appropriate sludge treatment system has been computed and are described below.

1) Structural Design

The required dimensions of the facility for one (1) unit are as follows:

- Gravity Thickener : Diameter 20 m x 4.0 m (d) x 3 tanks
- Centrifugal Thickener : 60 m^3/hr. x 3 sets
- Anaerobic Digestion : Diameter 25 m x 12.5 m (d) x 6 tanks
- Belt Filter Press : 3.0 m (belt width) x 9 sets

2) Construction Cost

Direct construction cost of sludge treatment system for one (1) unit is estimated to be N$ 65.88 million at 1994 price and breakdown is shown below.

(Unit : N$ million)

Facility	Construction Cost
Gravity Thickener	8.25
Centrifugal Thickener	4.50
Anaerobic Digestion Tank	39.00
Belt Filter Press	14.13
Total	65.88

Hence total direct construction cost for eight (8) units is N$ 527.0 million.

3) O/M Cost

Annual O/M cost is estimated to be N$ 33.9 million. The breakdown is as follows.

(Unit : N$ million)

Facility	Construction Cost
Land Disposal	29.3
Electrical expenditure for (Gravity thickener, Centrifugal Thickener, Anaerobic digestion including energy recovery and Belt Filter Press)	- 9.2
Repairing cost	13.8
Total	33.9

5.4 Financial Evaluation for the Selection of Optimum Wastewater and Sludge Treatment System for the Year 2015

Based on the above discussions, following three (3) integrated Wastewater and Sludge treatment systems are compared in terms of required construction and O/M costs.

Alternative	Wastewater Treatment System	Sludge Treatment System
I	CAS	ST (GT, CT) + AND + BF + LD
II	CG + CAS	GT + BF + SL
III	Dual Process (Biofilter + CAS)	ST (GT + CT) + AND + BF + LD

Note : CAS: Conventional Activated Sludge, CG : Primary Sedimentation with Coagulation,
ST : Separate Thickening, GT : Gravity Thickening, CT : Centrifugal Thickening,
AND : Anaerobic Digestion, BF : Belt Filter Press, LD : Land Disposal,
SL : Sanitary Landfill

Total direct construction and annual O/M costs of each alternative for the integrated wastewater and sludge treatment system have been compared. For comparison, construction costs for the items (e.g. administrative building, access roads) which are common in all the three (3) alternatives, have been neglected. Similarly O/M costs for items such as personal expenditure, repairing cost etc., which are common or negligibly different, have been ignored. The comparison of construction and O/M cost is shown below.

(Unit : N$ million)

Alternative	Construction Cost	Annual O/M Cost
I	2,644.6	127.8
II	2,574.3	304.7
III	3,095.2	117.2

Alternative II has the lowest direct construction cost of N$ 2574.3 million whereas Alternative III has the lowest annual O/M cost of N$ 117.2 million. The breakdown of construction cost is shown in Table F.4 and summary of construction and O/M costs are shown in Table F.5.

Construction and O/M costs of these three (3) alternatives for the project life time are compared, in terms of present values, estimated based on the same assumptions, as mentioned in Appendix F, section 5.3.2.

The comparison of the three (3) alternatives in terms of construction and O/M costs (in terms of present value) are shown below.

(Unit : N$ million)

Alternative	Construction Cost	O/M Cost	Total Cost
I	2,702	1,206	3,908
II	2,638	2,869	5,507
III	3,119	1,105	4,224

It is evident from the above comparative table that **Alternative I** is the most economical alternative and hence is selected as the Optimum Wastewater and Sludge Treatment system for the Final Project (Yr. 2015).

6. Proposed Wastewater and Sludge Treatment System

6.1 Design of Structures

6.1.1 Wastewater Treatment System

Conventional activated sludge system consists of (1) receiving tank, (2) distribution tank, (3) primary sedimentation tank, (4) aeration tank, and (5) secondary sedimentation tank. The effluent is disinfected to kill pathogens. The layout of one (1) unit for the treatment plant and the hydraulic profile of the treatment plant is shown in Fig. F.7 and F.8, respectively.

Total capacity of the treatment plant is 40 m^3/sec. The whole treatment system has been divided into eight (8) units, each having capacity of 5 m^3/sec. The stepwise construction of the system is recommended.

The structural design for the treatment has been done for one (1) unit.

(1) Receiving Tank

The structure of receiving tank for the complete treatment system is proposed to be constructed at the initial stage itself. The tank is divided into two (2) compartments by the center wall for maintenance purpose.

Hydraulic retention time of 1.5 minutes is considered for designing the receiving tank . The total capacity of tank is 3,628 m^3. The tank is 31.6 m long and 21.5 m wide, with an effective water depth of 5.34 m.

(2) Distribution Tank

The total wastewater discharge of 40 m^3/sec. is equally distributed to each unit of treatment system by the distribution tank. Each unit of treatment system has one distribution tank. The flow is controlled by weir provided in the distribution tank.

Hydraulic retention time of 1.5 minutes is considered for designing distribution tank also. The total capacity of each distribution tank is 450 m^3. The distribution tank is also divided into two (2) compartments to facilitate proper maintenance. The tank is 11.2 m long and 11.2 m wide, with an effective water depth of 3.59 m.

(3) Primary Sedimentation Tank

The width of primary sedimentation tank is decided based on the capacity of sludge collector. The tank is 10 m wide and 39 m long with an effective water depth of 3 m. Required number of tanks for one (1) unit are 32.

Hydraulic retention time of primary sedimentation tank is 2.1 hours with an overflow rate of 34.6 $m^3/m^2/d$.

Chain flight type sludge collector (2 in number) each with a capacity of 2.2 KW is installed in each tank. Cross sludge collector (1 in number) with a capacity of 1.5 KW is installed for each two (2) tanks. Sludge pump with a capacity of 7.5 KW is installed for each two (2) tanks.

(4) Aeration Tank

Aeration tank is 10.3 m wide and 89 m long with an effective water depth of 6 m. The required number of tank for one (1) unit are 32. Hydraulic retention time is 9.5 hours and sludge recirculation ratio is 35%. Diffused type aeration is installed in the aeration tank. The blower, with a capacity of 900 KW is installed for each eight (8) aeration tanks.

(5) Secondary Sedimentation Tank

The tank is 10 m wide and 54 m long with an effective water depth of 3.5 m. Required number of tanks for one (1) unit are 32.

Hydraulic retention time is 3.36 hours with an overflow rate of 25 $m^3/m^2/d$.

Chain flight type sludge collector with a capacity of 2.2 KW is installed in each tank. Sludge pump with a capacity of 11 KW for each two (2) tanks and 24 sludge return pumps with a capacity of 30 KW are installed for each unit.

(6) Disinfection

Chlorine gas is employed for disinfection. The chlorine contact time of 15 minutes is proposed before discharging Gran Canal. Contact tank is planned to be constructed besides the No. 2 wastewater treatment plant site. The contact tank is designed of 10 m width and 4 m effective depth.

The tank is divided into 12 compartments by baffles and total length of flow is 780 m. The contact tank has a capacity of 31,200 m^3 with a contact time of 13 minutes for the final project stage. Subsequently discharge channel of 250 m long functions a part of contact tank with a contact time of 2 minutes.

6.1.2 Sludge Treatment

Sludge treatment system consists of:

- Separate thickening (primary sludge to be thickened by gravity thickener and secondary sludge to be thickened by Centrifugal thickener)
- Anaerobic digester
- Belt filter press

The treated sludge has to be Land disposed.

The whole sludge treatment system is divided into four (4) units. Sludge from two (2) units of liquid treatment is to be treated by one (1) unit of sludge treatment system. Two (2) units of liquid treatment plants and one (1) unit of sludge treatment plant make one (1) block. And sludge treatment plant is situated in the middle of two (2) units of liquid treatment plant.

Structural design of sludge treatment system is conducted based on the solid balance as shown in Fig. F.9.

(1) Gravity Thickener

The total amount of primary sludge to be concentrated by Gravity thickener for one (1) unit is 4,020 m^3/day, having solid content of 3.0%.

Gravity thickener of 4 tanks with 19 m diameter and 4 m depth are required for each unit. Hydraulic retention time is 1.1 days with a solid loading of 106.9 kg/m^2/d.

(2) Centrifugal Thickener

The total amount of activated sludge to be concentrated by Centrifugal thickener for one (1) unit is 19,340 m^3/day, having solid content of 0.8%. Centrifugal thickener of 6 sets with a capacity of 170 m^3/hr are required for one unit. Centrifugal thickeners are installed in the centrifugal thickener house.

(3) Anaerobic Digester

Anaerobic digester stabilizes primary sludge of 1,600 m^3/day with a solid content of 6.0% and activated sludge of 2,320 m^3/day with a solid concentrate of 6.0% obtained from thickening unit.

Anaerobic digester of 12 tanks with 26 m diameter and 12.5 m depth are required for each unit. Retention time of anaerobic digester is 20.3 days. In anaerobic digester, 33% of solids are removed by digester gas. Blower with a capacity of 45 KW is installed to agitate sludge for each tank of anaerobic digester.

(4) Belt Filter Press

Belt filter press dewaters digested sludge of 2,220 m^3/d with a solid content of 6.0%. Polymer of 668 Kg/d is added as a coagulant.

Belt filter press of 20 sets with 3 m belt width are installed for each unit in the sludge processing building.

Dewatered sludge of 540 m^3/d with a solid content of 22% is produced.

(4) Land Disposal

About 540 m^3/d (120.54 t/d) of dewatered sludge is obtained from one unit, hence amount of sludge to be disposed annually from the whole sludge treatment system is 175,988 tons. For the dedicated land disposal site, 370 tons/ha of application rate is recommended. Hence about 500 ha of area for land disposal is required.

6.2 Layout and Hydraulic Profile

6.2.1 Proposed Ground Height of Treatment Plant

The altitude of existing ground elevation of the proposed treatment plant site ranges from 2,234 to 2,236 meter. The land is almost flat except the stock residue of soda production. Design ground elevation of the proposed treatment plant site is decided at the 2,235 meter as an average of the existing ground elevation.

6.2.2 Layout and Hydraulic Profile of the Treatment Plant

Layout of the integrated wastewater and sludge treatment plant is decided with due consideration to the following aspects.

- To minimize the length of influent and effluent pipes
- To avoid the crossing of influent and effluent pipes
- To preserve the existing buildings and structures of former soda producing factory

The layout is shown in Fig. F.10.

Receiving tank is located at the south boundary of the treatment plant which is nearest to the influent pumping station. The water flow direction of liquid treatment plant is from outside to inside.

For deciding the layout of the sludge treatment system, usually grouping of treatment facilities is adopted from the following view points;

- To reduce the required number of engineers and workers for system operation and maintenance

- To reduce the required units of stand-by equipments

- To easily maintain the sludge treatment system

However in the present study, sludge treatment system is divided into four (4) units and each unit treating sludge generated from two units of wastewater treatment. The reasons of treating sludge not at one location are listed below:

- The effect of differential settlement, that could happen because of poor subsoil condition, can be minimized.

- Any modification, if required in sludge treatment facility, can be easily done thus providing more flexibility in the construction plan.

Buffer zone of 50 m wide is planed surroundings the treatment plant. Total area of proposed treatment plant site is estimated to be 192 ha for the year 2015.

6.3 Project Cost

6.3.1 Basis of Cost Estimate

The project cost is estimated based on the following conditions.

(1) It is assumed that all construction works will be contracted to general Contractors by international tender.

(2) All base costs are expressed under the economic conditions that are prevailing in May, 1994.

(3) Overhead is assumed as 30% of the total cost of equipment and civil works and is incorporated in the direct construction cost.

(4) Engineering service and administration costs are assumed respectively at 3.5% and 1.0% of the total direct construction cost.

(5) Physical contingency allowance at the rate of 10% of the direct construction cost is assumed.

(6) Currency exchange rate of US$ 1 = N$ 3.2 = ¥ 105 is assumed.

(7) The unit construction costs are shown in Table F.6.

6.3.2 Estimated Project Cost

The total project cost, consisting of direct construction cost, land cost, administration cost, engineering cost and physical contingency amounts to N$ 4,212.9 million at 1994 price. Its breakdown is shown below.

	(Unit : N$ million)
(A) Direct Construction Cost	3,578.8
1) Wastetewater Treatment	2,250.2
(1) Receiving Tank	5.8
(2) Connecting Pipe	82.3
(3) Distribution Tank	4.0
(4) Primary Sedimentation Tank	433.9
(5) Aeration Tank	747.2
(6) Blower	172.8
(7) Secondary Sedimentation Tank	579.2
(8) Disinfection	20.9
(9) Discharge Channel	22.2
(10) Cost of using treated water within treatment plant	39.2
(11) Electrical Works	142.7
2) Sludge Treatment	1,016.7
(1) Gravity & Centrifugal Thickener	151.2
(2) Anaerobic Digester	336.0
(3) Belt Filter Press	125.6
(4) Gas generator	262.8
(5) Electrical Works	141.1
3) Building Construction	220.3
4) Other Works	91.6
(B) Land Acquisition Cost	115.1
(C) Administration Cost	35.8
(D) Engineering Cost	125.3
(E) Physical Contingency	357.9
Total	4,212.9

The above direct construction costs are further breakdown as shown in Table F.7.

6.3.3 Estimated O/M Cost

O/M cost of the project consists of following major components:

- Personal Expenditure
- Electrical Charge
- Chemical Cost (for dewatering and disinfection unit)
- Sludge Disposal Cost
- Repairing Cost.

Annual O/M cost of whole wastewater and sludge treatment systems in the year 2015 is estimated to be N$ 200.4 million. The total O/M cost will increase in accordance with the stepwise construction. And total O/M cost in the Yr. 2015 is expected to be N$ 200.4 million. The breakdown of the cost is shown below.

	(Unit : N$ million)
(1) Personal Expenditure	14.3
(2) Electrical Charge	52.6
(3) Chemical Cost	40.0
(4) Sludge Disposal Cost	26.4
(5) Repairing Cost	67.1
Total	200.4

The further breakdown of O/M cost is shown in Table F.8.

7. Selection of Urgent Project (Year 1997)

The optimum wastewater and sludge treatment system for the Final Project has been selected in the previous section. A portion of the selected treatment system with some modification is proposed as the treatment system for the Urgent Project. The major design considerations taken, in deciding the Urgent Project treatment system, are listed below:

1. The treatment system should be capable of treating design wastewater quantity as described in Appendix F, section 2.2.
2. The effluent of treatment system should meet design effluent quality as described in Appendix F, section 2.4. Design influent quality is also prescribed in Appendix F, section 2.3. The required removal efficiency of BOD_5 and SS are 45% and 49% respectively.
3. The treatment system should be in conformity with the treatment system for 2015.

Proposed Urgent Project Treatment System

Wastewater Treatment System

The wastewater characteristics of Gran Canal shows that proportion of soluble BOD is as high as 60% to the total BOD as described in Appendix F, section 2.3. Hence secondary treatment process is required for achieving the BOD_5 and SS removal efficiency of 45% and 49% respectively.

The selected optimum treatment system for the Year 2015 is conventional activated sludge process. At the Urgent Project stage, two (2) units of the Final Project (8 units) comprising of aeration tank and secondary sedimentation tank [without primary sedimentation tank] will be constructed. As a result, the two (2) units (each treating 17.5 m^3/sec.) will be operated as modified activated sludge system at the Urgent Project stage and will be operated as conventional activated sludge system at the Final Project stage (each unit treating 5 m^3/sec.).

<u>Sludge treatment system</u>

In the Urgent Project stage, only activated sludge is required to be treated. As described in Appendix F, section 4, centrifugal thickening, anaerobic digestion as a stabilization process and belt filter press for dewatering are proposed as the optimum sludge treatment process.

Table F.1 Comparative Study of Proposed Wastewater Treatment Process by the Master Plan

Alternative	Design Criteria	Plant Site Area	Construction Cost (10^6 N$)	Electrical Consumption (KWH/d)	Required Employee	Sludge Handling	Score
A	Detetion Time of Pond : 27 days	5,600 ha -1.0	3,200 - 3,700 1.0	Neglective 1.5	2.0	1.5	5.0
B	Detention Time of PST : 2.0 hrs. Detention Time of Pond : 19 days	4,000 ha -1.0	3,400 - 3,500 1.0	73,000 1.0	1.5	1.0	3.5
D	Overflow Rate of Biofilter : $100m^3/m^2 \cdot d$ Capacity of Pump Station : $40m^3/s$ Detention Time of Pond : 17 days	3,400 ha -1.0	3,000 - 3,500 1.5	174,000 1.0	1.5	1.0	4.0
F	Dentention Time of AL : 5 days Total Capacity of Aerator : 86,400 kw Detention Time of SST : 2 days	1,100 ha - 0.5	2,000-2,500 2.0	2,118,000 0	1.5	1.0	4.0
G	Overflow Rate of Bio-filter : $100m^3/m^2 \cdot d$ Capacity of Pump Station : $40m^3/s \times 5.0m$ Detention Time of AL : 2 days Detention Time of SST : 2 days	630 ha 0	1,800 - 2,300 2.0	1,039,000 0.5	1.0	0.5	4.0
H	Overflow Rate of PST : $35m^3/m^2 \cdot d$ HRT of Aeration Tank : 8 hrs. Overflow Rate of PST : $25m^3/m^2 \cdot d$	150 ha 3.0	4,000 - 4,500 0.5	730,000 0.5	0.5	0.5	5.0

Table F.2 (1) Comparative Study of Design Criteria for the Wastewater Treatment

Source	Sedimentation with Coagulation	Conventional Activated Sludge Process			Effluent Disinfection
		Primary Sedimentation	Aeration Tank	Secondary Sedimentation	
Wastewater Engineering (Metcalf/Eddy Inc.)	Overflow Rate 24~48 $m^3/m^2 \cdot d$ Removal Efficiency BOD : 50~80% SS : 80~90% Bacteria: 80~90%	Overflow Rate : 32~48 $m^3/m^2 \cdot d$ Removal Efficiency BOD : 25~40% SS : 50~70% Bacteria: 25~70%	MLSS :1200~3000mg/l FM ratio : 0.2~0.4 Recirculation Ratio : 0.2~0.75 HRT : 4~8hr Volumetric Loading: 0.32~0.64 kg•BOD/$m^3 \cdot d$	Overflow Rate : 16~33 $m^3/m^2 \cdot d$ Solid loading : 3.9~5.9 kg/m hr	Typical Chlorine Dosage Raw Wastewater : 6~25 mg/l Primary Effluent: 5~20 mg/l Activated sludge Effluent: 2~8 mg/l Filtered Effluent: 1~5mg/l
WEF Manual & ASCE Manual	Removal Efficiency BOD : 40~70% SS : 60~90% Bacteria: 80~90%	—	MLSS :1500~3000mg/l FM ratio : 0.2~0.4 Recirculation Ratio : 0.2~0.5 HRT : 4~8hr Volumetric Loading: 0.3~0.6 kg BOD/$m^3 \cdot d$	Overflow Rate : 16~29 $m^3/m^2 \cdot d$ Solid loading : 4~6 kg/m hr	—
Japanese Design Manual	—	Overflow Rate 25~50 $m^3/m^2 \cdot d$ Removal Efficiency BOD: 30% SS: 40%	MLSS :1500~2000mg/l BOD-SS Loading: 0.2~0.4 Recirculation Ratio : 0.25~0.4 HRT : 6~8hr Volumetric Loading: 0.3~0.8 kg BOD/$m^3 \cdot d$	Overflow Rate : 20~30 $m^3/m^2 \cdot d$	Activated sludge Effluent: 2~4mg/l Nos. of Fecal Coli. <3,000 per cm
Cerro de la Estrella (WWTP in Mexico DF)	—	Overflow Rate: 48 $m^3/m^2 \cdot d$ Design Removal Efficiency BOD : 13% SS : 49%	MLSS :1650mg/l BOD-SS loading : 0.35 Recirculation Ratio : 0.25 Return Sludge Concent-lation : 8,000mg/l	Overflow Rate : 36 $m^3/m^2 \cdot d$	

Table F.2 (2) Comparative Study of Design Criteria for the Wastewater Treatment

Source	Gravity Thickening Type of Sludge	Feed Solids Concentration	Thickened Sludge Concentration	Solids Loading (kg/m^2 •d)	Centrifugal Thickening	Anaerobic Digestion	Lime Stabilitation
Wastewater Engineering (Metcalf/Eddy Inc.)	Primary(PRI) Trickling Filter(T/F) PRI + T/F PRI + Activated sludge (AS) AS + T/F	2~7 % 1~4 % 2~6 % 2~5 % 0.5~2.5 %	5~10 % 3~6 % 4~9 % 2~8 % 2~4 %	89~136 34~49 59~98 39~78 12~34	Thickened Concentration : 4~6 %	Solids Residence Time : for 24°C - 20 days for 30°C - 14 days for 35°C - 10 days for 45°C - 10 days	Typical Lime Dosage for stabilizing liquid sludge : $Ca(OH)_2$ /dry solids for PRI 0.12~0.34 for AS 0.42~0.86
WEF Manual & ASCE Manual	Primary(PRI) Trickling Filter(T/F) PRI + iron PRI + T/F PRI + AS AS + TF (PRI + iron) + AS	2.0~7.0 % 1.0~4.0 % 2.0 % 2.0~6.0 % 0.5~1.5 % 1.8 %	5.0~10.0 % 3.0~6.0 % 4.0 % 5.0~9.0 % 4.0~6.0 % 2.0~4.0 % 3.6 %	97~145 39~48 29 58~97 24~68 19~34 29	Thickened Concentration : (reported operating results) 1.8~10%	Solids Residence Time : 20 days	Pilot study determination of lime dosage $Ca(OH)_2$ /dry solids for PRI 0.10~0.15 for AS 0.30~0.50
	Overflow Rate for PRI Sludge : 16~32 m^3 /m^2 •d						
Japanese Design Manual	Thickened Solids Concentration : 2.0~4.0 % Solids Loading : 60~90 kg/m^2 •d Effective Depth : 4.0 m				Thickened Concentration : 4 %	Detention Time 20 days (operating temperature 30°C~35°C)	—

Table F.2 (3) Comparative Study of Design Criteria for the Wastewater Treatment

source	Mechanical Dewatering (belt filter press)				Open Drying Bed		Drying Lagoon
	Type of Sludge	Feed Solids (%)	Cake Solids (%)	Loading per belt width (kg/hr•m)	Type of Sludge	Solids Loading Rate (kg/m^2 •yr)	
Wastewater Engineering (Metcalf/Eddy Inc.)	PRI PRI + AS PRI + TF AS Anaerobically digested (PRI + AS)	3~7 3~6 3~6 1~4 3~6	28~44 20~35 20~35 12~20 20~25	- - - - -	PRI digested PRI + TF digested PRI + AS digested PRI + chemical coagulation corresponding area for covered beds vary from70 to 75% of open beds	122~146 88~122 59~98 98~161	- not suitable for untreated sludges /limed sludges -Sludge depth : 0.75~1.25m -Solids Loading : 36~39 kg/m yr -Typical cycle time : 2 years
WEF Manual & ASCE Manual	PRI PRI + AS PRI + TF AS Anaerobically Digested (PRI + AS) AS	3~7 3~6 3~6 1~4 3~6 3~4	28 23 25 15 22 15	360~550 180~320 180~320 45~180 180~320 45~135	Type of sludge PRI digested PRI + TF digested PRI + AS digested PRI + chemical coagulation	Solids Loading Rate (kg/m^2 •yr) 134 110 73 110	—
Japanese Design Manual	Cake Solids Concentration : 25 % Operating Results : -loading per meter belt width : 90~150 kg/hr -cake solids 20~25 %				A = QT/D where, A : drying bed area (m) Q :sludge volume feeded (m^3 /d) D : thickness of feeded sludge (m) 0.15~0.25 T : drying duaration (days) 15~20		—

Table F.3 Design Criteria of the Final Project

Parameter	Alternative - I	Alternative - II	Alternative - III
(1) Primary Sedimentation			
1) Overflow Rate ($m^3/m^2 \cdot d$)	35	35	35
2) Chemical for Coagulation	-	$FeCl_3$ 20 mg/l Poymer 0.5 mg/l	-
3) Removal Efficiency			
BOD	20%	30%	20%
SS	40%	80%	40%
(2) Biofilter			
1) Overflow Rate	-	-	$100m^3/m^2 \cdot d$
2) Removal Efficiency			
BOD			40%
SS			40%
(3) Aeration Tank			
1) F M Ratio	0.3	0.3	0.3
2) Recirculation Ratio	0.35	0.35	0.35
(4) Secondary Sedimentation			
1) Overflow Rate ($m^3/m^2 \cdot d$)	25	25	25
(5) Chlorination Tank			
1) Chlorine Dosage	5mg/l	5mg/l	5mg/l
(6) Gravity Thickening			
1) Feed Solids Concentration	3.0	2.0%	2.5%
2) Thickend Solids Concentration	6.0%	4.0%	5.0%
3) Solids Loading ($kg/m^2 \cdot d$)	110	30	75
(7) Centrifugal Thickning			
1) Feed Solids Concentration	0.8%	0.8%	0.8%
2) Thickend Solids Concentration	6.0%	6.0%	6.0%
3) Operation Time per Day (hrs.)	24	24	24
4) Operation Efficiency	80%	80%	80%
(8) Anaerobic Digestion			
1) Detention Time (days)	20	20	20
(9) Belt Filter Press		RRI | AS	
1) Loading per Belt Width (kg/hr•m)	250	200 | 90	250
2) Dry Polymer (g/kg•Dry Solids)	5	3 | 7	5
3) Cake Solids Concentration	22%	22% | 15%	22%
4) Operation Time per Day (hrs.)	12	12 | 12	12
5) Operation Efficiency	80%	80% | 80%	80%

Table F.4 (1) Construction Cost of Wastewater Treatment Facilities for Comparative Evaluation

Alternative I

(Unit : Million N$)

Item	Civil / Architect				Mechanical / Electrical				Construction Cost
	Quantity		Unit Cost	Construction Cost	Quantity		Unit Cost	Construction Cost	
1. Wastewater Treatment									
1) P/S	8	Unit	32.10	256.8	8	Unit	20.83	166.6	423.4
2) A/T	8	Unit	67.10	536.8	8	Unit	26.30	210.4	747.2
3) Blower	---	---	---	---	8	Unit	21.60	172.8	172.8
4) S/S	8	Unit	43.90	351.2	8	Unit	28.50	228.0	579.2
Sub-total				1,144.8				777.8	1,922.6
2. Electrical Work	---	---	---	---	1	ls.	---	155.6	155.6
Total Construction Cost				1,144.8				933.4	2,078.2

Alternative II

(Unit : Million N$)

Item	Civil / Architect				Mechanical / Electrical				Construction Cost
	Quantity		Unit Cost	Construction Cost	Quantity		Unit Cost	Construction Cost	
1. Wastewater Treatment									
1) Mixing Tank	8	Unit	1.10	8.8	8	Unit	0.77	6.2	15.0
2) Flocculation Chamber	8	Unit	8.10	64.8	---	---	---	---	64.8
3) P/S	8	Unit	32.10	256.8	8	Unit	20.83	166.6	423.4
4) A/T	8	Unit	62.00	496.0	8	Unit	24.20	193.6	689.6
5) Blower	---	---	---	---	8	Unit	18.90	151.2	151.2
6) S/S	8	Unit	43.90	351.2	8	Unit	28.50	228.0	579.2
Sub-total				1,177.6				745.6	1,923.2
2. Electrical Work	---	---	---	---	1	ls.	---	149.1	149.1
Total Construction Cost				1,177.6				894.7	2,072.3

Alternative III

(Unit : Million N$)

Item	Civil / Architect				Mechanical / Electrical				Construction Cost
	Quantity		Unit Cost	Construction Cost	Quantity		Unit Cost	Construction Cost	
1. Wastewater Treatment									
1) P/S	8	Unit	32.10	256.8	8	Unit	20.83	166.6	423.4
2) A/T	8	Unit	44.00	352.0	8	Unit	17.30	138.4	490.4
3) Blower	---	---	---	---	8	Unit	13.10	104.8	104.8
4) Biofilter	8	Unit	65.50	524.0	8	Unit	4.80	38.4	562.4
5) Pumping Station	8	Unit	5.20	41.6	8	Unit	19.30	154.4	196.0
6) S/S	8	Unit	43.90	351.2	8	Unit	28.50	228.0	579.2
Sub-total				1,525.6				830.6	2,356.2
2. Electrical Work	---	---	---	---	1	ls.	---	166.1	166.1
Total Construction Cost				1,525.6				996.7	2,522.3

Table F.4 (2) Construction Cost of Sludge Treatment Facilities for Comparative Evaluation

Alternative I

(Unit : Million N$)

Item	Civil / Architect				Mechanical / Electrical				Construction Cost
	Quantity		Unit Cost	Construction Cost	Quantity		Unit Cost	Construction Cost	
1. Sludge Treatment									
1) Gravity Thickener (ø16.0m*2tank)	8	Unit	2.40	19.2	8	Unit	1.6	12.8	32.0
2) Centrifuge (180m3/hr*2set.)	---	---	---	---	8	Unit	8.0	64.0	64.0
3) Anaerobic Digester (ø24mx12.5m*6)	8	Unit	29.40	235.2	8	Unit	7.2	57.6	292.8
4)Belt Filter Press (Width = 3.0m,10set)	---	---	---	---	8	Unit	15.7	125.6	125.6
Sub-total				254.4				260.0	514.4
2. Electrical Work	---	---	---	---	1	ls.	---	52.0	52.0
Total Construction Cost				254.4				312.0	566.4

Alternative II

(Unit : Million N$)

Item	Civil / Architect				Mechanical / Electrical				Construction Cost
	Quantity		Unit Cost	Construction Cost	Quantity		Unit Cost	Construction Cost	
1. Sludge Treatment									
1) Gravity Thickener (ø23.0m*8tank)	8	Unit	19.20	153.6	8	Unit	9.60	76.8	230.4
2)Belt Filter Press (Width = 3.0m,17set)	---	---	---	---	8	Unit	26.69	213.5	213.5
Sub-total				153.6				290.3	443.9
2. Electrical Work	---	---	---	---	1	ls.	---	58.1	58.1
Total Construction Cost				153.6				348.4	502.0

Alternative III

(Unit : Million N$)

Item	Civil / Architect				Mechanical / Electrical				Construction Cost
	Quantity		Unit Cost	Construction Cost	Quantity		Unit Cost	Construction Cost	
1. Sludge Treatment									
1) Gravity Thickener (ø20.0m*3set)	8	Unit	5.40	43.2	8	Unit	2.85	22.8	66.0
2) Centrifuge (60m3/hr.*3set)	---	---	---	---	8	Unit	4.50	36.0	36.0
3)Anaerobic Digester (ø25mx12.5m*6)	8	Unit	31.80	254.4	8	Unit	7.20	57.6	312.0
4) Belt Filter Press (Width = 3.0m,9set)	---	---	---	---	8	Unit	14.13	113.0	113.0
Sub-total				297.6				229.4	527.0
2. Electrical Work	---	---	---	---	1	ls.	---	45.9	45.9
Total Construction Cost				297.6				275.3	572.9

Table F.5 Summary of Construction and Operation & Maintenance Costs

Alternative	Facilities	Construction Cost (Million N$)			Operation & Maintenance Cost (Million N$/Year)
		Civil / Architect	Mechanical / Electrical	Total	
Alternative I	Wastewater	1,144.8	933.4	2,078.2	89.4
	Sludge	254.4	312.0	566.4	38.4
	Sub-total	1,399.2	1,245.4	2,644.6	127.8
Alternative II	Wastewater	1,177.6	894.7	2,072.3	198.3
	Sludge	153.6	348.4	502.0	106.4
	Sub-total	1,331.2	1,243.1	2,574.3	304.7
Alternative III	Wastewater	1,525.6	996.7	2,522.3	83.3
	Sludge	297.6	275.3	572.9	33.9
	Sub-total	1,823.2	1,272.0	3,095.2	117.2

Table F.6 (1) Unit Cost for Construction

1. Fuel and Material Cost

Item No.	Description	Unit	Unit Cost (N$)
1	Gasoline	lit.	1.04
2	Disel oil	lit.	0.74
3	Lubricant oil	lit.	6.60
4	Portland cement	bag	22.00
5	Sand for concrete	m 3	45.45
6	Sand for others	m 3	45.45
7	Sand gravels	m 3	45.45
8	Crushed stone for concrete	m 3	42.90
9	Brick	pc	1.90
10	Meranti Wood (class III) :		
	a. Plank (1 1/2" x 12")	pc	2.58
	b. Square (4" x 4")	pc	2.58
11	Plywood (1.22m x 2.44m, t = 6mm)	sheet	43.45
12	Plywood (1.22m x 2.44m, t = 16mm)	sheet	90.20
13	Reinforced steel bar (D = 9.5 mm)	ton	1,430.00
14	Wire	kg	2.00
15	Nails	kg	3.30
16	Polyvinyl Chloride (pvc) Pipes :		
	a. Diameter 150 mm	m	56.00
	b. Diameter 200 mm	m	93.00
	c. Diameter 250 mm	m	146.00
	d. Diameter 300 mm	m	246.00
17	Reinforced Concrete (RC) Pipes:		
	a. Diameter 300 mm	m	114.38
	b. Diameter 380 mm	m	144.97
	c. Diameter 450 mm	m	170.68
	d. Diameter 600 mm	m	185.49
	e. Diameter 760 mm	m	233.51
	f. Diameter 910 mm	m	353.59
	g. Diameter 1,080 mm	m	509.87
	h. Diameter 1,220 mm	m	620.30
	i. Diameter 1,520 mm	m	994.74
	j. Diameter 1,830 mm	m	1,452.65

2. Labor Wage

Item No.	Description	Unit	Unit Cost (N$)
1	Common labor	Man-day	30.00
2	Semi skilled labor	Man-day	32.20
3	Skilled labor	Man-day	36.40
4	Mason	Man-day	55.70
5	Plasterer	Man-day	51.40
6	Concrete worker	Man-day	51.40
7	Steel worker	Man-day	51.40
8	Carpenter	Man-day	60.00
9	Foreman	Man-day	40.00
10	Welder	Man-day	49.30
11	Electrician	Man-day	60.00
12	Plumber	Man-day	60.00
13	Operator	Man-day	66.70
14	Assistent Operator	Man-day	40.00
15	Driver (dump truck)	Man-day	66.70
16	Mechanic	Man-day	53.60

3. Rental Cost of Equipment

Item No.	Description	Capacity	Unit Price (N$/hr.)
1	Concrete mixer	0.1 m 3	12.73
2	Concrete vibrator	dia. 40 m m	9.65
3	Water pump	dia. 75 m m	2.40
4	Excavator / Backhoe	0.6 m 3	455.50
5	Bulldozer	15 ton	415.34
6	Dump truck	8 ton	67.53
7	Compressor	3 m 3 / m i n.	40.94
8	Vibratory compactor	23 ton	84.02

Table F.6 (2) Unit Construction Cost

Description	Unit	Unit Cost (N$)
1. Earth work		
1-1 Excavation by manpower (Depth : 0 ~ 2 m)	m^3	15.09
1-2 (Depth : 2 ~ 4 m)	m^3	21.37
1-3 (Depth : 4 ~ 6 m)	m^3	27.72
1-4 (Depth : 6 ~ 8 m)	m^3	34.51
1-5 Excavation by backhoe (Depth : 0 ~ 2 m)	m^3	3.59
1-7 (Depth : 2 ~ 4 m)	m^3	4.39
1-8 (Depth : 4 ~ 6 m)	m^3	6.39
1-9 (Depth : 6 ~ 8 m)	m^3	12.04
1-10 (Depth : 8 ~ 10 m)	m^3	15.33
1-11 Backfill with granular	m^3	55.11
1-12 Transportation of residual soil (L = 10 km)	m^3	10.49
2. Molding work	m^2	26.87
3. Concrete work		
3-1 Reinforced concrete (s = 250 kg/cm^2)	m^3	440.11
3-2 Reinforced bar (D = 9.5 mm)	kg	1.96
3-3 (D = 12.7 mm)	kg	2.23
3-4 (D = 15.6 mm)	kg	1.97
3-5 (D = 19.1 mm)	kg	1.94
3-6 (D = 25.4 mm)	kg	1.96
3-7 (D = 37.8 mm)	kg	1.96
4. Frame work	m^3	2.95
5. Foundation work		
5-1 Lean concrete (s = 100 kg/cm^2)	m^3	15.63
5-2 Cobblestone	m^3	52.56
5-3 Pile foundation (ø = 600 mm, l = 30 m)	pile	8,159.7
5-4 Pile foundation (ø = 750 mm, l = 30 m)	pile	10,969.8
5-5 Pile foundation (ø = 900 mm, l = 30 m)	pile	14,383.6
5-6 Pile foundation (ø = 1,000 mm, l = 30 m)	pile	17,160.3

Source : Unidad Department de Precios Unitarios, DGCOH

Table F.7 Breakdown of Direct Construction Cost for Final Project

Description	Civil / Architecture			Mechanical / Electrical			Total
	Quantity	Unit Cost	Const. Cost	Quantity	Unit Cost	Const. Cost	
1) Wastewater Treatment							
(1) Receiving Tank	1 ls.	-	3.2	1 ls.	-	2.6	5.8
(2) Connecting Pipe	9,960 m	0.00826	82.3	-	-	-	82.3
(3) Distribution Tank	8 unit	0.5	4.0	-	-	-	4.0
(4) Influent Channel	8 unit	1.31	10.5	-	-	-	10.5
(6) Primary Sedimentation Tank	8 unit	32.1	256.8	8 unit	20.83	166.6	423.4
(7) Aeration Tank	8 unit	67.1	536.8	8 unit	26.3	210.4	747.2
(8) Blower	-	-	-	32 set	5.4	172.8	172.8
(9) Secondary Sedimentation Tank	8 unit	43.9	351.2	8 unit	28.5	228.0	579.2
(10) Disinfection	-	-	11.9	8 unit	1.13	9.0	20.9
(11) Discharge Channel	1 ls.	-	22.2	-	-	-	22.2
(12) Treated Water Reuse	-	-	-	8 unit	4.9	39.2	39.2
Sub-Total			1,278.9			828.6	2,107.5
(11) Electrical Work	-	-	-	1 ls.	-	142.7	142.7
Sub-Total of 1) Wastewater Treatment			1,278.9			971.3	2,250.2
2) Sludge Treatment							
(1) Sidestream Reservoir	4 tank	1.7	6.8	4 tank	2.3	9.2	16.0
(2) Gravity Thickener	8 unit	3.4	27.2	8 unit	1.8	14.4	41.6
(3) Centrifugal Thickener	-	-	-	24 set	3.9	93.6	93.6
(4) Anaerobic Digester	48 tank	5.7	273.6	48 tank	1.3	62.4	336.0
(5) Mechanical Dewatering (Belt Filter Press)	-	-	-	80 set	1.57	125.6	125.6
(6) Gas Holder	16 tank	0.12	2.0	16 tank	10.1	161.6	163.6
(7) Gas Generator	-	-	-	16 set	6.2	99.2	99.2
Sub-Total			309.6			566.0	875.6
(8) Electrical Work	-	-	-	1 ls.	-	141.1	141.1
Sub-Total of 2) Sludge Treatment			309.6			707.1	1,016.7
3) Building Construction							
(1) Blower House	8 house	5.85	46.8	-	-	-	46.8
(2) Centrifugal Thickener House	4 house	17.2	68.8	-	-	-	68.8
(3) Anaerobic Digester (Electrical Room)	4 house	1.2	4.8	-	-	-	4.8
(4) Mechanical Dewatering House (Belt Filter Press)	4 house	15.28	61.1	-	-	-	61.1
(5) Co-Generator House	4 house	1.6	6.4	-	-	-	6.4
(6) Control Building	1 house	7.2	7.2	-	-	-	7.2
(7) Sub-Control Building	7 house	3.6	25.2	-	-	-	25.2
Sub-Total of 3) Building Construction			220.3			-	220.3
4) Other Works							
(1) Preparatory Work	1 ls.	-	14.2	-	-	-	14.2
(2) Main Earth Work	1 ls.	-	39.0	-	-	-	39.0
(3) Site Preparation	1 ls.	-	38.4	-	-	-	38.4
Sub-Total of 4) Other Works			91.6			-	91.6
Grand Total			1,900.4			1,678.4	3,578.8

Table F.8 Breakdown of Operation & Maintenance Cost

1. Personnel Expenditure

Item	No. of Employee	Unit Cost (N$/year)	Personnel Expenditure (Million N$)
Employee	840	17,000	14.3

2. Electrical Cost

Item	Estimation	Electrical Cost (Million N$/year)	Remarks
Basic Charge	42,200kw * 24N$/mon. kw * 12mon./year = 12.2Million N$		Including energy recovery from digester gas
Consumption	0.79Mkwh/d * 365days * 0.14N$/kwh = 40.4 Million N$	52.6	

3. Chemical Cost

Chemical	Quantity (ton/year)	Unit Cost (N$/ton)	Chemical Cost (Million N$)
Anionic Polymer	975	30,000	29.3
Gas (Cl_2)	6,307	1,700	10.7
Total			40.0

4. Sludge Disposal Cost

Landfill Type	Cake Volume (m3/year)	Unit Cost (N$/m3)	Disposal Cost (Million N$)	Remarks
Disposal	788,400	33.5	26.4	Including land acquisition cost of equivalent to 15 N$/cake volume m3

5. Repairing Cost assume to 5% of M/E work 1,678.4 x 0.05 = 67.1

6. Total of Operation & Maintenace Cost 200.4

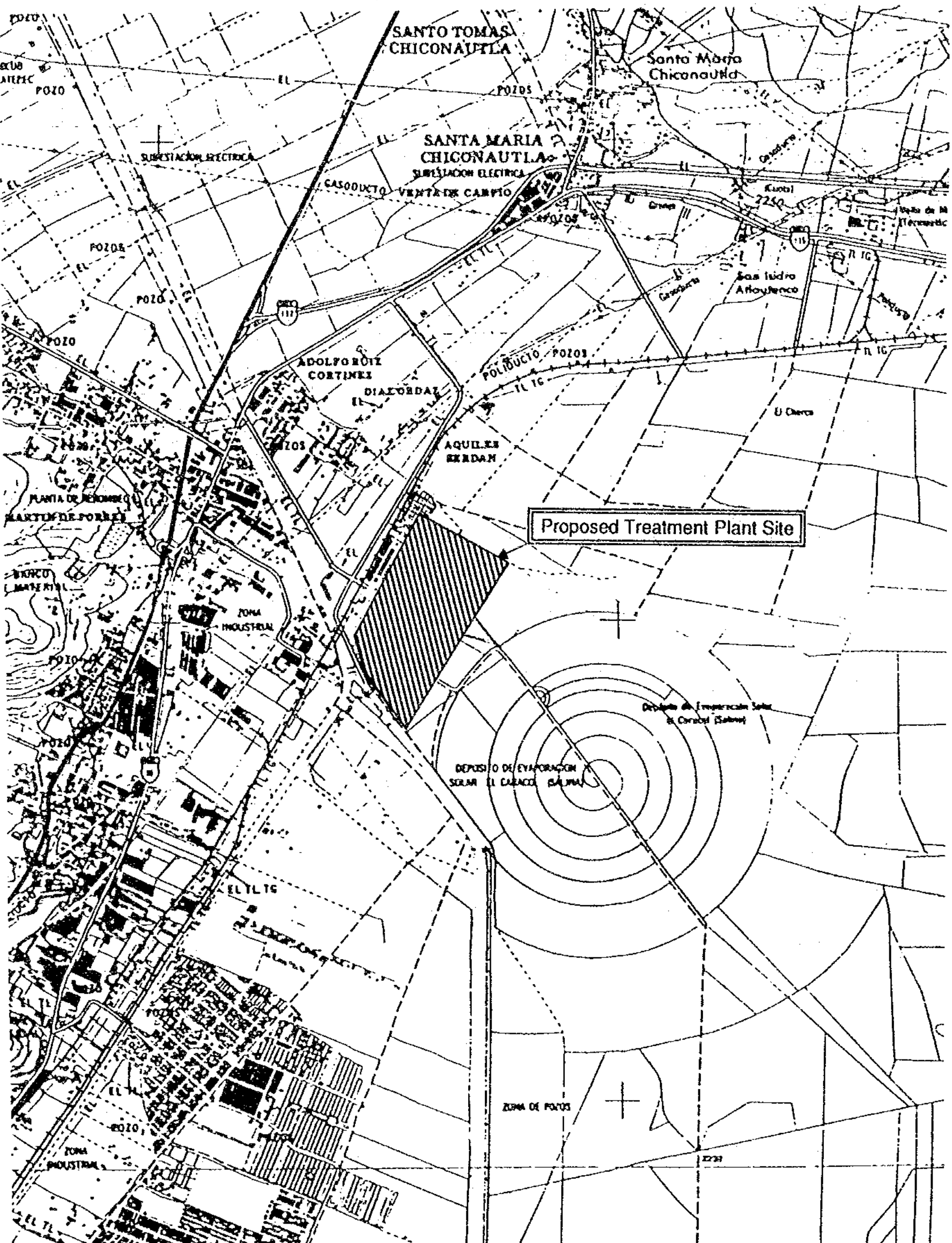


Fig. F.1 Location of Proposed Treatment Plant Site

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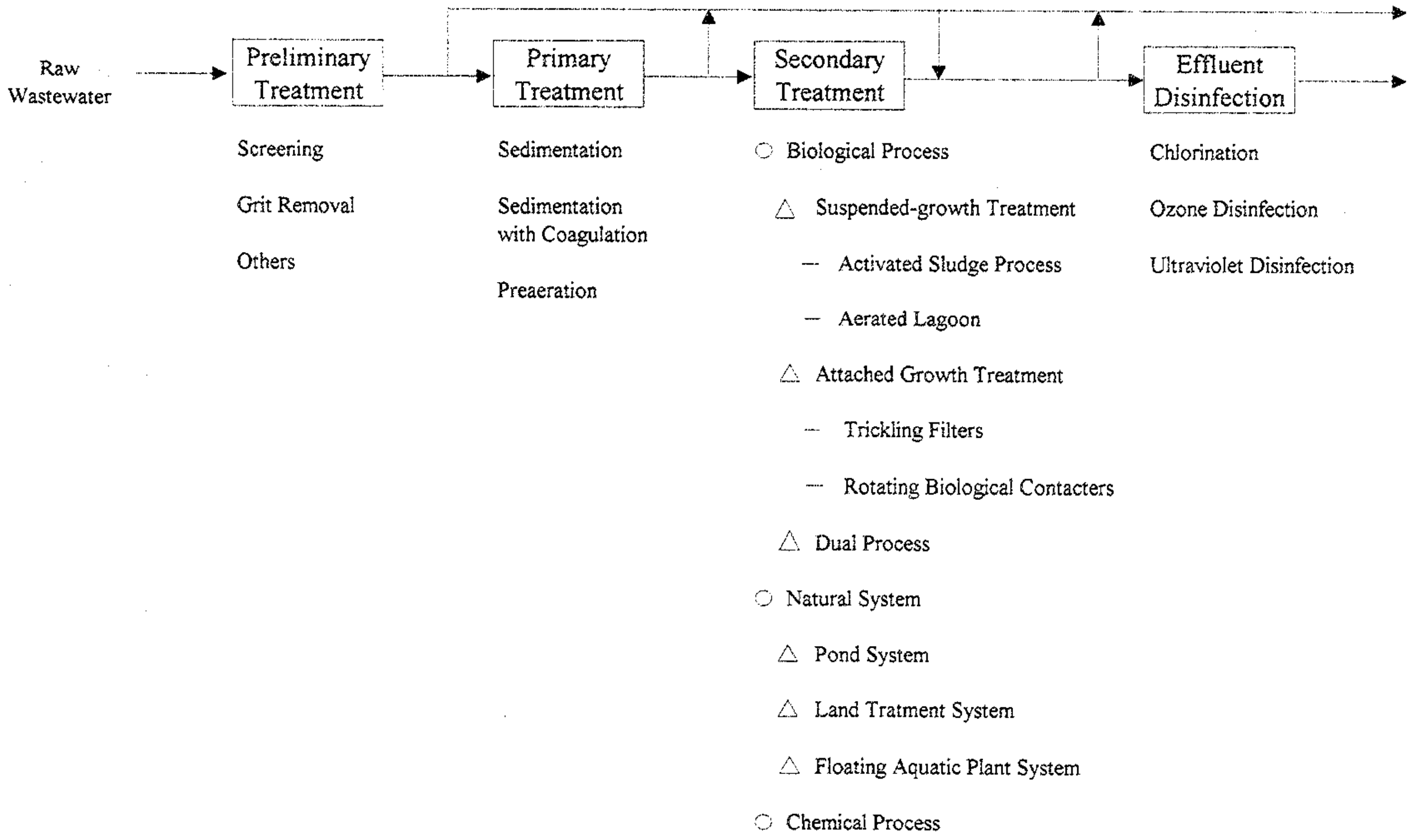
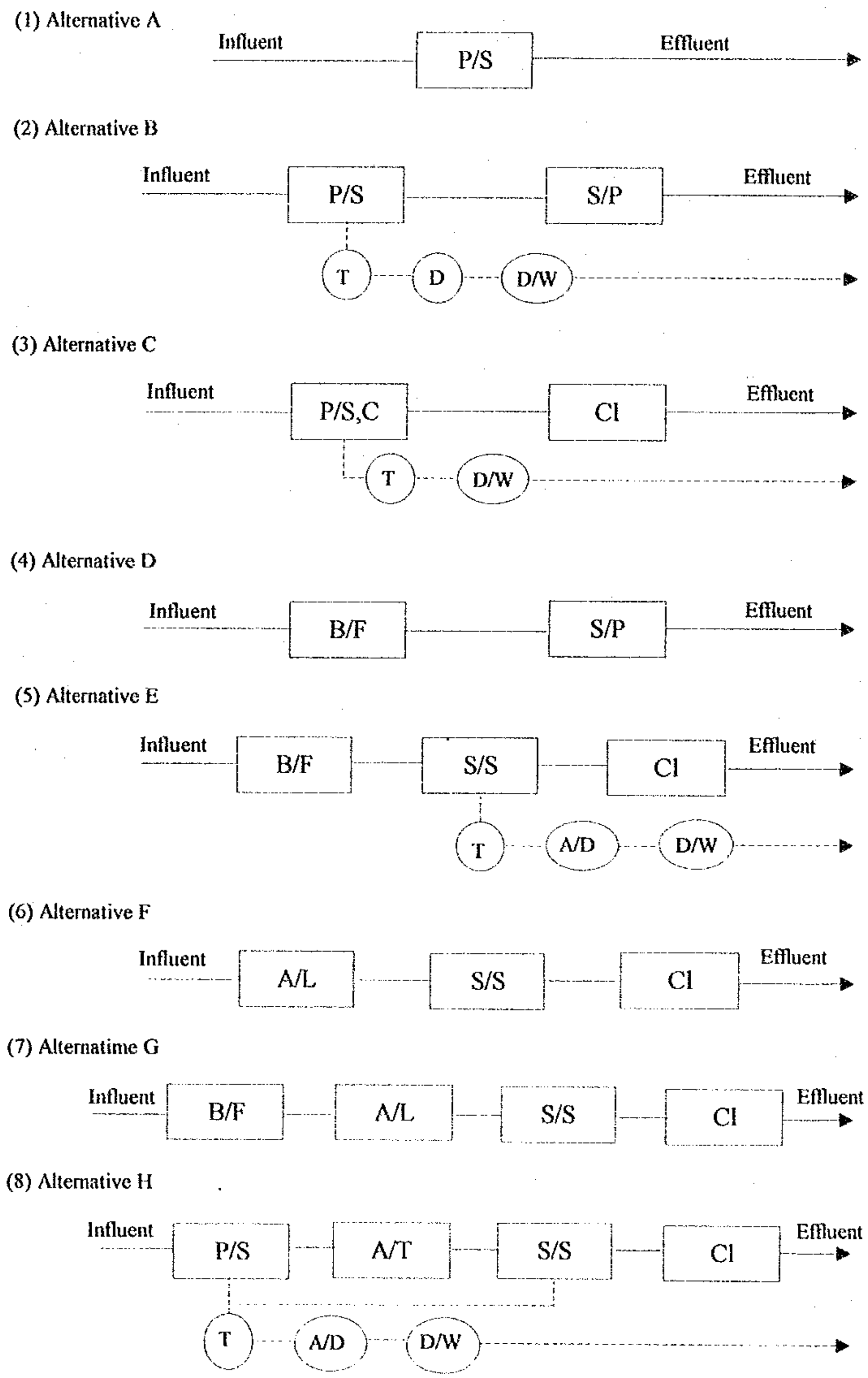


Fig. F.2 Wastewater Treatment Process for the Project



Note: S/P: Stabilization Pond, P/S: Primary Sedimentation Tank, T: Thickener, D: Digestion Tank,
D/W: Dewatering, P/S, C: Primary Sedimentation Tank with Coagulation, Cl: Chlorination Tank,
B/F: Biofiltration, S/S: Secondary Sedimentation Tank, A/D: Anaerobic Digestion, AL: Aerated Laggon
A/T: Aeration Tank

Fig. F.3 Alternatives of Wastewater Treatment System in the Master Plan

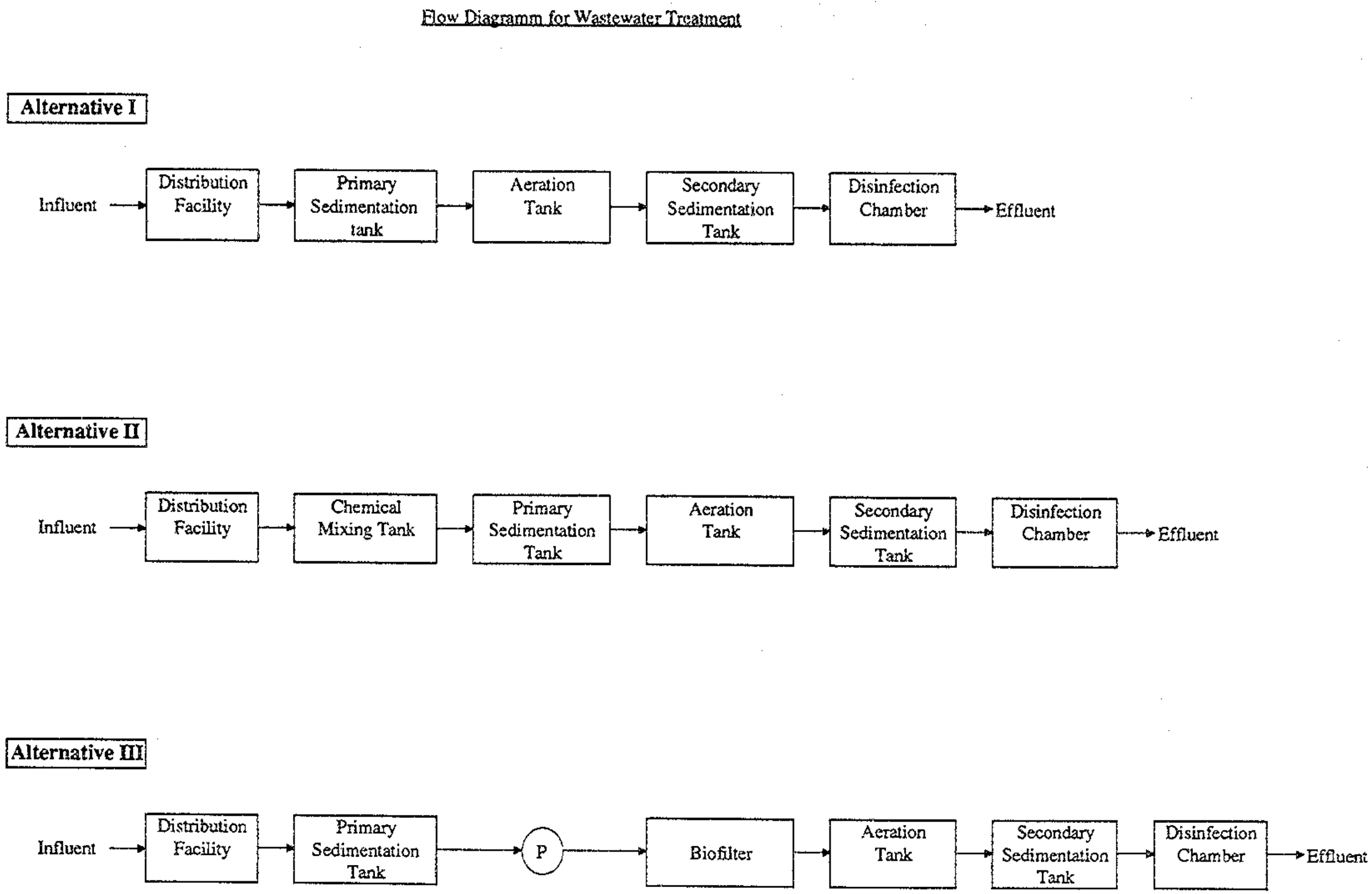


Fig. F.4 Selected Alternatives of Wastewater Treatment System for the Final Project

THE FEASIBILITY STUDY ON WASTEWATER TREATMENT IN THE FEDERAL DISTRICT OF MEXICO

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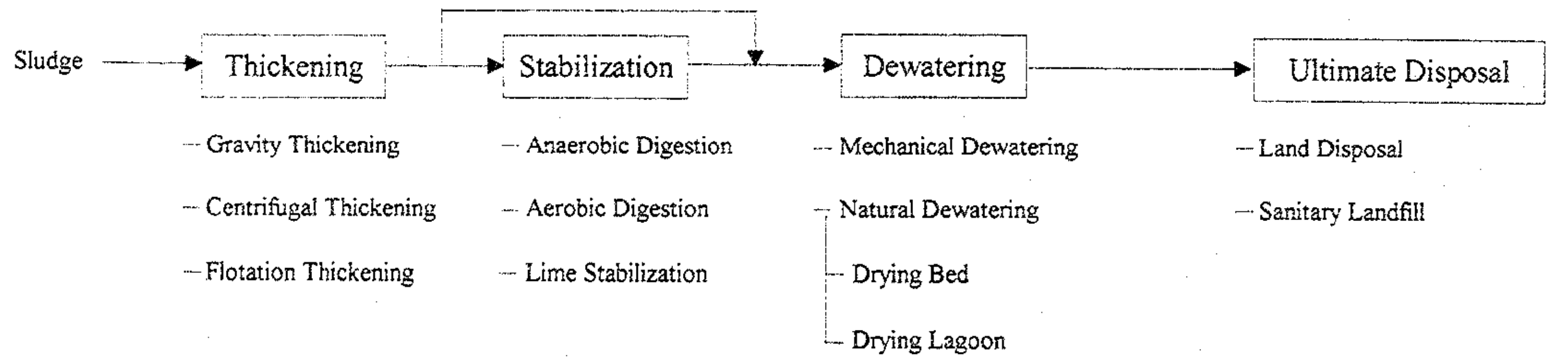
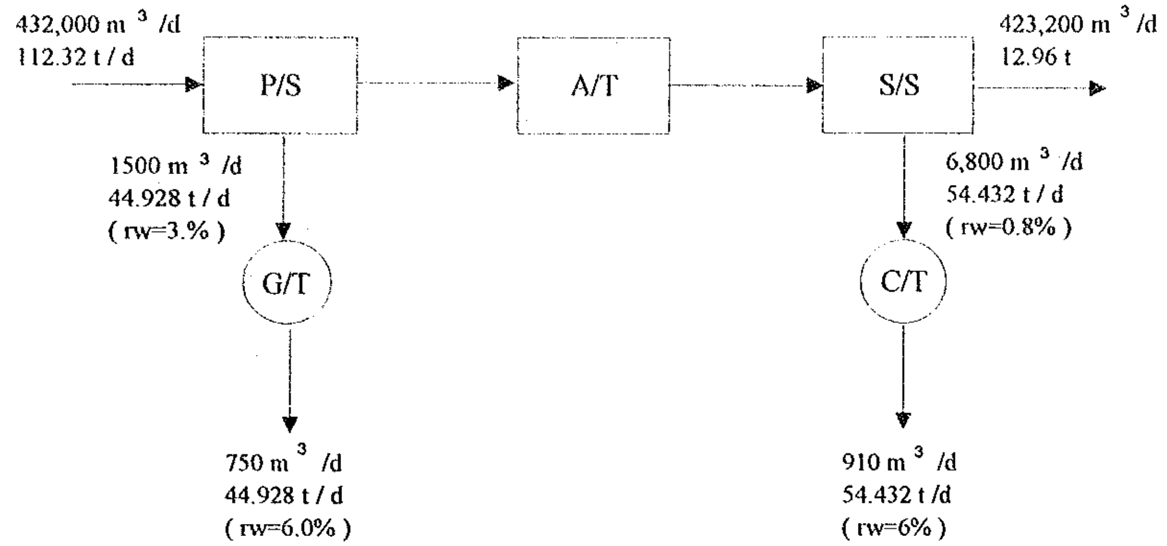


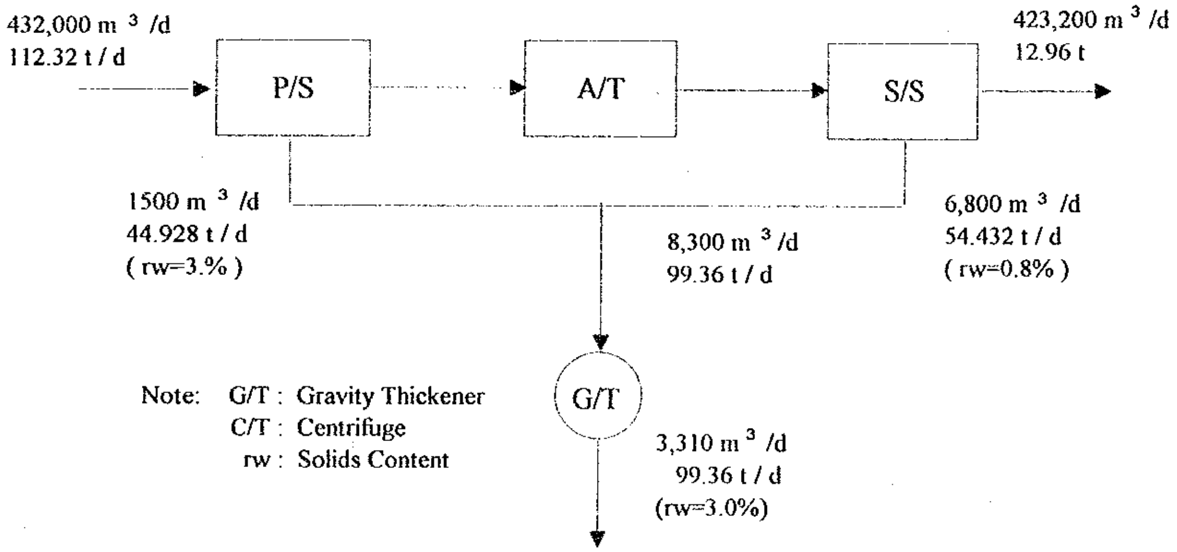
Fig. F.5 Sludge Treatment Processes for the Project

THE FEASIBILITY STUDY ON WASTEWATER TREATMENT IN THE FEDERAL DISTRICT OF MEXICO

(1) Calculation of Sludge Volume (Seperated Thickening) per 1 Unit



(2) Calculation of Sludge Volume (Conbined Thickening) per 1Unit



Note: G/T : Gravity Thickener
C/T : Centrifuge
rw : Solids Content

Fig. F.6 Solid Balance of Separate Thickening and Combined Thickening

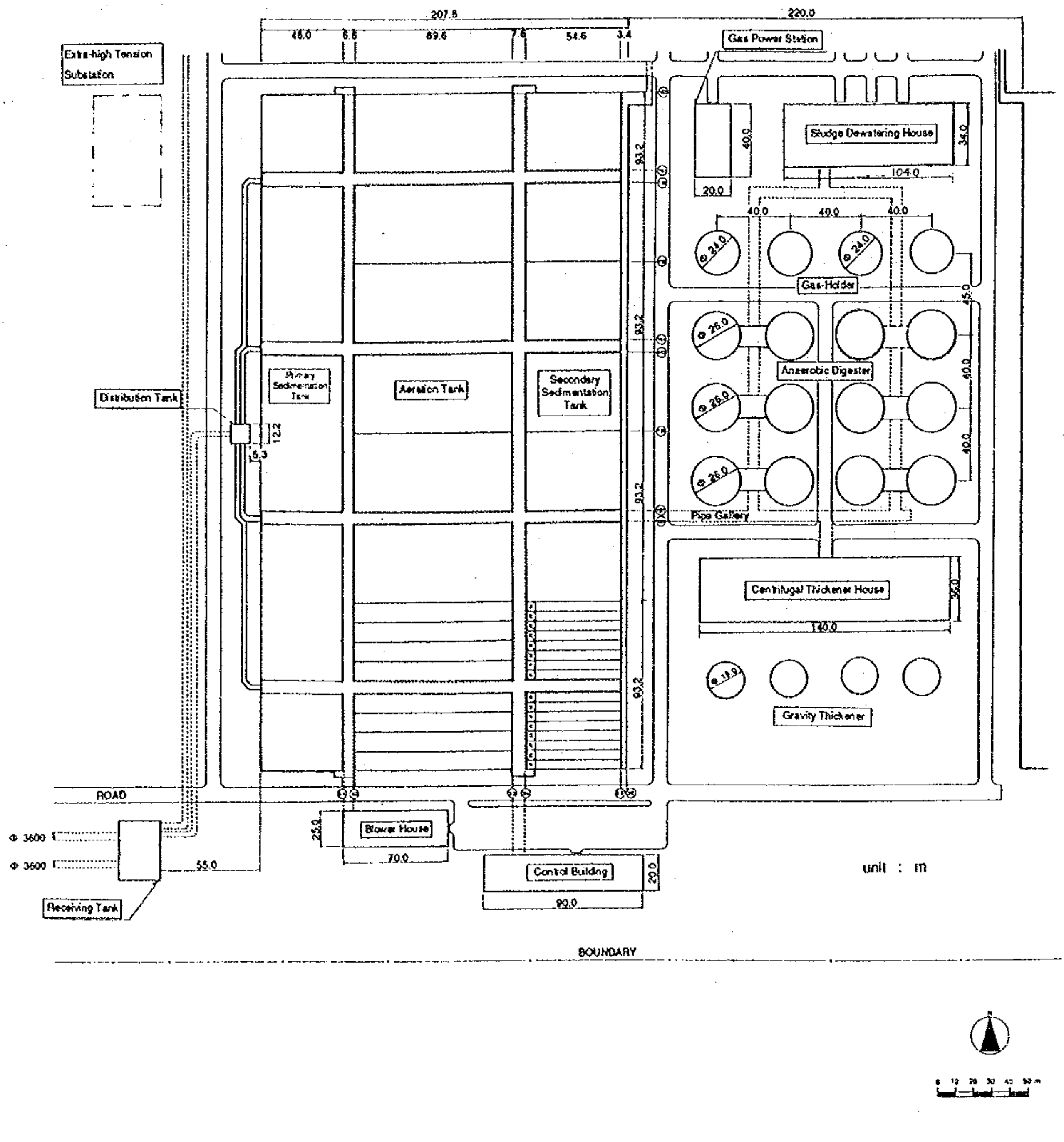


Fig. F.7 Layout of the One (1) Unit for the Final Project

THE FEASIBILITY STUDY ON WASTEWATER TREATMENT IN THE FEDERAL DISTRICT OF MEXICO

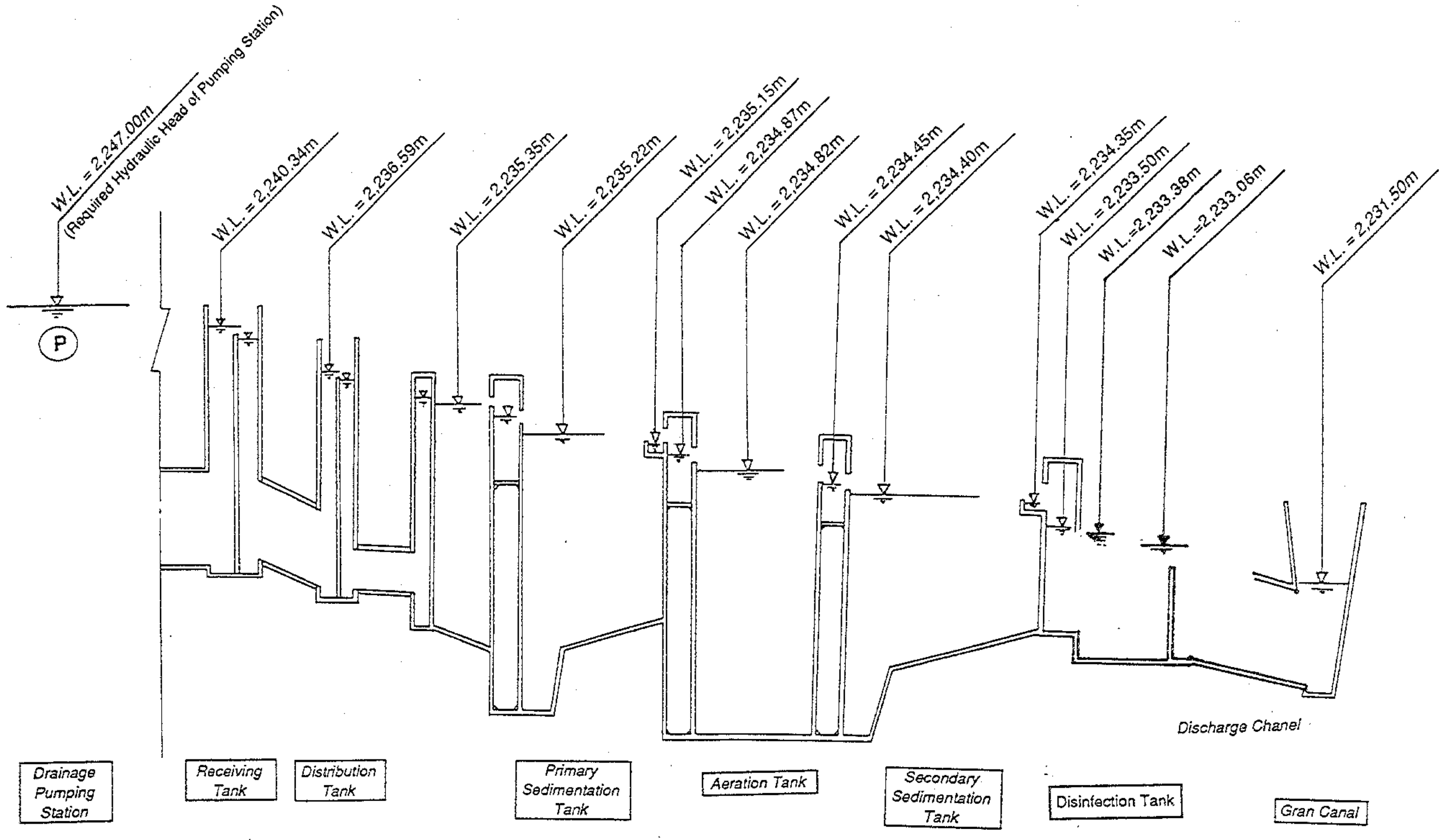


Fig. F.8 Hydraulic Profile of the Treatment Plant for the Final Project

THE FEASIBILITY STUDY ON WASTEWATER TREATMENT IN THE FEDERAL DISTRICT OF MEXICO

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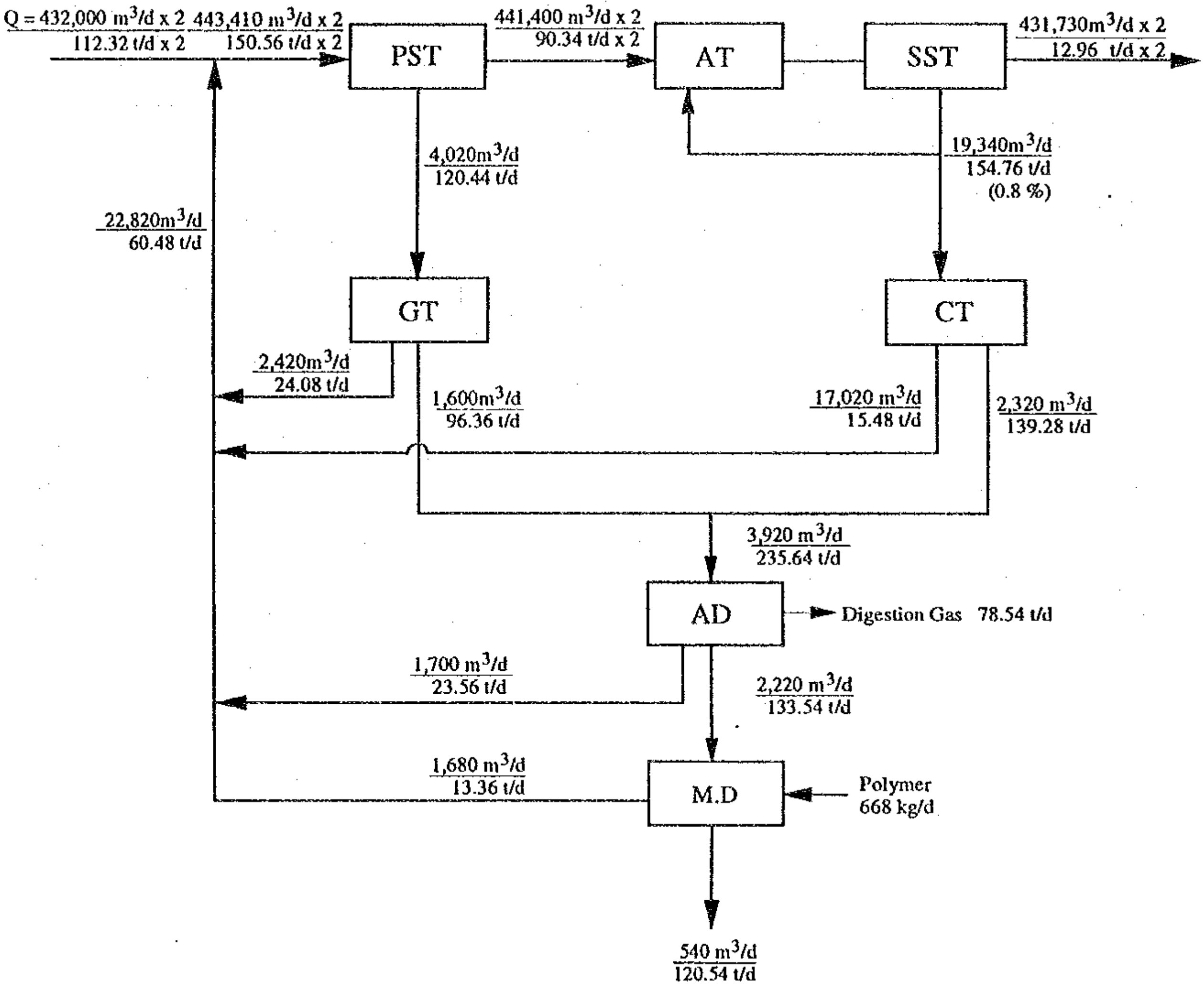

Note : 0,000 ----- Quantity of WW/sludge
00.00 ----- Dry Solid

GT : Gravity Thickening
CT : Centrifugal Thickening
AD : Anaerobic Digester
MD : Mechanical Dewatering by Belt Filter Press

Fig. F.9 Solid Balance of Each Unit for the Final Project

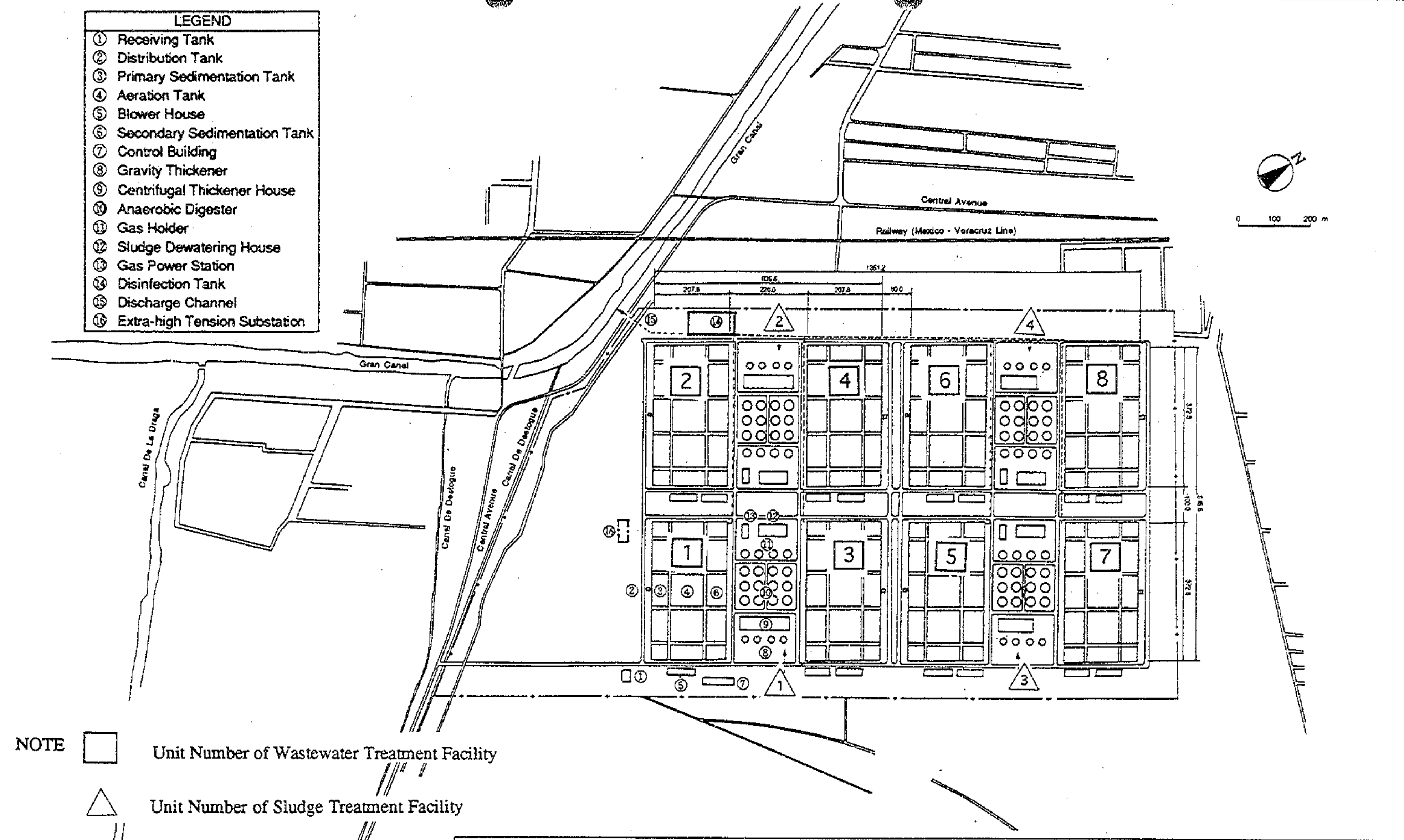

Fig. F.10 General Layout of the Treatment Plant for the Final Project

THE FEASIBILITY STUDY ON WASTEWATER TREATMENT IN THE FEDERAL DISTRICT OF MEXICO

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APPENDIX G

APPENDIX G DESIGN OF WASTEWATER AND SLUDGE TREATMENT SYSTEM FOR URGENT PROJECT

1. General

Basic design of wastewater and sludge treatment plant for the Urgent Project with a capacity of 35 m^3/sec has been conducted. Two (2) units of wastewater treatment plant have been proposed. Each unit having capacity of 17.5 m^3/sec, consists of aeration tank and secondary sedimentation tank. Two (2) units of sludge treatment plant consisting of centrifugal thickener, anaerobic digestion tank and belt filter press are designed. Layout and hydraulic profile of wastewater and sludge treatment plant for the Urgent Project is shown in Fig. G.1 and Fig. G.2 respectively.

Dimensions of each facility are designed according to the conditions of Final Project stage.

Design influent and effluent wastewater quality of the Urgent Project are described below.

Parameter	Influent	Effluent
BOD_5	220 mg/l	120 mg/l
SS	235 mg/l	120 mg/l
Coliforms (MPN/100 ml)	10^7	<100,000

2. Wastewater Treatment Facilities

Details of each facility is shown in the attached "Drawings".

2.1 Receiving Tank

Two (2) Influent pipes, each having diameter of 3.6 m are designed to carry wastewater from the influent pumping station to the Receiving Tank.

Only about 10 % of treatment capacity is supposed to be augmented from Urgent Project stage to Final Project stage, hence the structure of receiving tank for the complete treatment system till Final Project is proposed to be constructed at the Urgent Project stage itself.

Proposed elevation of the crest of overflow weir is 2,239.40 m. Width of overflow weir is proposed to be 3.0 m. Required water depth of the overflow weir to discharge wastewater of 35 m^3/sec is calculated to be 2.16 m. Hence the water level of receiving tank at the Urgent Project stage is required to be at the level of + 2,241.56 m. Hydraulic retention time of 1.8 min is achieved with an effective depth of 6.56 m. Detailed hydraulic calculations are described in Data Book.

Manually operated sluice gate with a diameter of 2.8 m is installed in each unit of the Urgent Project stage.

2.2 Connection Pipe

Connection pipe of 2.8 m diameter, between Receiving tank and Distribution tank, is designed for each unit of the Urgent Project. Connection pipes of 2.0 m diameter is designed for the each of the remaining six (6) units of treatment plant, to be constructed at the Final Project stage. These diameter are decided to make the hydraulic loss same in both urgent and final stages.

2.3 Distribution Tank

Distribution tank distributes wastewater of 17.5 m^3/sec to four (4) sub-units of each unit by rectangular weirs, each having width of 2.5 m. The crest elevation of rectangular weir is proposed at the level of 2,236.17 m. Required overflow depth of weir, to discharge wastewater of 4.375 m^3/sec, is 1.196 m. Hydraulic retention time of distribution tank is estimated to be 0.5 min.

Wastewater of 17.5 m^3/sec is distributed to four (4) sub-units by open channel with a width and depth of 2.5 m and 1.5 m respectively.

2.4 Aeration Tank

Crest elevation of overflow weir is proposed at a level of 2,234.73 m with overflow depth of 0.19 m. Water level of aeration tank is 2,234.92 m. Bottom elevation of aeration tank is 2,228.92 m with an effective water depth of 6.0 m. Hydraulic retention time is calculated to be 2.7 hrs with a sludge recirculation ratio of 10%.

Aeration tank is 89.0 m long and 10.3 m wide. Number of tanks for one (1) unit are 32. At the Urgent Project stage, two (2) unit of aeration tank are required.

Required number of blower with a capacity of 900 kW for one (1) unit of aeration tank are seven (7), for the Urgent Project stage. At the Final Project stage, required number of blower for one (1) unit of aeration tank is reduced to four

(4). Remaining three (3) blowers of one (1) unit will be removed and installed to newly constructed treatment unit at the Final Project stage.

2.5 Secondary Sedimentation Tank

One (1) unit of secondary sedimentation tank consists of 64 number of channels. At the urgent stage two (2) units of secondary sedimentation tank are required. Surface loading at the urgent stage is calculated to be 87.5 $m^3/m^2/d$. Required length of effluent trough with V-notch weir is calculated based on the overflow rate of 190 $m^3/m^2/day$. Effluent trough of 125 m is required in the each channel of secondary sedimentation tank. Total length of effluent trough at the urgent stage is estimated to be 16,000 m.

2.6 Disinfection

Chlorine gas is used for disinfection. Required chlorine gas dosage ratio of 2.0 mg/l is estimated from coliform survival ratio and chlorine contact time. After dosage of chlorine, treated wastewater contact chlorine for 15 minutes in the contact tank and 2 minutes in the discharge channel before discharging Gran Canal.

3. Sludge Treatment Facilities

At the Urgent Project stage, only activated sludge is produced. Hence sludge thickening is proposed to be done by centrifugal thickener. For liquid treatment system, required capacity for the Urgent Project is one fourth of the final treatment capacity. While from the solid balance studies, about half of the final sludge treatment capacity is required at the urgent stage. (ref. Fig. G.3) Two (2) units of sludge treatment plant are constructed in the urgent stage.

3.1 Centrifugal Thickener

Activated sludge of 35,240 m^3/d, having solid content of 0.65%, is discharged from one (1) unit of wastewater treatment plant. Then total daily discharged activated sludge is estimated to be 70,480 m^3/d.

Required number of centrifugal thickener, each with a capacity of 170 m^3/hr, are 11 sets, for one (1) unit of sludge treatment plant. Required power of one (1) set of centrifugal thickener is 200 kW.

Centrifugal thickener thickens the sludge with a solid content of 6.0%. Total daily thickened sludge produced per unit is 3,440 m^3/d with dry solid weight of 206.18 ton/d.

3.2 Anaerobic Digester

Thickened sludge of 3,440 m^3/d per unit is stabilized by the anaerobic digester. Anaerobic digester, 10 tanks, each with 26 m diameter and 12.5 m depth are required for each unit at the urgent stage. Retention time of anaerobic digester is 19.3 days. In anaerobic digester, 33% of solids are designed to be removed as digestion gas.

Blower with a capacity of 45 kW is installed to agitate sludge in each tank of anaerobic digester.

3.3 Belt Filter Press

Belt filter press is designed to dewater digested sludge of 1,950 m^3/d with a solid content of 6.0% for each one (1) unit. Polymer of 0.584 ton/d is added as a coagulant.

Belt filter press of 16 sets with 3 m belt width are installed for each unit of the sludge processing building. At the Final Project stage, required number of belt filter are 20 sets, hence remaining four (4) sets will be are to be newly installed at each unit of sludge dewatering house. Required power capacity of each belt filter is 5.5 kW.

3.4 Land Disposal

About 480 m^3/d (105.73 t/d) of dewatered sludge is obtained from one unit, hence amount of sludge to be disposed annually from the whole sludge treatment system is 154,366 tons. For the dedicated land disposal site, 370 tons/ha of annual application rate is recommended. Hence about 420 ha of area for land disposal is required.

3.5 Power Generation by Digestion Gas

Thichkened sludge, having Solids of 68.73 ton/d, is digested and digestion gas is produced in the anaerobic digester. Digestion gas to be produced is assumed to be 0.9 N m^3/kg of VSS. Thus digestion gas of 62,000 N m^3/d will be produced in one (1) unit of sludge treatment plant in the urgent stage.

Digestion gas has a calorific value of about 5,500 kcal/N m^3. This energy is proposed for using the operation of power generator as shown in Fig. G.4.

Capacity of electrical generation is calculated as shown below.

Power of engine
Assuming efficiency of engine as 30%
Pe = (62,000 x 5,500 x 0.3) / (24 hr x 860 kcal/KWH x 0.736 PS/KW)
= 6,800 PS

Power of generator
Assuming efficiency of generator as 90 % and Power factor as 80 %
Pg = (6,800 x 0.9) / (1.36 PS/KW x 0.8) = 5,625 KVA = 4,500 KW

Required energy for heating the digestion tank is supplied by the waste heat of engine operation (Refer to Fig. G.4).

4. Electrical Design

Required capacity of electrical supply for each unit in the Urgent Project is estimated to be 12,854 kw and details are summarized below.

Facility	Required Power (KW)
Aeration tank	12.0
Secondary Sedimentation Tank	1,006.4
Disinfection	43.7
Blower for Aeration	6,401.6
Sidestreams Reservoir	159.8
Water Supply for Treatment	539.8
Centrifugal Thickener	2,797.8
Anaerobic Digester	855.1
Belt Filter Press	662.8
Others	187.5
Total	12,854.0

Required electrical power for the Urgent Project is 25,708 kw. While electrical generation of 9,000 kw by digestion gas can be achieved. Hence the total required electrical supply is estimated to be 16,708 kw.

Detailed calculation of required electrical power of each facility are described in Table G.1.

5. Design of Foundation

As previously mentioned in Appendix F, section 1, the existing soil condition of the proposed Texcoco treatment plant site is very weak. Proper foundation should be considered for the treatment facilities.

5.1 Design Considerations

5.1.1 Soil Conditions

Soil conditions of the proposed treatment plant site is described in Appendix F, section 1.4. Characteristics of each soil layer is summarized below.

Layer	Depth (m)	Nature of soil	SPT (N value)	Cohession (t/m^2)	Angle of Internal Friction (Ø)
(1)	0.0~G.L -9.0 m	Very soft clay	0 ~ 3	1.25~2.5	0
(2)	GL-9.0~-12.0 m	Silty sand	10	3.0	27°
(3)	GL-12.0~16.0 m	Soft clay	< 5	4.0	0
(4)	GL-16.0~19.0 m	Silty sand	10 ~ 50	0	27~42°
(5)	GL-19.0~28.0 m	Clay and sand	0 ~ 20	3.5~7.0	0~20°
(6)	GL-28.0~37.0 m	Silty sand	30 ~ 50	0	36~42°
(7)	GL-37.0~55.0 m	Soft clay and silty sand	10 ~ 50	-	-

Soil data deeper than 37.0 meter below ground surface is achieved from the previous relevant study.

Ground water table at the proposed site is found to be 7.3 meter below ground surface.

5.1.2 Design Load of Superstructures

Unit vertical load of each structure is calculated as shown below.

Structure	Unit Vertical Load (ton/m^2)
Receiving Tank	12.3
Aeration Tank	8.7
Secondary Sedimentation Tank	6.0
Anaerobic Digester	18.7
Control Building	7.0

5.2 Design of Foundation

Keeping in view the poor subsurface soil conditions, following two (2) alternatives are considered for the foundation of the proposed treatment facilities.

- Improving Site Soil condition by preloading/sand drain method for Foundation construction
- Adopting Pile Foundation

Major purpose of the improving site soil is to accelerate the settlement and hence to improve the shear strength of the subsoil.

Based on the preliminary calculation, the present soil conditions require 15 years to complete the land settlement with the preload of 40 ton per m^2. Hence improving site soil by preloading and/or sand drain methods is not recommended for this project.

Hence Pile foundation is proposed and basic design is described below.

5.2.1 Pile Foundation

Cast insitu reinforced concrete piles with a diameter of 600 mm and 800 mm are proposed for the foundation of the facilities.

(1) Bearing Capacity of Soil

Ultimate bearing capacity is calculated by the following formula.

$$Ru = (15 \times N \times Ap) + (V \times \Sigma(l_i \times f_i))$$

Ru	: Ultimate bearing capacity (ton)
N	: SPT at the tip of pile
Ap	: Cross section of pile tip (m^2)
V	: Length of pile circle (m)
l_i	: Depth of the each soil layer which consider the skin friction (m)
f_i	: Maximum skin friction of the each layer (ton/m^2)
	{for sand layer: $f_{is} = N/5 \leq 5$ t/m^2 for clay layer: $f_{ic} = q_u/2 \leq 5$ t/m^2}

Proposed base layer is the silty sand layer located 28 m to 37 m below ground surface which has SPT of about 50.

Ultimate bearing capacity of piles of 600 mm and 800 mm diameter are estimated as below.

Ø 600 mm : Ru = (15 x 50 x 0.283) + (1.88 x 2.0 x 5) = 231 ton/pile
Ø 800 mm : Ru = (15 x 50 x 0.503) + (2.51 x 2.0 x 5) = 402 ton/pile

Allowable bearing capacity of piles diameter of Ø600 and Ø800 are calculated by the following equation:

Ra = Ru / Factor of safety - (Weight of reinforced concrete pile - Weight of soil replaced by concrete pile)
Ø600 : Ra = Ru/2 - 8 = 231/2 - 8 = 108 ton/pile
Ø800 : Ra = (15 x 50 x 0.503)/2.67 + (2.51 x 2.0 x 5)/2 - 15 = 139 ton/pile

(2) Negative Skin Friction

Negative skin friction in the following soil layers is considered because land settlement of about 5 cm is expected per annum.

Soil Layer (Depth (m))	Cohesion & SPT	Characteristics
0 ~ 4	C = 1.25 t/m²	Clay
4 ~ 9	C = 2.5 t/m²	Clay
9 ~ 12	N = 10	Silty Sand
12 ~ 16	C = 4.0 t/m²	Clay

Annual land settlement at the soil layer between 16 m to 30 m below ground surface is expected to be less than 1 cm, and hence negative skin friction is not necessary to consider.

Negative skin friction is calculated by the following formula.

$P_{NF} = V \times \Sigma(l_i \times f_{ni}) \times \lambda$

P_{NF} : Negative skin friction (ton)
V : Length of pile circle (m)
li : Depth of each soil layer (m)
f_{ni} : Negative skin friction of each soil layer (ton)
{ for sand layer : $f_{ns} = 3 + N/5$, for clay layer : $f_{nc} = C$}
λ : 0.8

Ø600 : P_{NF} = 1.88 x (4.0 x 1.25 + 5.0 x 2.5 + 3.0 x (3 + 10/5) + 4.0 x 4.0) x 0.8 = 65 ton/pile

Ø800 : P_{NF} = 2.51 x (4.0 x 1.25 + 5.0 x 2.5 + 3.0 x (3 + 10/5) + 4.0 x 4.0) x 0.8 = 87 ton/pile

(3) Allowable Capacity of Pile Foundation

With due consideration to the negative skin friction, allowable design vertical load of pile foundation (Pv) is calculated as follows.

Ø600 : Pv = Ru/1.2 - P_{NF}= 231/1.2 - 65 = 128 ton/pile

Ø800 : Pv = 402/1.2 - 87 = 248 ton/pile

Considering horizontal earthquake coefficient of 0.2, the horizontal load is estimated to be 21.6 ton/pile (0.2 x 108 ton/pile) for pile diameter of 600 mm. However pile foundation can not support the horizontal load of 21.6 ton/pile. The allowable horizontal design load of a pile with a diameter of 600 mm is less than **14** ton/pile. Hence from horizontal load consideration, the allowable design capacity of a pile foundation is **70** ton/pile.

The allowable design capacity of a pile with a diameter of 800 mm is calculated to be **139** ton/pile.

(4) Pile Alignment

Based on the design unit load of each facility and allowable capacity of pile foundation, pile alignment of each facility is designed as follows.

Structure	Unit Vertical Load (ton/m^2)	Pile Diameter (mm)	Pile Pile Pitch (m)
Receiving Tank	12.3	Ø800	3.4
Aeration Tank	8.7	Ø600	2.8
Secondary Sedimentation Tank	6.0	Ø600	3.4
Anaerobic Digestor	18.7	Ø800	2.7
Control Building	7.0	Ø600	3.2

6. Construction Plan, and Operation and Maintenance of Facilities

6.1 Construction Method, and Operation and Maintenance

Open cut method is proposed for facility construction. The earth works will be done mainly by machines of backhoe, bulldozer and dragline. Reinforced concrete pile foundation is proposed for supporting all structures. Dewatering from the construction site is required during rainy season. All structures are to be constructed by reinforced concrete.

The operation and maintenance of the Texcoco wastewater treatment plant shall be the responsibility of DGCOH in D.F Mexico.

To achieve the expected effluent water quality, the treatment plant should be operated under appropriate conditions.

The following work items by each facility should be performed daily and/or intermittently.

(1) Aeration Tank

- Control of aeration time
- Control of aeration and mixing
- Control of MLSS

(2) Secondary Sedimentation Tank

- Control of sedimentation time
- Control of inflow gate
- Inspection of sludge scraper
- Control of return and excess sludge desludging
- Inspection of transparency

(3) Disinfection

- Inspection of effluent water quality and quantity
- Control of chlorine gas dosing rate

(4) Centrifugal Thickener

- Control of sludge feeding
- Inspection of rotation speed of dram and screw
- Control of water level

(5) Anaerobic Digester

- Inspection of mixing and other equipment
- Control of retention time
- Control of dewatering and collection of exhaust gas

(6) Belt Filter Press

- Inspection of belt filter (washing and/or replacement)
- Control of chemical dozing
- Control of mechanical devices
- Control of sludge scattering

(7) Connection Pipe

- Inspection of sludge accumulation and scum appearance
- Inspection of foaming
- Inspection of corrosion and settlement of conduit
- Inspection of gates

6.2 Mitigation Measures Against Potential Negative Impact

A) Preparation of the site and preconstruction stage

During this stage, historical assets around the site, flora and fauna present, need to be assessed. The flora present in the project site is negligible. The project site has practically negligible fauna species. The surrounding zones are inhabited by certain species represented mainly by migratory birds. The human activities, machinery operation, sound generation will probably scare away few fauna species. However considering the minimum distance to the shallow water bodies, no important damage to the migratory fauna is expected.

B) Construction stage

During this stage, vibration and noise generated could affect the surrounding inhabitants. The minimum distance from the treatment plant site to the existing permanent building is 250 m. By employing pre boring method for pile construction and planning only daytime work, the negative impact of vibration and noise can be significantly reduced.

Dust nuisance to some extent is unavoidable during construction. However cleaning and water spraying of the roads in and/or around the construction site will be employed to minimize dust nuisance.

Transport of construction materials, equipments and heavy machinery will cause traffic problems specially on the Central Avenue where traffic is complicated due to slowness of the trucks and the buses. The part of

Central Avenue should be fixed exactly in front of the main access to the treatment plant. This will consist basically the construction of additional lanes to use them as entrance and exit lanes to and from the plant. This measure must be complemented with the appropriate signals in both sides of the road. These measures could mitigate the traffic problems.

C) Operation stage

The vehicle traffic on the access roads to the treatment plant, specially on the Central Avenue will be significantly increased. At the main access to the plant, the road is narrow, with one lane in each way, so the problem will be worse by the time the plant operates. The mitigating measures are same as mentioned above. It is necessary to build a specific space on the road lanes to make easier and less troublesome the ascent and descent to and from the public transport, without interfering with the vehicles traffic.

Another potential negative impact could be the generation of odor due to operation of treatment plant. By properly maintaining the operation of treatment process and further by providing sufficient buffer zone of 50 m width the impact of odor can be significantly reduced.

7. Cost Estimates

7.1 Basis of Cost Estimate

The project cost is estimated based on the following conditions.

(1) It is assumed that all construction works will be contracted to general Contractors by international tender.

(2) All base costs are expressed under the economic conditions that are prevailing in May, 1994.

(3) Overhead is assumed as 30% of the total cost of equipment and civil works and is incorporated in the direct construction cost.

(4) Land compensation of N$ 115.1 million for the proposed Texcoco wastewater treatment site of 191.9 ha has been considered.

(5) Engineering service and administration costs are assumed respectively at 3.5% and 1.0% of the total direct construction cost.

(6) Physical contingency allowance at the rate of 10% of the direct construction cost is assumed.

(7) Currency exchange rate of US $ 1 = N$ 3.2 = ¥ 105 is assumed.

7.2 Basic Unit Cost

Basic unit costs for construction are shown in Table F.6.

7.3 Estimated Project Cost

The total project cost of the Urgent Project , consisting of direct construction cost, land compensation, administration cost, engineering cost and physical contingency amounts to N$ 1,392.1 million at 1994 price. Its breakdown is shown below.

	(Unit : N$ million)
(A) Direct Construction Cost	1,115.4
1) Wastewater Treatment	503.4
(1) Receiving Tank	15.0
(2) Distribution Tank	5.2
(3) Aeration Tank	262.4
(4) Secondary Sedimentation Tank	144.8
(5) Disinfection	14.9
(6) Discharge Channel	11.1
(7) Equipment for reclaimed wastewater	9.8
(8) Electrical Works	40.2
2) Sludge Treatment	481.9
(1) Centrifugal Thickener	93.8
(2) Anaerobic Digester	140.0
(3) Belt Filter Press	50.2
(4) Gas Generation System	131.4
(5) Electrical Works	66.5
3) Building Construction	95.2
4) Other Works	34.9
(B) Land Compensation	115.1
(C) Administration Cost	11.1
(D) Engineering Cost	39.0
(E) Physical Contingency	110.5
Total	1,392.1

The above direct construction costs are further breakdown as shown in Table G.2.

7.4 Estimated O/M Cost

O/M cost of the project consists of following major components:

- Personal Expenditure
- Electrical Charge
- Chemical Cost (for dewatering and disinfection unit)
- Sludge Disposal Cost
- Repairing Cost.

Annual O/M cost of whole wastewater and sludge treatment systems after completion of the Urgent Project is estimated to be N$ 83.7 million.

The breakdown of the O/M cost is shown below.

	(Unit : N$ million)
(1) Personal Expenditure	3.9
(2) Electrical Charge	21.4
(3) Chemical Cost	16.6
(4) Sludge Disposal Cost	11.7
(5) Repairing Cost	30.1
Total	83.7

The further breakdown of O/M cost is shown in Table G.3.

Table G.1(1) Required Electrical Power of Each Facility for the Urgent Project

Design Wastewater for One (1) Unit = 1,512,000 m3/d

1 Aeration Tank		
Floor Drain Pump	1.5 kw x 8	12.00 kw
Sub-Total		12.00 kw
2 Secondary Sedimentation Tank		
Scraper	2.2 kw x 32	70.40 kw
Sludge Draw Valve	0.75 kw x 16	12.00 kw
Return Sludge Pump	30.0 kw x 24	720.00 kw
Valve of RSP	0.4 kw x 24	9.60 kw
Excess Sludge Pump	11.0 kw x 16	176.00 kw
Valve of ESP	0.4 kw x 16	6.40 kw
Floor Drain Pump	1.5 kw x 8	12.00 kw
Sub-Total		1,006.40 kw
3 Disinfection		
Chlorine Pressure Pump	3.7 kw x 5	18.50 kw
Neutralization Pump	3.7 kw x 4	14.80 kw
Ventilation Blower	3.7 kw x 2	7.40 kw
Floor Drain Pump	1.5 kw x 2	3.00 kw
Sub-Total		43.70 kw
4 Blower for Aeration		
Blower	900 kw x 7	6,300.00 kw
Inlet Valve of Blower	2.2 kw x 7	15.40 kw
Outlet Valve of Blower	1.5 kw x 7	10.50 kw
Blower Valve	1.5 kw x 4	6.00 kw
Dry Filter	0.75 kw x 7	5.25 kw
Wet Filter	0.75 kw x 7	5.25 kw
Cooling Tower	1.5 kw x 4	6.00 kw
Cooling Tower Pump	3.7 kw x 8	29.60 kw
Fuel Pump	2.2 kw x 8	17.60 kw
Floor Drain Pump	1.5 kw x 4	6.00 kw
Sub-Total		6,401.60 kw
5 Water Supply for Treatment Plant		
Raw Water Pump (1)	22.0 kw x 6	132.00 kw
Raw Water Pump (2)	22.0 kw x 6	132.00 kw
Strainer (1)	0.4 kw x 6	2.40 kw
Strainer (2)	0.4 kw x 6	2.40 kw
Lift Pump	22.0 kw x 3	66.00 kw
Back Wash Pump	11.0 kw x 2	22.00 kw
Distribution Pump	30.0 kw x 6	180.00 kw
Floor Drain Pump	1.5 kw x 2	3.00 kw
Sub Total		539.80 kw
6 Sidestreams Reservoir		kw
Transmission Pump	22.0 kw x 7	154.00 kw
Valve of T.P	0.4 kw x 7	2.80 kw
Floor Drain Pump	1.5kw x 2	3.00 kw
Sub-Total		159.80 kw

Table G.1(2) Required Electrical Power of Each Facility for the Urgent Project

7 Centrifugal Thickener		
Centrifugal Thickener	200.0 kw x 11	2,200.00 kw
Sludge Supply Pump	11.0 kw x 16	176.00 kw
Valve of SSP	0.4 kw x 16	6.40 kw
Sludge Distribution Pump	7.5 kw x 16	120.00 kw
Mixer of Receiving tank	5.5 kw x 8	44.00 kw
Mixer of Distribution Tank	7.5 kw x 8	60.00 kw
Supernatant Pump	11.0 kw x 16	176.00 kw
Valve of SP	0.4 kw x 16	6.40 kw
Floor Drain Pump	1.5 kw x 6	9.00 kw
Sub-Total		2,797.80 kw
8 Anaerobic Digester		
Gas Compressor	45.0 kw x 10	450.00 kw
Sludge Supply Pump	7.5 kw x 10	75.00 kw
Mixer of Receiving tank	7.5 kw x 4	30.00 kw
Sludge Circulation Pump	15.0 kw x 10	150.00 kw
Sludge Distribution Pump	7.5 kw x 10	75.00 kw
Mixer of Distribution Tank	7.5 kw x 5	37.50 kw
Washing Pump	7.5 kw x 4	30.00 kw
Valve of Washing Pump	0.4 kw x 4	1.60 kw
Floor Drain Pump	1.5 kw x 4	6.00 kw
Sub-Total		855.10 kw
9 Dewatering		
Belt Filter Press	5.5 kw x 16	88.00 kw
Sludge Supply Pump	7.5 kw x 16	120.00 kw
Chemical Supplier	0.4 kw x 16	6.40 kw
Mixer of Chemical Tank	3.7 kw x 16	59.20 kw
Chemical Dosing Pump	0.75 kw x 16	12.00 kw
Filter Washing Pump	11.0 kw x 12	132.00 kw
Valve of FWP	0.4 kw x 12	4.80 kw
Liquid Pump	5.5 kw x 12	66.00 kw
Valve of Liquid Pump	0.4 kw x 12	4.80 kw
Air Compressor	3.7 kw x 12	44.40 kw
Mixer of Sludge Stock Tank	7.5 kw x 8	60.00 kw
Conveyor	2.2 kw x 16	35.20 kw
Hopper	1.5 kw x 16	24.00 kw
Floor Drain Pump	1.5 kw x 4	6.00 kw
Sub-Total		662.80 kw
10 Others (Lighting)		
Control Building		100.00 kw
Blower House		10.00 kw
Thickening House		15.00 kw
Dewatering House		200.00 kw
Other Facilities		50.00 kw
Sub-Total		375.00 kw
Total		12,854.00 kw

Table G.2 Breakdown of Direct Construction Cost for Urgent Project

Description	Civil / Architecture			Mechanical / Electrical			Total
	Quantity	Unit Cost	Const. Cost	Quantity	Unit Cost	Const. Cost	
1) Wastewater Treatment							
(1) Receiving Tank	1 ls.	-	3.2	1 ls.	-	0.9	4.1
(2) Connecting Pipe (ø2,800mm)	1,040 m	0.0105	10.9	-	-	-	10.9
(3) Distribution Tank	2 unit	0.5	1.0	-	-	-	1.0
(4) Influent Channel	2 unit	2.1	4.2	-	-	-	4.2
(5) Aeration Tank	2 unit	67.1	134.2	2 unit	26.3	52.6	186.8
(6) Blower	-	-	-	14 set	5.4	75.6	75.6
(7) Secondary Sedimentation Tank	2 unit	43.9	87.8	2 unit	28.5	57.0	144.8
(8) Disinfection	-	-	11.9	2 unit	1.5	3.0	14.9
(9) Discharge Channel	1 ls.	-	11.1	-	-	-	11.1
(10) Treated Water Reuse	-	-	-	2 unit	4.9	9.8	9.8
Sub-Total			264.3			198.9	463.2
(11) Electrical Work	-	-	-	1 ls.	-	40.2	40.2
Sub-Total of 1) Wastewater Treatment			264.3			239.1	503.4
2) Sludge Treatment							
(1) Sidestream Reservoir	2 tank	1.7	3.4	2 tank	2.3	4.6	8.0
(2) Centrifugal Thickener	-	-	-	22 set	3.9	85.8	85.8
(3) Anaerobic Digester	20 tank	5.7	114.0	20 tank	1.3	26.0	140.0
(4) Mechanical Dewatering (Belt Filter Press)	-	-	-	32 set	1.57	50.2	50.2
(5) Gas Holder	8 tank	0.12	1.0	8 tank	10.1	80.8	81.8
(6) Gas Generator	-	-	-	8 set	6.2	49.6	49.6
Sub-Total			118.4			297.0	415.4
(7) Electrical Work	-	-	-	1 ls.	-	66.5	66.5
Sub-Total of 2) Sludge Treatment			118.4			363.5	481.9
3) Building Construction							
(1) Blower House	2 house	6.3	12.6	-	-	-	12.6
(2) Centrifugal Thickener House	2 house	20.0	40.0	-	-	-	40.0
(3) Anaerobic Digester (Electrical Room)	2 house	1.2	2.4	-	-	-	2.4
(4) Mechanical Dewatering House (Belt Filter Press)	2 house	13.1	26.2	-	-	-	26.2
(5) Co-Generator House	2 house	1.6	3.2	-	-	-	3.2
(6) Control Building	1 house	7.2	7.2	-	-	-	7.2
(7) Sub-Control Building	1 house	3.6	3.6	-	-	-	3.6
Sub-Total of 3) Building Construction			95.2			-	95.2
4) Other Works							
(1) Preparatory Work	1 ls.	-	3.4	-	-	-	3.4
(2) Main Earth Work	1 ls.	-	13.0	-	-	-	13.0
(3) Site Preparation	1 ls.	-	18.5	-	-	-	18.5
Sub-Total of 4) Other Works			34.9			-	34.9
Grand Total			512.8			602.6	1,115.4

Table G.3 Breakdown of Operation & Maintenance Cost

1. Personnel Expenditure

Item	No. of Employee	Unit Cost (N$/year)	Personnel Expenditure (Million N$)
Employee	230	17,000	3.9

2. Electrical Cost

Item	Estimation	Electrical Cost (Million N$/year)
Basic Charge	17,200kw * 24N$/mon. kw * 12mon./year = 5.0Million N$	
Consumption	0.32Mkwh/d * 365days * 0.14N$/kwh = 16.4 Million N$	21.4

3. Chemical Cost

Chemical	Quantity (ton/year)	Unit Cost (N$/ton)	Chemical Cost (Million N$)
Anionic Polymer	426	30,000	12.8
Gas (Cl2)	2,207	1,700	3.8
Total			16.6

4. Sludge Disposal Cost

Landfill Type	Cake Volume (m3/year)	Unit Cost (N$/m3)	Disposal Cost (Million N$)	Remarks
Disposal	350,400	33.5	11.7	Including land acquisition cost of equivalent to 15 N$/cake volume m3

5. Repairing assume to 5% of M/E work 602.6*0.05 30.1

6. Total of Operation & Maintenance Cost 83.7

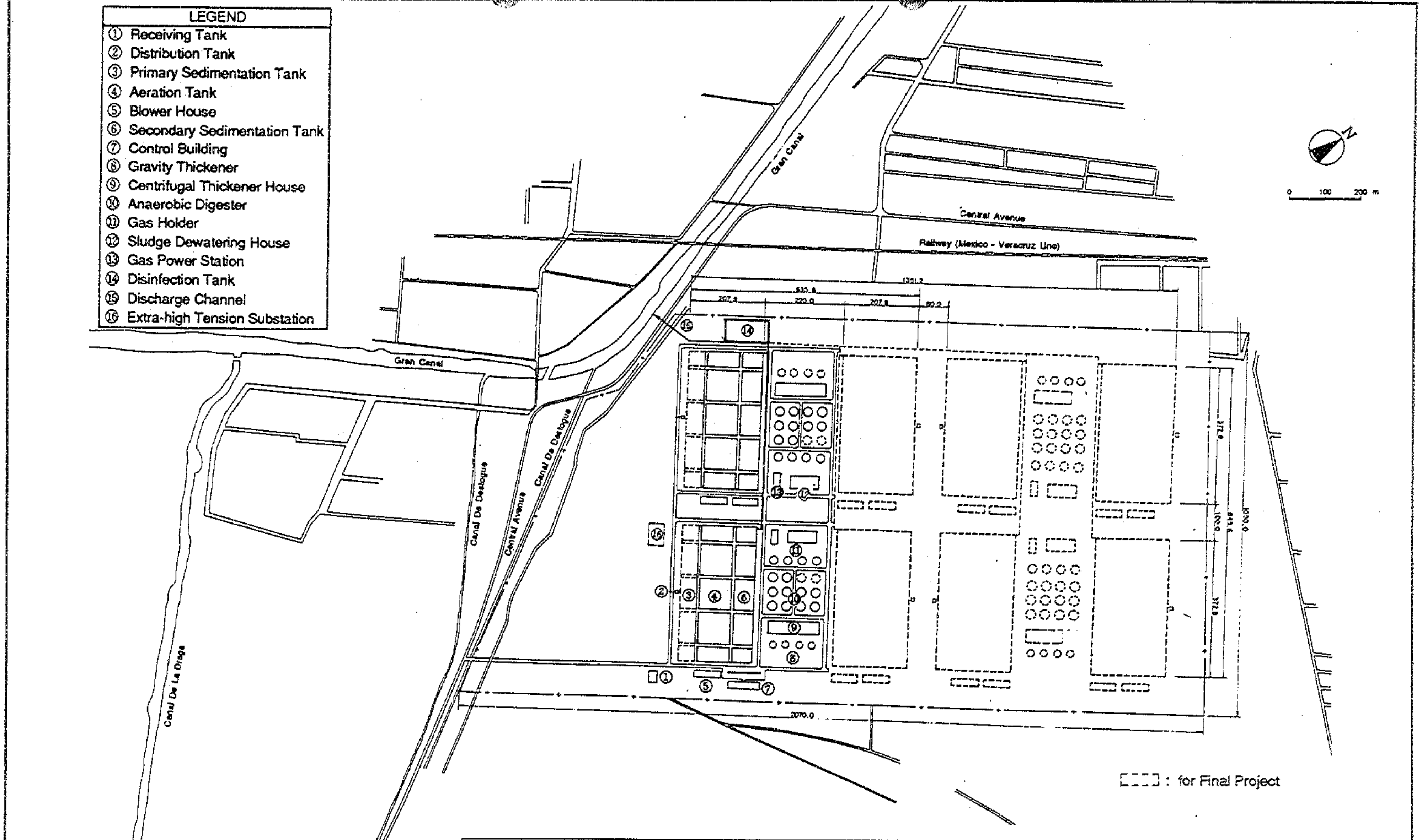

Fig. G.1 General Layout of the Treatment Plant for the Urgent Project

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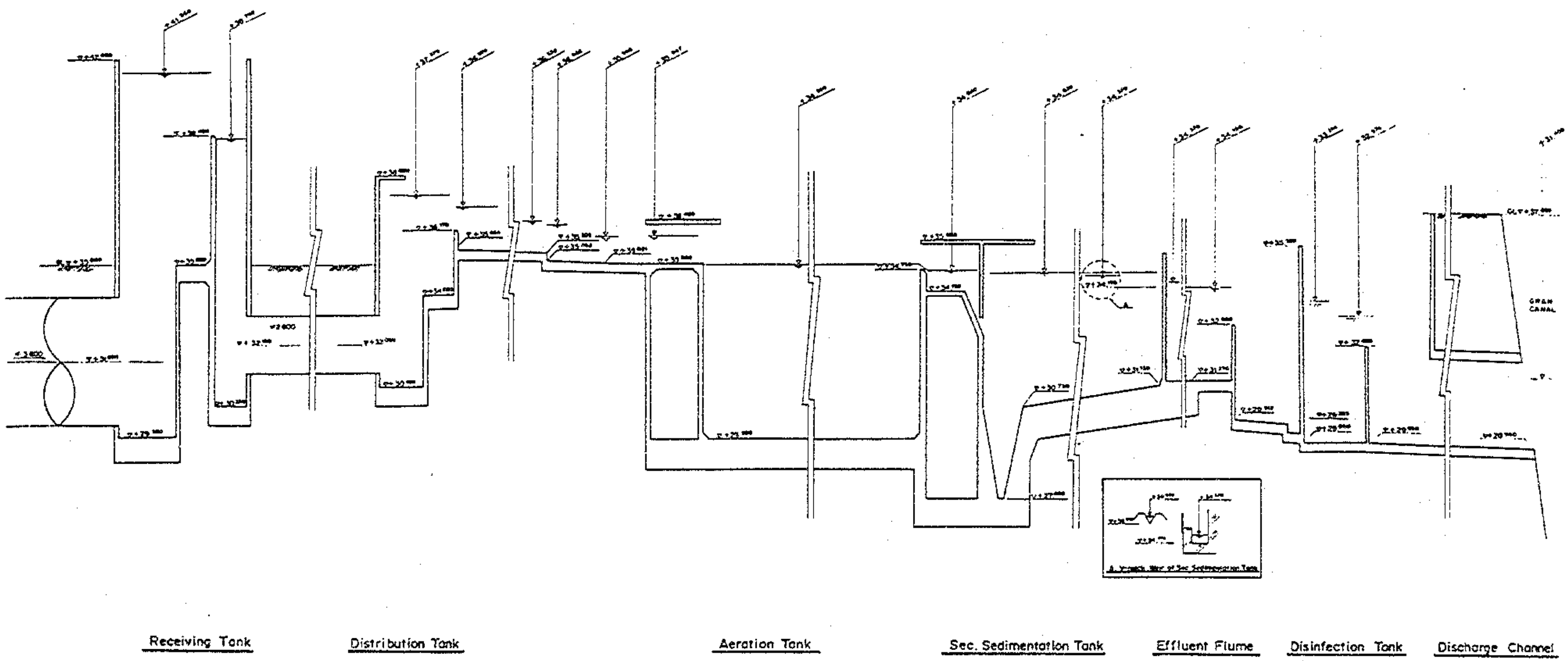

Fig. G.2 Hydraulic Profile of the Proposed System for the Urgent Project

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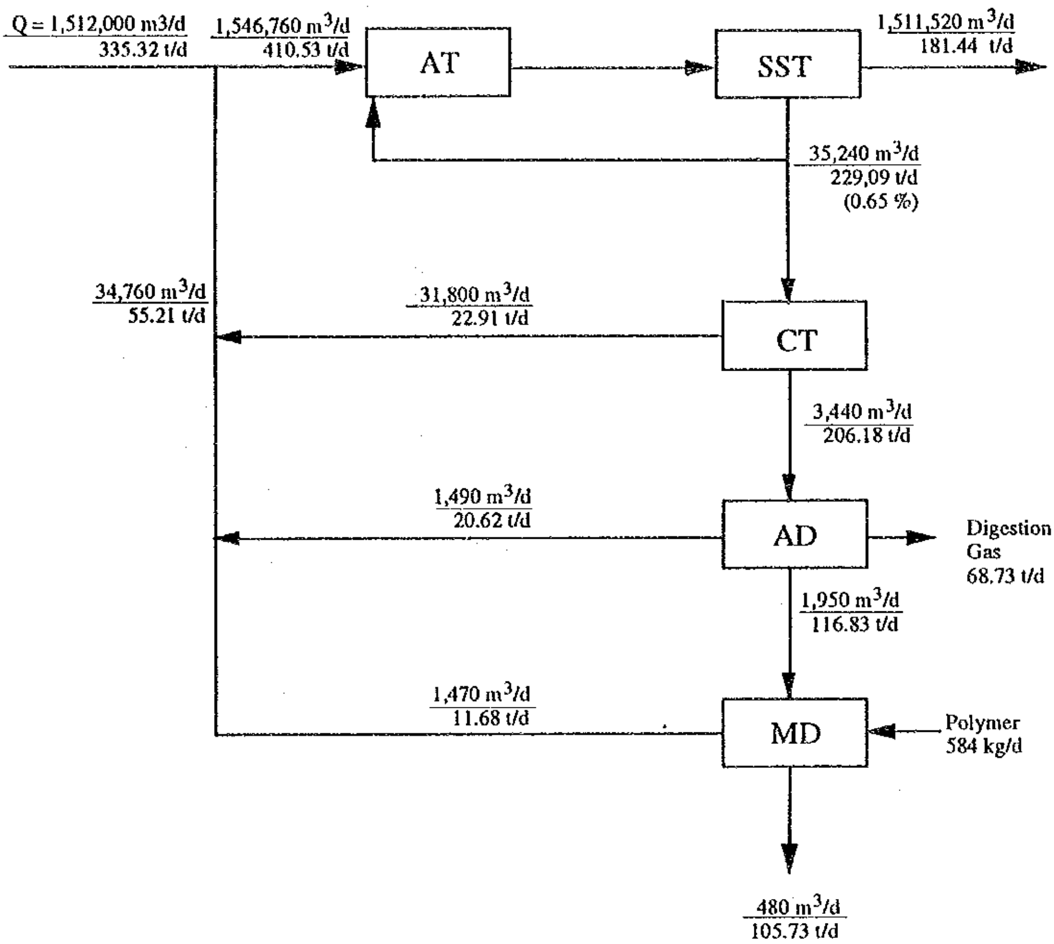

Note : 0,000 / 00.00 — Quantity of WW/sludge / Dry Solid

CT : Centrifugal Thickening
AD : Anaerobic Digester
MD : Mechanical Dewatering by Belt Filter Press

Fig. G.3 Solid Balance of Each Unit for the Urgent Project

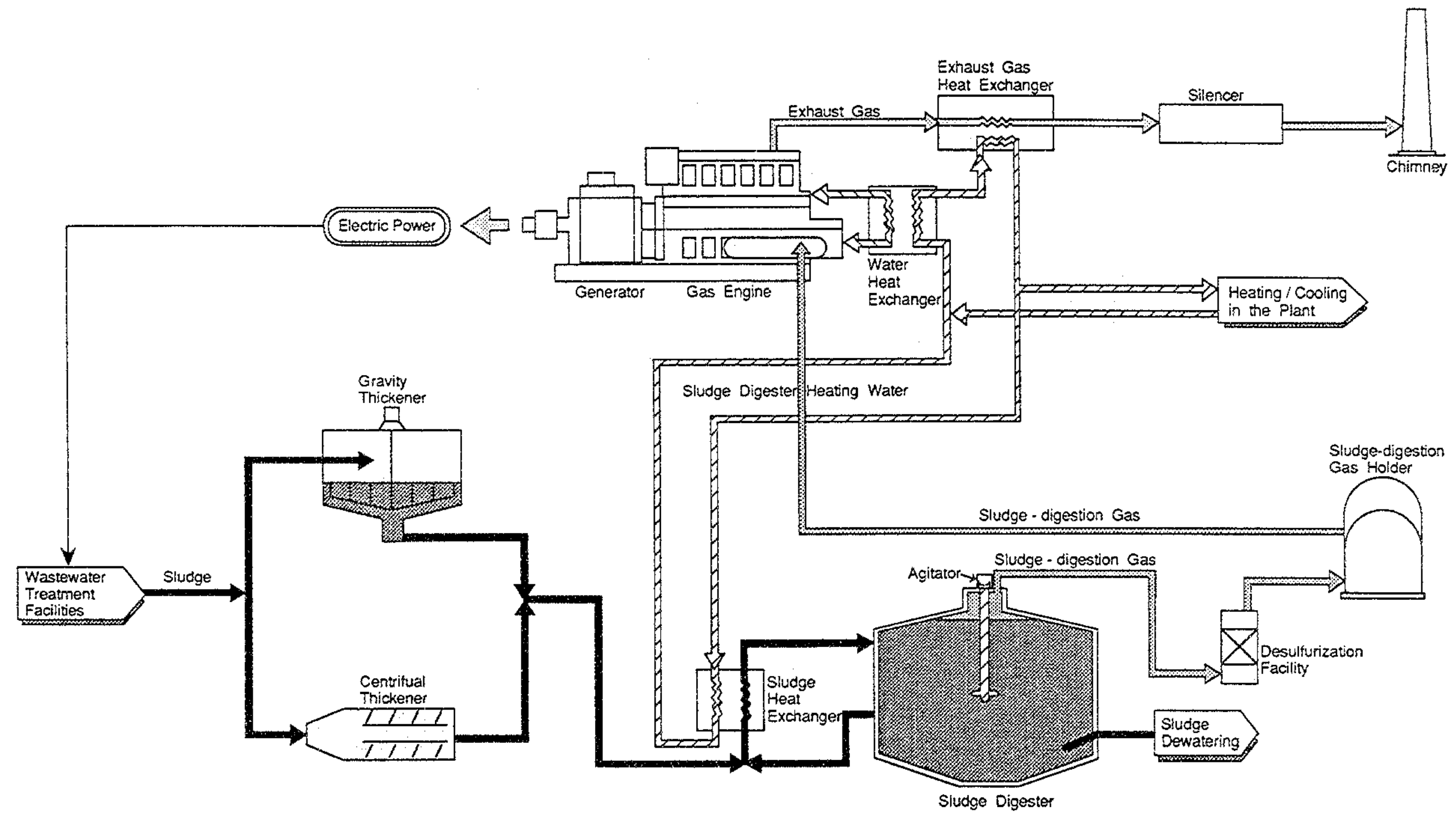

Fig. G.4 Power Generation System for Digestion Gas

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APPENDIX H

APPENDIX H IMPLEMENTATION PROGRAM

1. Implementation Schedule

The Urgent Project will be completed until 1997 and the Final Project will be constructed within 9 years from 2007 to 2015. The construction works will be divided into four (4) stages as described below.

1st Stage	Urgent Project consists of preparatory work of construction site, construction of two (2) units of wastewater and sludge treatment facilities and construction of common facilities such as receiving tank, discharge station and substation.
2nd stage	Primary sedimentation tanks of the wastewater treatment plant for the Urgent Project Gravity thickener for two (2) units of sludge treatment plant for the Urgent Project Additional four (4) anaerobic digesters for completion of two (2) units of sludge treatment plant Additional two (2) units of wastewater treatment plant of conventional activated sludge process
3rd stage	Additional two (2) units of wastewater treatment plant of conventional activated sludge process Additional one (1) complete unit of sludge treatment plant
4th stage	Additional two (2) units of wastewater treatment plant of conventional activated sludge process Additional one (1) complete unit of sludge treatment plant

The inflow pumping station which will convey wastewater to Texcoco treatment plant is designed by the Mexican side. And it is necessary to construct pumping station simultaneously with Texcoco treatment Plant.

The proposed implementation schedule is shown in Fig. H.1.

2. Disbursement Schedule

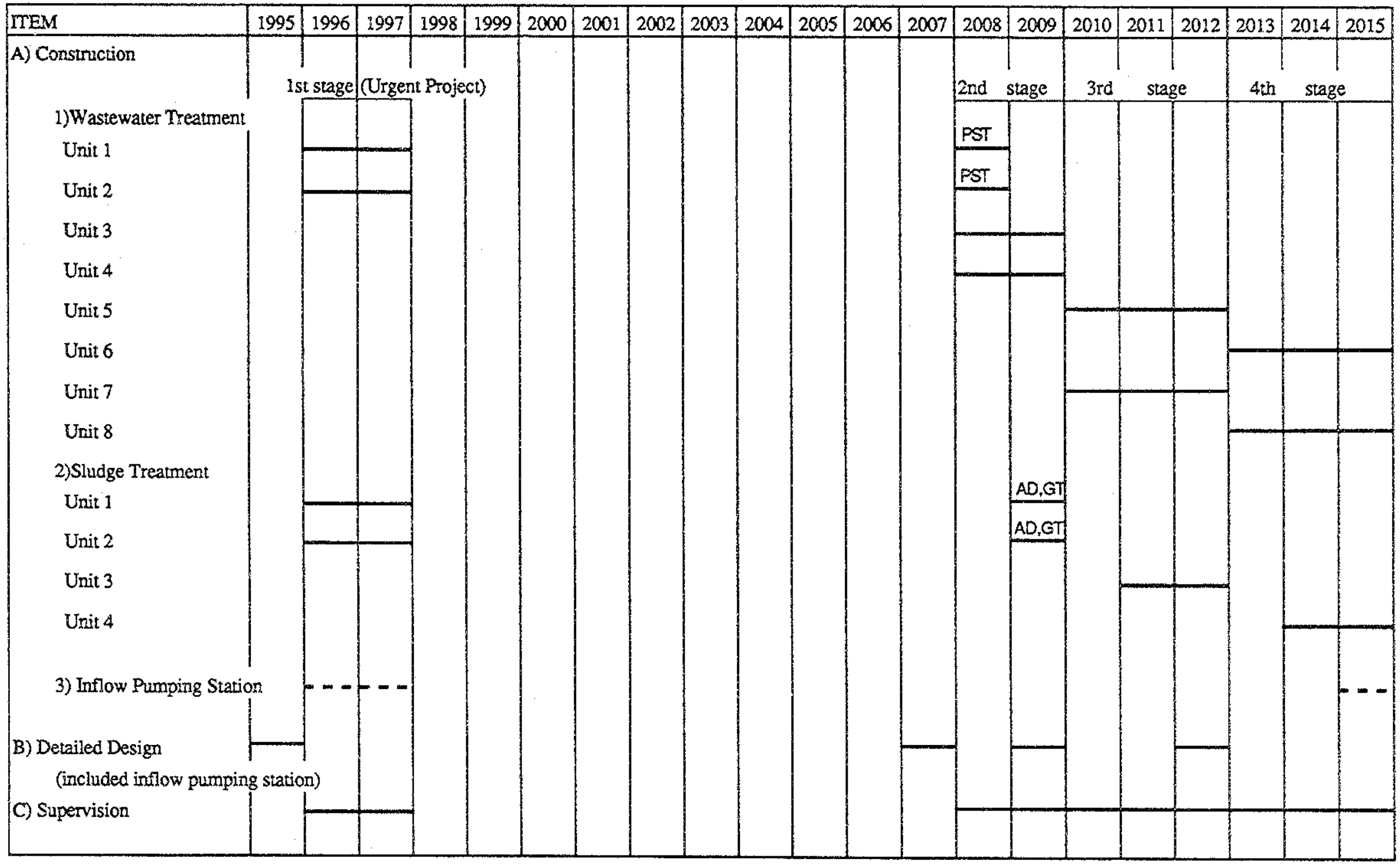
The proposed disbursement schedule is shown in Table H.1.

Table H.1 Disbursement Schedule

(Unit : Million N$)

Item \ Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Direct Construction Cost		557.7	557.7											375.5	375.3	285.4	285.4	285.5	285.4	285.4	285.5	3,578.8
(1) First Stage(Urg. Project)		557.7	557.7																			1,115.4
Wastewater Treatment		251.7	251.7																			503.4
Sludge Treatment		241.0	240.9																			481.9
Building Construction		47.6	47.6																			95.2
Other Works		17.4	17.5																			34.9
(2) Second Stage														375.5	375.3							750.8
Wastewater Treatment														326.4	326.4							652.8
Sludge Treatment														32.4	32.4							64.8
Building Construction														9.6	9.5							19.1
Other Works														7.1	7.0							14.1
(3) Third Stage																285.4	285.4	285.5				856.3
Wastewater Treatment																182.3	182.3	182.4				547.0
Sludge Treatment																78.4	78.3	78.3				235.0
Building Construction																17.6	17.7	17.7				53.0
Other Works																7.1	7.1	7.1				21.3
(4) Fourth Stage																			285.4	285.4	285.5	856.3
Wastewater Treatment																			182.3	182.3	182.4	547.0
Sludge Treatment																			78.4	78.3	78.3	235.0
Building Construction																			17.6	17.7	17.7	53.0
Other Works																			7.1	7.1	7.1	21.3
Land Compensation	115.1																					115.1
Administration Cost		5.6	5.5											3.8	3.7	2.9	2.9	2.8	2.9	2.9	2.8	35.8
Engineering Cost	26.6	6.2	6.2										16.3	5.0	20.0	5.0	5.0	20.0	5.0	5.0	5.0	125.3
Physical Contingency		56.0	55.5											37.6	37.6	28.5	28.5	28.6	28.5	28.5	28.6	357.9
Total	141.7	625.5	624.9										16.3	421.9	436.6	321.8	321.8	336.9	321.8	321.8	321.9	4,212.9

Fig. H.1 Implementation Schedule



NOTE
AD: Anaerobic Digester
GT : Gravity Thickener
PST : Primary Sedimentation Tank
- - - : Designed by Mexican side

APPENDIX I

APPENDIX I EVALUATION OF PROJECT

1. Economic, Social and Environmental Evaluation

1.1 General

At the present moment in the Study Area wastewater collected by the sewerage system is mostly discharged into open channels without treatment and carried to the irrigation areas of the Municipality of Ecapetec in the Mexico State and Tula and Alfajayucan in the Hidalgo State.

In those three (3) areas the untreated wastewater is used by the farmers for irrigation. It has given rise to two major problems among farmers as described below:

a. High incidence of water-borne diseases

b. Restrictions on the kind of crops to be cultivated

The first problem is well known by the persons concerned. Economically it incurs medical costs. Thus, it causes a negative impact not only on the home economy of agricultural households, but also on the economy of the states and the nation by an untoward spending of tax. More generally, it presents a health problem to the farming and other population.

The second problem is economically more serious. It deals a blow to the economy of agricultural households by prohibiting the cultivation of more lucrative cash crops.

If the Project is implemented, above mentioned problems will be removed. In other words medical costs that are spent for the treatment of water-borne disease patients will be drastically reduced, people will get more healthy and farmers will have more income.

1.2 Number of Beneficiaries

The direct party who will benefit from the implementation of the Project is the farming population, that is, agricultural households in the untreated wastewater irrigated areas.

The non-agricultural households in those areas also suffer from water-borne diseases because the diseases are contagious. Therefore, they will too benefit from project implementation. Furthermore, households outside the areas will also be benefited in the same way.

As shown in Table I.1, the number of agricultural households in 1990 is estimated to be 14,939, 11,598 and 1,096 in the irrigation areas of Tula, Alfajayucan and the Municipality of Ecatepec respectively, adding up to 27,633. The average number of members in an agricultural household is estimated to be 5.62. The total number of non-agricultural households in the three areas is found to be 284,702 in the year 1990. There is no way at the present moment to estimate the number of households outside the three areas.

1.3 Reduction of Water-Borne Diseases

1.3.1 Results of Sampling Questionnaire Surveys

JICA Study Team conducted sampling questionnaire surveys to compare the incidence of water-borne diseases in the untreated wastewater irrigated areas with the treated wastewater irrigated areas, in order to eventually arrive at the estimation of project benefits.

The areas surveyed are the irrigation areas of Tula, the Municipality of Ecatepec and the Delegations of Tlahuac and Xochimilco in the Federal District. The irrigation area of Alfajayucan was not surveyed because the area is adjacent to the irrigation area of Tula and it is assumed that the results of the survey in Tula can be applied to Alfajayucan. Tlahuac and Xochimilco have been selected since irrigation is practiced there using treated wastewater. The number of samples surveyed are 70 for Tula, 30 for Ecatepec, 30 for Tlahuac and 40 for Xochimilco, totaling 170 on agricultural household basis.

Water-borne diseases considered include malaria, diarrhea, dysentery, cholera, typhoid, para-typhoid, gastro-enteritis, dengue fever, tuberculosis, diphtheria, measles and hepatitis A & B. Besides them parasitic and skin diseases are considered as important water related diseases.

It has been revealed that the average annual incidence of water-borne diseases is 0.7241 case per household in the untreated wastewater irrigated areas, while 0.0755 in the treated wastewater irrigated areas (Refer to Table I.2.). In the same way, the average annual incidence of water related diseases is 0.5591 case per household in the untreated wastewater irrigated areas, while 0.0781 in the treated wastewater irrigated areas. Combining the water-borne and water related diseases, the average annual incidence is 1.2832 cases per household in the untreated wastewater irrigated areas, while 0.1536 in the treated wastewater irrigated areas, the difference is about 1.1296.

The major reason of the difference is whether one uses treated wastewater or untreated wastewater for irrigation. However there seem to be other reasons also. In the untreated wastewater irrigated areas of Tula, Alfajayucan and Ecatepec the average service ratios of water and sewerage are 77.4% and 64.5% respectively, while in the treated wastewater irrigated areas of Tlahuac and Xochimilco they are 100% and 81.0% respectively according to the sampling questionnaire surveys. These differences in the service ratios of water and sewerage in the two areas appear to be also related to the difference of incidence. However, to make matters simple it is assumed that the first reason is the only reason of the difference in the incidence of water-borne and water related diseases.

The two diseases with the high incidence in the untreated wastewater irrigated areas are diarrhea with the average annual incidence of 0.5054 case per household and parasitic diseases with 0.3871.

1.3.2 Reduction of Medical Costs

It has been observed from the sampling questionnaire surveys that the annual reduction of water-borne and water related diseases is 1.1296 cases per household. The household considered are agricultural household. The number of agricultural households in the untreated wastewater irrigated areas in 1990 are estimated to be 27,633. The number of agricultural households are assumed to be the same from 1990 onward.

Multiplying 27,633 by 1.1293 one gets 31,206, which is the annual number of water-borne and water related disease cases in the agricultural households to be reduced by project implementation.

Based on the information and data collected from Servicios Coordinados de Salud Publica in the Hidalgo State it is estimated that the average medical costs of water-borne and water related diseases are N$ 74.3 per case. This is the amount which is actually incurred including consultation, medicine, hospitalization - in rare serious cases - and indirect costs. It is not the amount paid by the patients who are protected by the social security system.

Multiplying 31,206 by N$ 74.3 one gets N$ 2.3 million, which is the annual amount of medical costs which could be saved from the agricultural households in the untreated wastewater irrigated areas by project implementation.

At the present moment, there is no way to estimate the saving of medical costs for the non-agricultural households in the untreated wastewater irrigated areas and also for the households in the surrounding areas.

1.4 Increase of Agricultural Products

1.4.1 Results of Sampling Questionnaire Surveys

JICA Study Team conducted sampling questionnaire surveys to know the kinds of crops farmers cultivate, the average annual agricultural income per household, the average cultivated area per household, etc. in the untreated wastewater and treated wastewater irrigated areas. The number of samples is already mentioned in the preceding section.

Results show that maize and alfalfa are the two (2) major crops in the untreated wastewater irrigated areas. It is also noted that vegetables such as lettuce, onion and carrot are among the ten (10) major crops in the untreated wastewater irrigated areas in spite of the fact that their cultivation is not allowed. The restrictions on the kinds of crops to be cultivated were introduced in 1992. Respondents who answered that they knew it were 68.9%. While in the treated wastewater irrigated areas vegetables such as lettuce, spinach, cauliflower, carrot and cabbage, and flowers are predominantly cultivated (Refer to Table I.3).

The kinds of crops farmers in the untreated wastewater irrigated areas want to cultivate, when wastewater is treated, are mostly vegetables represented by lettuce, onion, carrot, etc. These are not exactly the same as those being cultivated in the treated wastewater irrigated areas now, but essentially similar in the aspect that lettuce occupies the No. 1 position, carrot occupies an important place and, generally, vegetables are predominant.

The average annual agricultural income and the average cultivated area per household in the untreated wastewater irrigated areas were calculated to be N$ 10,225 and 4.90 ha respectively, while in the treated wastewater irrigated areas found to be N$ 5,667 and 2.24 ha respectively. (Refer to Table I.1.)

If 4.9 ha of area is irrigated by treated wastewater the annual agricultural income per household will be N$ 12397. In other words an additional income of N$ 2172. It holds true only when farmers cultivate the same kinds of crops after project implementation as those in Tlahuac and Xochimilco. It holds true only when there is no difference in the costs of input per ha between the two areas. Again, it holds true only when climatic conditions, land productivity, prices of crops, etc. are the same between the two areas. To make matters simple it is assumed that all of them are not much different.

1.4.2 Increase of Agricultural Income

The number of agricultural households in the untreated wastewater irrigated areas is estimated at 27,633 in 1990. It is assumed that the number does not increase, nor decrease from the year onward. An agricultural household in those areas is assumed to earn an additional amount of N$ 2,172 on average per annum when it cultivates vegetables using treated wastewater. In other words N$ 60.0 million is the annual incremental amount of agricultural income expected in the untreated wastewater irrigated areas after project implementation.

1.5 Economic Evaluation

1.5.1 Quantitative Evaluation

From the preceding sections, there are two project benefits, namely, reduction of medical costs and increase of agricultural income. These benefits are estimated to be N$ 2.3 million and N$ 60.0 million respectively, adding up to N$ 62.3 million. To convert them into economic values one applies the standard conversion factor of 0.9633 (refer to Table I.4) and gets N$ 60.0 million.

The O/M costs of the Urgent Project is estimated to be N$ 83.7 million and for the Final Project is N$ 200.4 million. By applying the standard conversion factor of 0.9633, one gets the economic O/M costs of N$ 80.6 million and N$ 193.0 million for the Urgent and Final Project respectively.

The initial costs of the Urgent and Final Projects are estimated at N$ 1,392.1 million and N$ 2,820.8 million respectively, summing up to 4,212.9 million. The economic initial costs of the two projects work out at N$ 1,350.4 million and N$ 2,726.9 million respectively, adding up to N$ 4,077.3 million.

Hence it is apparent that the benefits neither cover the initial costs nor the O/M costs. Indeed, benefits can meet only about one thirds of O/M costs.

1.5.2 Justification of the Project

As described in the preceding quantitative evaluation, the direct beneficiaries of the Project are the agricultural households whose number is estimated at no greater than 27,633. It is equivalent to the population of 155,297.

The Project is the construction of a gigantic wastewater treatment plant at Texcoco, the number of potential domestic clients coming to 2,448,257 households in 1993. It is equivalent to the population of 12,192,300. It is obvious that the enormous costs be incurred since the plant will treat the wastewater generated by such a big population.

It is also obvious that the benefits are limited because polluters and beneficiaries are not one and the same, and the number of beneficiaries are very small compared with that of polluters.

This is the reason that it is difficult to arrive at the affirmative conclusion in quantitative terms regarding the economic feasibility of the Project. And long-term viewpoint is required to discuss the justification of the Project.

The current administration has initiated the modernization drive in the political, economic and social spheres of the nation. In connection with the Project the administration stressed the importance of environmental protection. And the Law of National Water was enforced and the role of CNA was provided in the law. Through such institutional measures the objective is to protect, preserve and improve water quality in hydraulic basins and aquifers of the nation and the use of wastewater must comply with the quality standards of water.

The Project must be viewed in the context of the national environmental protection policy.

2. Financial Evaluation

2.1 Analysis of Water Price in the Study Area

2.1.1 Analysis of Current Water Price (1993)

It is estimated that the annual volume of water served in 1993 was 779.3 million m^3 in the Federal District and 323.3 million m^3 in the Mexico State. The number of households served with water in the same year are estimated to be 1,703,119 and 908,814 in the Federal District and Mexico State respectively. Thus the monthly volume of water consumed per household was on average 38.1 m^3 in the Federal District and 29.6 m^3 in the Mexico State. (Refer to Table I.5.)

Based on the ratio of the volume of water consumed by domestic clients, the monthly volume of domestic water consumed on average per household is calculated to be 26.0 m^3 in the Federal District and 20.5 m^3 in the Mexico State.

At present a household is estimated to pay water supply charge on average per month N$ 20.85 in the Federal District and N$ 17.92 in the Mexico State. Hence the price of domestic water per m^3 is estimated to be N$ 0.802 in the Federal District and N$ 0.874 in the Mexico State.

Based on the existing water tariffs for domestic and non-domestic clients on one hand and the ratios of the volume of water consumed by the two divisions of clients on the other, the price of water per m^3 is estimated to be N$ 1.056 in the Federal District and N$ 1.142 in the Mexico State.

2.1.2 Estimation of Water Price Fully Covering O/M Costs

The O/M costs for DGCOH (budget) and the Mexico State - the Study Area - (estimation) were something like N$ 1,217 million and N$ 240 million respectively in 1993.

The volume of water served in the same year is estimated to be 779.3 million m^3 in the Federal District and 323.3 million m^3 in the Mexico State.

The collection rate of water bills in 1992 was 60.0% in the Federal District and 59.6% in the Mexico State.

Supposing the revenue from water supply is to be fully covered by the O/M costs, then it follows from the above that the price of water per m^3 would have been N$ 2.603 in the Federal District and N$ 1.246 in the Mexico State.

Using the existing water tariffs for domestic and non-domestic clients on one hand and the ratios of the volume of water consumed by the two divisions of clients on the other, the price of domestic water per m^3 covering the O/M costs is estimated to be N$ 1.976 in the Federal District and N$ 0.953 in the Mexico State.

Supposing that the collection rate of water bills will be 85% in both the Federal District and the Mexico State and also the O/M costs in the Mexico State will go up by 50% in future, the price of water per m^3 fully covering the O/M costs will be N$ 1.837 in the Federal District and N$ 1.310 in the Mexico State. Likewise, the price of domestic water per m^3 covering the O/M costs, will be N$ 1.395 in the Federal District and N$ 1.002 in the Mexico State.

2.2 People's Willingness to Pay

2.2.1 Results of Sampling Questionnaire Surveys

JICA Study Team conducted sampling questionnaire surveys to find out the amount which people in the Study Area are willing to pay for sewerage service and water supply, household income, water payment, etc.

Beneficiaries were classified into households, commerce and institutions. The number of samples for households totaled 372. The number of samples for commerce and institutions was 116 and 114 respectively. The surveys covered all the Delegations and Municipalities of the Study Area. Households were classified into three (high, middle and low) income classes.

The results of the surveys for commerce and institutions were eventually not used due to imperfect factors that were observed regarding the answers of respondents.

As a result of the surveys it was revealed that the monthly amount a household is on average willing to pay for both water supply and sewerage service is N$ 61 in the Federal District and N$ 49 in the Mexico State (Refer to Table I.6 (1)). Out of which, the percentage of payment for water supply was on average 61.6% in the Federal District and 57.9% in the Mexico State. Hence, the percentage of payment for sewerage service was on average 38.4% in the Federal District and 42.1% in the Mexico State.

For the sake of planning the shares of payment for water supply and sewerage service were assumed to be 60% and 40% respectively in both the Federal District and the Mexico State.

Hence the monthly amount a household is on average willing to pay for water supply is N$ 36.6 in the Federal District and N$ 29.4 in the Mexico State. Similarly, the monthly amount a household is on average willing to pay for sewerage service is N$ 24.4 in the Federal District and N$ 19.6 in the Mexico State.

2.2.2 Willingness to Pay as Percentage of Household Income

It is estimated as a result of the sampling questionnaire surveys that the monthly household income is on average N$ 4,530 in the Federal District and N$ 2,421 in the Mexico State.

From the forgone discussions the average willingness to pay for water supply as percentage of household income works out at 0.81% in the Federal District and 1.21% in the Mexico State. Similarly, the average willingness to pay for sewerage service as percentage of household income comes to 0.54% in the Federal District and 0.81% in the Mexico State.

As discussed in the previous sections, at present a household is estimated to pay water supply charge on average per month N$ 20.9 in the Federal District and N$ 17.9 in the Mexico State. In other words, the current water supply charge as percentage of household income is on average 0.46% in the Federal District and 0.74% in the Mexico State. (Refer to Table I.6 (2)).

It is noted that the households' willingness to pay for water supply is greater than the current domestic water supply charge by 75% in the Federal District and by 64% in the Mexico State.

Supposing the water tariffs are revised in future so as to fully recover the O/M costs of water organizations, the average monthly water supply charge per household will be N$ 36.3 in the Federal District and N$ 20.5 in the Mexico State. In other words, the planned water supply charge as percentage of household income is on average 0.80% in the Federal District and 0.85% in the Mexico State.

2.2.3 Willingness to Pay per m^3

The monthly volume of domestic water consumed by a household is estimated to be on average 25.5 m^3 in the Federal District and 20.5 m^3 in the Mexico State. The monthly amount a household is on average willing to pay for water supply and sewerage service is already mentioned in section 2.1.1. One now divides the monthly willingness to pay by the monthly domestic water consumption. Then, households' average willingness to pay for both water supply and sewerage service per m^3 of domestic water works out to be

N$ 2.392 in the Federal District and N$ 2.390 in the Mexico State (Refer to Table I.6 (2)). Also, households' average willingness to pay for water supply per m^3 of domestic water works out to be N$ 1.435 in the Federal District and N$ 1.434 in the Mexico State.

Based on the existing water tariffs for domestic and non-domestic clients on one hand and the ratios of the volume of water consumed by the two divisions of clients on the other, beneficiaries' average willingness to pay for water supply per m^3 of water is estimated to be N$ 1.890 in the Federal District and N$ 1.874 in the Mexico State.

Further, households' average willingness to pay for sewerage service per m^3 of domestic water works out at N$ 0.957 in the Federal District and N$ 0.956 in the Mexico State.

Based on the existing water tariffs for domestic and non-domestic clients on one hand and the ratios of the volume of water consumed by the two divisions of clients on the other, beneficiaries' average willingness to pay for sewerage service per m^3 of water is estimated at N$ 1.260 in the Federal District and N$ 1.249 in the Mexico State.

2.3 Proposed Sewerage Charge

As a result of sampling questionnaire surveys it was revealed that the beneficiaries are on average willing to pay for sewerage service per m^3 of wastewater N$ 1.260 in the Federal District and N$ 1.249 in the Mexico State.

The sewerage service charge per m^3 of wastewater under the proposed plan is N$ 0.605 for the Federal District and N$ 0.600 for the Mexico State, which amounts to 48% of what beneficiaries are willing to pay. This is the ultimate price, meaning that the price will be applied from 2016, the year immediately following the completion of the Final Project.

From 1998, the year immediately following the completion of the Urgent Project up to 2015 when the Final Project will be completed it is proposed that the sewerage service charge per m^3 will be N$ 0.378 for the Federal District and N$ 0.375 for the Mexico State. They are 30% of what beneficiaries are willing to pay.

The reasons why the proposed sewerage service charge is below what beneficiaries agree to pay are mentioned below:

- the enormous costs that have been invested for the construction of sewerage facilities in the Study Area for many years up to the present are not incorporated in the charge

- the O/M costs of the existing sewerage facilities are not included in the charge.

The proposed combined water supply and sewerage service charge per m^3 is shown below.

Year	Combined Water supply and Sewerage Charge per m^3	
	Federal District	Mexico State
1998-2015	N$ 2.215 (1.837 + 0.378)	N$ 1.685 (1.310 + 0.375)
2016 onwards	N$ 2.442 (1.837 + 0.605)	N$ 1.910 (1.310 + 0.600)

2.4 Financial Analysis

2.4.1 Project Costs, Financial Resources, Lending Terms and Establishment of Alternatives

1) Project Costs

The initial costs of the Project are estimated to be N$ 1,392.1 million for the Urgent Project and N$ 2,820.8 million for the Final Project, totaling N$ 4,212.9 million.

The annual O/M costs are estimated at N$ 83.7 million after the completion of the Urgent Project and N$ 200.3 million after the completion of the Final Project.

2) Financial Resources and Lending Terms

DGCOH envisages that the Project will be fully financed by the external resources. JICA Study Team expected four (4) alternatives of external lending agencies and the lending terms of the four (4) agencies at the present moment are as follows:

External Agency	Annual Interest Rate	Repayment Period	Grace Period
A	5.25 %	15 years (maximum)	construction period
B	5 %	25 years	7 years
C	7.4 %	20 years	5 years
D	7.3%	15 years	3 years

The interest rate of external agency A, 5.25 % is derived from LIBOR + 0.25 %. LIBOR is now around 5 %. This is the dollar loan rate.

The loan from external agency B will be lent and repaid in the yen. The loan from external agency C is dollar loan rate. One third of the loan from external agency D will be lent and repaid in the yen.

BANOBRAS is the intermediary agency for receiving international loans. DDF will get the loan for the project by way of the Bank. In transferring the loan to DDF the bank will add an annual interest rate of 0.25 % for the first five years of repayment and 0.125 % from the sixth year onwards as commission charge. That is to say, DDF will ultimately pay the annual interest rate of an external lending agency plus the commission charge of BANOBRAS.

3) Establishment of Alternatives

It is assumed by JICA Study Team that the Mexican government will ask the loans from external agency A for one hundred percent of the initial costs required. This is the proposed alternative for financing this project.

In Alternative I it is assumed that external agency B will provide the loan for 60% of the initial costs of the Project and the balance of 40% will be borrowed from external agency C. Under Alternative II it is assumed that the external agency C will fully finance the Project. Under Alternative III the financial resources of the Project will fully come from the external agency D.

2.4.2 Preconditions and Assumptions

Before embarking on financial analysis the following preconditions and assumptions were established:

1) Full recovery of costs

Initial costs, O/M costs, repayment costs and replacement costs will be fully recovered.

2) Depreciation period

Facilities	:	30 years
Electro-mechanical equipment	:	15 years

3) Period of projection: : 30 years

4) Rate of tax on corporate income : 50%

5) Collection efficiency of bills : 85%

The above will be applied to the Proposed alternative, Alternatives I, II and III.

6) Sewerage Service Charge

Sewerage service charge will be established for the respective alternatives as follows:

(Unit: N$/m^3)

Alternatives	Sewerage Service Charge (/m^3)			Sewerage Service charge (/month/household)
	1998 to 2007	2008 to 2015	from 2016 onward	from 2016 onwards
Proposed Alternative				
Federal District	0.378	0.378	0.605	11.9
Mexico State	0.375	0.375	0.600	9.4
Alternative I				
Federal District	0.252	0.441	0.567	11.2
Mexico State	0.250	0.437	0.562	8.8
Alternative II				
Federal District	0.315	0.441	0.630	12.4
Mexico State	0.312	0.437	0.625	9.8
Alternative III				
Federal District	0.378	0.441	0.630	12.4
Mexico State	0.375	0.437	0.625	9.8

The above table indicates that there is not a markedly wide difference in the sewerage service charge among the four alternatives and also that the sewerage service charge itself is generally not a heavy one, accounting for 0.25 % to 0.27 % of the household income in the Federal District and 0.36 % to 0.40 % of the household income in the Mexico State.

Therefore, it will not be reasonable to determine the priority order between the alternatives based on the level of sewerage service charge.

2.4.3 Financial Analysis

1) Projection of financial statements

Under the above listed preconditions and assumptions, the projection of financial statements including the income statement and funds statement was performed for the proposed wastewater treatment plant.

The projected financial statements for the Proposed Alternative, Alternative I, Alternative II and Alternative III are shown in Tables I.7, I.8, I.9 and I.10. Fig. I.1 graphs some important aspects of the financial statement for the proposed alternative.

It is evident that the wastewater treatment plant will be financially sound and stable in terms of earnings as well as solvency during the projection period of 30 years for all the alternatives.

2) Estimation of Financial Internal Rate of Return

The cost benefit streams were prepared for 30 years to estimate financial internal rate of return (FIRR) for the four alternatives as shown in Tables I.11, I.12, I.13 and I.14.

Using the tables, FIRR was calculated to be:

13.3 %	for Proposed Plan
8.3 %	for Alternative I
11.4 %	for Alternative II
14.3 %	for Alternative III.

FIRR for each alternative is greater than the annual interest rates of the loan plus the commission charge of BANOBRAS for the respective alternative. Thus, all the four alternatives are judged to be financially feasible.

It is to be reminded that in this case one cannot compare FIRR of the alternatives to determine the priority order of the alternatives because costs concerned are the same for all the alternatives. A higher FIRR means a greater revenue and a greater revenue in turn means a higher sewerage service charge. Under such circumstances what is relevant and meaningful is to compare the FIRR with the annual interest rate of the loan plus the BANOBRAS commission charge regarding a particular alternative

3) Repayment Costs

The total amount of repayment including principal and interest for the four alternatives has been calculated at the present value. In calculating the present value of repayment, firstly the opportunity cost of capital (OCC) was assumed as 10% (repayment costs at present value (1)). Secondly, in addition to the above it was assumed that the exchange rate of the yen against the dollar would appreciate at the annual rate of 5 % in future (repayment costs at present value (2)). The value of repayment should be expressed in the US dollars. But, for the sake of convenience it has been presented in N$ on the premise that the current exchange rate of the US dollar to N$ is fixed. The results are shown below:

(Unit : N$ Million)

Alternatives	Initial Costs at 1994 Prices	Repayment Costs at Current Prices	Repayment Costs at Present Value (1)	Repayment Costs at Present Value (2)
Proposed Plan	4,212.9	6,954.6	3,402.8	3,402.8
Alternative I	4,212.9	9,745.7	3,299.2	4,729.9
Alternative II	4,212.9	10,352.3	3,991.3	3,991.3
Alternative III	4,212.9	8,104.2	3,965.2	4,549.2

The table indicates that supposing the yen currency does not appreciate vis-a-vis the US dollar in future, then the sewerage organization's financial obligations will be lighter in the order of Alternative I, Proposed Plan, Alternative III and Alternative II. And also it is evident that if the yen appreciates vis-a-vis the US dollar at the annual rate of 5 % in future, then the sewerage organization's financial obligations will be lighter in the order of Proposed Plan, Alternative II, Alternative III and Alternative I.

The Proposed Plan is favored by JICA Study Team because the amount of the repayment will be the lowest, taking every condition into