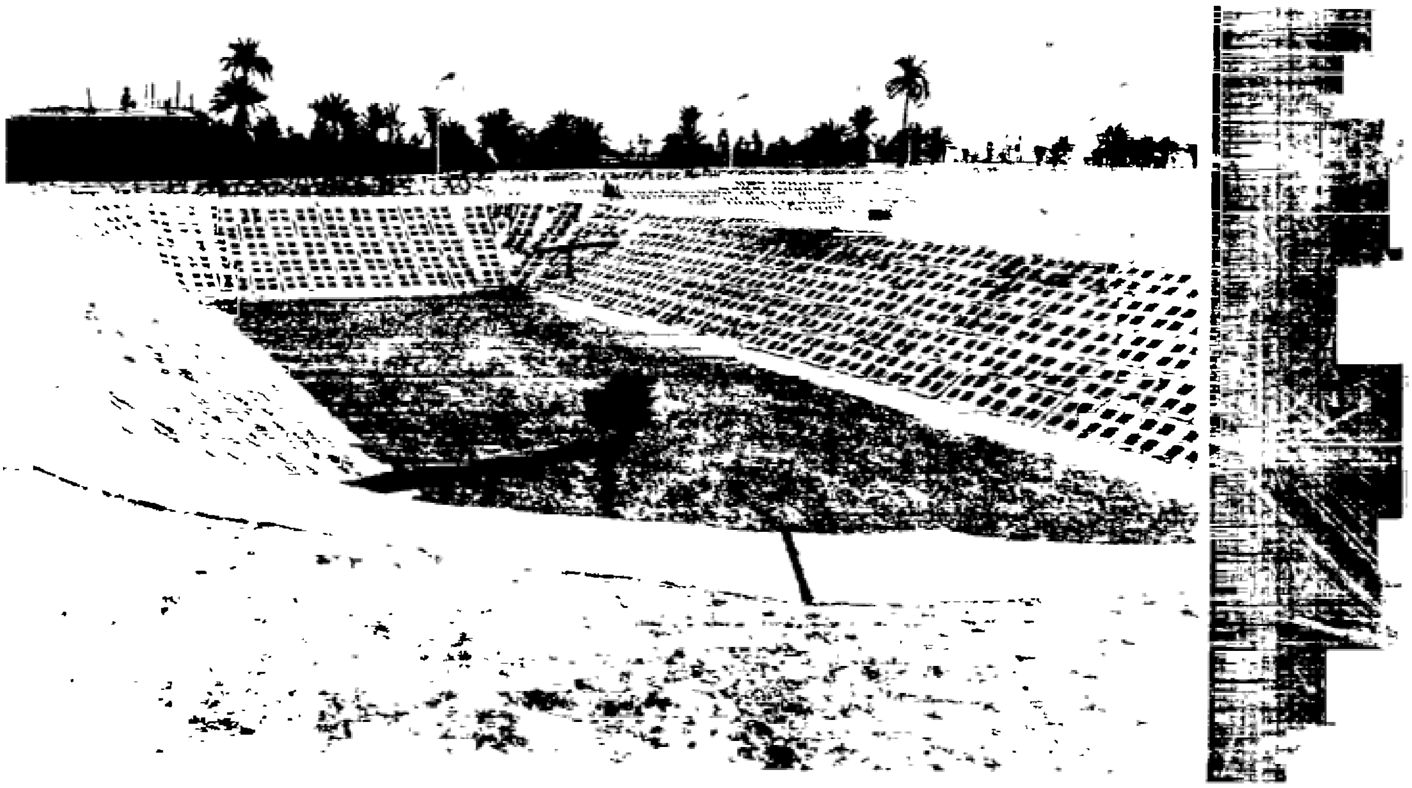
WHO ORDEV UNDP UNICEF

**DRINKING WATER SUPPLY AND SANITATION
SECTOR SUPPORT PROJECT IN EGYPT**

(UNDP: EGY/82/002 WHO: EGY/CWS/001)

DESIGN AND CONSTRUCTION, OPERATION AND MAINTENANCE AND PERFORMANCE MONITORING OF EL NAZLAH PONDS



WORLD HEALTH ORGANIZATION
Regional Office for the Eastern Mediterranean
Alexandria
1992

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DESIGN AND CONSTRUCTION, OPERATION AND MAINTENANCE AND PERFORMANCE MONITORING OF EL NAZLAH SEWAGE TREATMENT PLANT

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In the name of God, the Compassionate, the Merciful

FOREWORD

I am pleased to have the opportunity of contributing a foreword to this series of two booklets compiled on the design and construction of two different types of wastewater treatment ponds implemented in Egypt.

Booklet 1: Design and construction, operation and maintenance and performance monitoring of Mit Mazah aerated ponds, Daqahliya Governorate, Egypt.

Booklet 2: Design and construction, operation and maintenance and performance monitoring of El Nazlah stabilization ponds, Fayoum Governorate, Egypt.

These booklets describe the preliminary and other supporting studies, design criteria, final designs with bills of quantities and costs, construction drawings, operational control problems and solutions and performance monitoring of the treatment processes.

The World Health Organization as the executing agency of the International Drinking Water Supply and Sanitation Decade (1981-1990) Programmes, pursued the task of promotion of decade approaches in Egypt, under the Organization of Reconstruction and Development of Egyptian Villages (ORDEV) of the Government of Egypt, UNDP, UNICEF project "Drinking Water Supply and Sanitation Sector", with the financial support of these agencies. The approaches used call for complementarity of sanitation with drinking water, together with the involvement of communities in the planning and execution of the projects, leading to the utilization of appropriate technologies and training of personnel in operation and maintenance of drinking water and sanitation systems. This project covered both software and hardware aspects and, with its intersectoral approaches, has achieved considerable success in rural Egypt.

In many rural areas of Egypt, disposal of wastewater and its treatment are not adequate. Wastewater is usually discharged into drains and canals, which affects the quality of surface as well as ground waters and results in serious pollution of water resources. It also leads to increased prevalence of communicable diseases, especially typhoid, dysenteries, infective hepatitis and schistosomiasis.

A few stabilization ponds had been established in Egypt before this project was implemented. However, the technology adopted in the design and construction of those ponds is not fully in line with recent research and development. Not only this, the lack of proper operation and maintenance of these ponds has made them almost redundant.

WHO has, therefore, carefully selected the most cost-effective, affordable wastewater treatment systems, more efficient in removal of pathogens, with less construction and operation and maintenance costs for rural Egypt, with the expectation of further replication. Treatment including an aerated pond has been constructed at Mit Mazah, Daqahliya Governorate, which takes up a smaller area, compared with that of the other system adopting "stabilization ponds", implemented at El Nazlah, Fayoum Governorate. These pond systems are regarded as representing self-reliant and self-sustaining technology and are considered most appropriate for rural areas.

Furthermore, I would like to place on record the fact that, in some countries in our Region, wastewater treatment plants, though well-designed and constructed, sometimes cease to function efficiently, mainly due to lack of operation and maintenance resources, including trained personnel. We trust that it will not be the case in Egypt and the authorities will initiate the necessary action for first-rate operation and maintenance of these pond systems.

We also believe that waste stabilization ponds' treatment technology is suitable for replication not only in rural Egypt, but in other countries of the Eastern Mediterranean Region as well.

These booklets have been compiled so that this important technology can be adapted to produce suitable designs and operating protocols which will be applicable after slight modifications as required to suit local conditions.

I trust that the booklets will do much to raise the general awareness of this highly appropriate technology and arouse interest in Member States of the Eastern Mediterranean Region and elsewhere in the development of sustainable sanitation programmes in rural areas.

Hussein A. Gezairy, M.D., F.R.C.S.
Regional Director

ACKNOWLEDGEMENTS

The World Health Organization's Eastern Mediterranean Regional Office EMRO acknowledges with gratitude the work undertaken by the following, who assisted in preparing the preliminary and final designs, and also the efforts of those who compiled and reviewed the draft.

Special thanks are owed to Prof. M.B. Pescod who prepared the basic designs of the stabilization ponds, prepared operation and maintenance and monitoring manuals and also edited the drafts and provided useful assistance in the finalization of these booklets.

Prof. M.B. Pescod	Head, Department of Civil Engineering, University of Newcastle upon Tyne, Newcastle upon Tyne, UK
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Dr. I. Hespanhol	Sanitary Engineer, WHO/HQ, Geneva
Dr. M.I. Sheikh	Director Environmental Health, Regional Office for the Eastern Mediterranean, Alexandria, Egypt
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1. INTRODUCTION

1.1 Stabilization Pond Treatment in Egypt

Before the El Nazlah Sewage Treatment Plant Project was implemented, there were few wastewater stabilization ponds operating in Egypt. Some are located in the South of Sinai Governorate and are in operation in the cities of Sharm El Sheikh, Dahab and in Noweiba. These ponds were constructed after the 1967 war and, unfortunately, there are no available data to indicate their design basis or performance record. In general, these pond systems comprise an anaerobic pond followed by a facultative stabilization pond.

Over the past eight years, some waste stabilization ponds have also been constructed in the newly planned cities, such as Tenth of Ramadan and Sadat City. The performance of these ponds is unsatisfactory as a result of the adoption of unsuitable design criteria and lack of operation and maintenance back-up support. At Tenth of Ramadan City, the embankments of the ponds have settled, due to poor construction, and this has resulted in leakage of wastewater. The whole surface of the ponds is also covered with a heavy growth of reeds, up to two metres high, due to lack of regular maintenance. Hardly any water surface is exposed and, consequently, the ponds are completely anaerobic and cause severe environmental health problems, with the emission of obnoxious odours and propagation of insects.

Similarly, the ponds at Sadat City have been grossly over designed for the present population and, with the unnecessarily large surface area and high evaporation rate, there is no effluent flow. The ponds simply act as evaporative lagoons and now serve as a habitat for animals and birds.. In addition, extensive use of bitumen in lining the embankments of the ponds has given rise to bleeding of the bitumen due to the hot weather conditions in Egypt. This has inhibited algal growth and photosynthesis in many areas.

Waste stabilization ponds are no longer a novelty. Considerable design and operating experience has accumulated over the past two decades so as to allow engineers to adopt them as the simplest and most reliable means of wastewater treatment, at a cost lower than conventional wastewater treatment plants used hitherto.

The technology for design and construction of wastewater stabilization ponds, in line with recent research and developments, has neither been fully developed nor encouraged in Egypt. Perhaps due to the poor performance of existing ponds, caused by inappropriate designs and lack of operation and maintenance, the authorities and designers have been afraid to adopt this technology in Egypt. This has been the case, despite the fact that ponds are widely acknowledged to be the most suitable form of wastewater treatment in warm developing countries and are known to be a particularly robust, almost fail-safe, treatment system with low construction and operating costs, requiring little or no equipment and are considered to be more efficient and effective in removing helminths, pathogenic bacteria and viruses than conventional treatment processes. A well-designed and properly-operated and maintained series of stabilization ponds can achieve essentially total removal of helminths.

The characteristics and efficiencies of removal of pollutants and pathogens by various wastewater treatment processes, also their advantages and disadvantages, are given in Table 1.1 (adapted from Arthur, 1983). This clearly indicates the benefits to be gained by adopting stabilization pond treatment of wastewaters where land is available and of reasonable cost.

In the context of the International Drinking Water Supply and Sanitation Decade (IDWSSD), 1981-1990, and the grave situation of sanitation coverage in Egypt, UNDP/WHO/UNICEF initiated a joint collaborative project with the Egyptian Government, starting in 1987. This collaborative project included extensive training on the planning, design, operation and maintenance of water and sanitation systems, coupled with construction of demonstration waste stabilization ponds.

The demonstration waste stabilization ponds (anaerobic + facultative + maturation ponds) have been constructed where land was available and the demonstration aerated pond plant introduced where availability of land was limited. WHO carefully selected these most cost-effective wastewater treatment systems, with greater efficiency in removal of pathogens and with less construction and operation and maintenance costs, for rural Egypt and for further replication. The aerated pond treatment plant has been constructed at Mit Mazah, Daqahliya Governorate and takes up a smaller area than the stabilization ponds plant constructed at El Nazlah, Fayoum Governorate. These pond systems are regarded as representing self-reliant and self-sustaining technology and are considered most appropriate for rural areas of developing countries.

Effluent from the final maturation pond at Mit Mazah is discharged to the nearby drainage canal while the effluent from anaerobic, facultative and maturation ponds at El Nazlah is given further treatment in pilot macrophyte ponds. The experimental macrophyte ponds have been incorporated into the plant with a view to evaluating their operating complexity, their efficiency, the effluent quality produced and the best locally available species of macrophyte plants.

Among possible species of floating macrophytes are water hyacinth, water lettuce and duckweed, whereas reeds, bull rushes and cane are potential forms of emergent macrophytes. The choice between floating and emergent macrophytes will be determined on the basis of an evaluation of the data collected, particularly in respect of operating complexity and harvesting cost and an economic and market analysis of the utilization of harvested macrophytes as a by-product for animal feed, together with an assessment of associated environmental health impacts.

1.2 El Nazlah Stabilization Ponds Sewage Treatment Plant

El Nazlah village, with a present population circa 10,700, is situated about 40 km west of Fayoum city. The site of the stabilization ponds sewage treatment plant is 1.8 km south of El Nazlah village.

TABLE 1.1 ADVANTAGES AND DISADVANTAGES OF VARIOUS WASTEWATER TREATMENT SYSTEMS

Criteria	Package Plant	Activated Sludge Plant	Trickling Filter	Extended Aeration Plant	Oxidation Ditch	Aerated Lagoon System	Waste Stabilization Pond System (including anaerobic units)	Waste Stabilization Pond System (excluding anaerobic units)
BOD_5 Removal	**	**	**	**	***	***	***	***
FC Removal	*	*	*	**	**	***	***	***
SS Removal	**	***	***	***	***	**	**	**
Helminth Removal	*	**	*	*	**	**	***	***
Virus Removal	*	**	*	**	**	***	***	***
Ancillary Use Possibilities	*	*	*	*	*	***	***	***
Effluent Reuse Possibilities	*/a	*/a	*/a	**	**	***	***	***
Simple and Cheap Construction	*	*	*	*	**	**	***	***
Simple Operation	*	*	**	*	**	*	***	***
Land Requirement	***	***	***	***	***	**	**	*
Maintenance Costs	*	*	**	*	*	*	***	***
Energy Demand	*	*	**	*	*	*	***	***
Minimization of sludge for removal	*	**/b	**/b	**/b	*	**	***	***

a/ The effluents from activated sludge, trickling filter and package plants frequently have high ammonia levels (>5mg/l) and fecal bacterial concentrations, and are usually not suitable for irrigation or fish farming without tertiary treatment.

b/ Assumes provision of sludge digesters.

Key: ***good; ** fair; * poor.

Source: Arthur (1983)

The groundwater level at the village was very high in certain areas and, as a result, the groundwater was polluted due to the absence of a sewerage system in the village. Since availability of land was no problem, the chosen system for sewage treatment was stabilization ponds.

1.2.1 El Nazlah System Description

i) The sewerage system consists of:

250, 200 and 160 mm PVC pipes of about 9500 m total length.

ii) The ponds system consists of:

- Inlet chamber 1.10 m in length, fitted with a screen bar
- Two anaerobic ponds in parallel, followed by
- One large facultative pond, followed by
- One maturation pond
- Two experimental macrophyte ponds are included in the design, one to receive effluent from the anaerobic pond and the other to receive effluent from the facultative pond.

The objective in establishing the macrophyte ponds was mainly to carry out experiments under local conditions so as to evaluate the performance of these ponds and make recommendations on their potential for use in the future. The surface areas at mid-depth and total water depths of the various ponds are as follows:

	Area	Water Depth
- Two anaerobic ponds	1000 m^2	depth 4.0 m
- One facultative	6800 m^2	depth 1.6 m
- One maturation pond	1300 m^2	depth 1.4 m
- One macrophyte pond receiving effluent from the anaerobic pond	425 m^2	depth 0.5 m
- One macrophyte pond receiving effluent from the facultative pond	425 m^2	depth 1.6 m

iii) Other system elements include:

- Two pumping stations equipped with submersible pumps, one with capacity 15 l/sec against 17 m head and the second, with two pumps, each with capacity 5 l/sec against 19 m head,

- One 200 mm diameter magnetic flowmeter/recorder supplied by Simon Hartley, UK,

- Inlet chamber, grit chamber and screens, flow measuring weir,

- Laboratory/administrative building.

iv) Operational Parameters:

Design retention times in the anaerobic, facultative, maturation and macrophyte ponds are 5, 27, 4 and 5 days, respectively.

1.2.2 System information

Site area	19200 m^2
Design flow	463 m^3/day
Design population connected to the treatment ponds	8200
Total cost of stabilization ponds	LE 627,565*

Total cost of the sewerage system was LE 1905 000
The ponds were funded by UNDP, WHO, UNICEF and the Government of Egypt.

1.3 Benefits

1.3.1 Health Impacts

The El Nazlah sewerage scheme (construction of sewers, pumping station and ponds) will improve the health conditions by:

- Improving sanitation in the village,

- Connecting houses to sewerage system and eliminating individual cesspits of all types, resulting in considerably reduced associated health hazards,

- Protecting house water supply service and preventing groundwater and surface water pollution,

- Protecting water bodies, such as drainage canals, by removing organic material and pathogens, bacteria, helminths and other potentially harmful organisms from wastewater by treatment at El Nazlah Sewage Treatment Plant (STP).

1.3.2 Technical and Economic Factors

- The system chosen requires minimum land area of any stabilization pond system,

- Construction materials, including mechanical/electrical supplies, are all available locally. Even floating surface aerators can be manufactured locally at very reduced cost.

*3.32 Egyptian Pounds (LE) were equivalent to 1 U.S. Dollar (US$) in 1989.

- Operates in its primary, secondary and tertiary processes on the principle of natural treatment

- The scheme uses minimum electric power and no chemicals

- Operation and maintenance of the scheme is very simple and requires minimum spare parts and no particular skills

- The system minimizes operation and maintenance staff

- Effluent reuse for certain agricultural crops and aquaculture is possible

- Stabilized sludge can be used as a fertilizer on agricultural land.

1.3.3 Social and Environmental Benefits

- The scheme will encourage villagers to use more water for hygiene purposes, due to ease of wastewater disposal

- The scheme will reduce the canal washing practice by village women

- The scheme will reduce contamination of drainage canals.

1.4 Nomenclature

Waste stabilization ponds have been referred to by many different names such as oxidation ponds, anaerobic, facultative, aerobic and maturation stabilization ponds.

In these booklets, stabilization ponds are classified according to the biological process taking place; aerated ponds have mechanically induced aeration, while in facultative ponds the growth of algae is maximized through photosynthetic action occurring under natural aerobic conditions. Anaerobic ponds are totally devoid of oxygen, serve as primary sedimentation ponds and provide anaerobic biological breakdown of organic matter. Maturation ponds provide polishing treatment, following secondary treatment, and are primarily used to reduce the pathogen content of the effluent.

2. AVAILABLE DATA AND INFORMATION

2.1 General Location

El Nazlah village is situated within the property of Markaz Abshway in Fayoum Governorate approximately 40 km west of Fayoum city, as shown in Fig. 2.1. Ground levels at the village range between + 10.00 and - 00.40 metres above sea level. The site of the sewage treatment plant is located approximately 1.8 km southwest of El Nazlah village, as shown on Fig. 2.2.

2.2 Climate

Ambient temperature averages about 15°C in winter and about 35°C in summer. Rain falls once or twice yearly at average intensity but heavy rain is rare.

2.3 Existing Utilities

2.3.1 Water network

El Nazlah village is supplied with drinking water, as are most of the cities and villages in Fayoum Governorate, from Azab water treatment plant through a steel main pipeline. The route of this line starts at the Azab plant and passes through adjacent villages.

From the main pipeline of diameter 300 mm passing through El Nazlah village, a lateral of diameter 125 mm is branched to supply the village.

2.3.2 Sewerage system

Before this project was initiated, there was no real sewage collection network within the village, apart from two gravity sewers which discharged into the El-Wadi drain at the village entry. Dr. A.A. Warith consulting engineers studied the existing situation in El Nazlah village and presented an integrated final design for the sewage collection network together with ancillary works, such as pumping stations and force mains to the treatment plant site.

2.4 Pre-Project Social Conditions

The project team of Dr. A.A. Warith, the local consulting engineers, made several visits to El Nazlah village during the preparation of the proposal as well as during the course of conducting the study. These visits gave the project team the opportunity to conduct interviews with village officials and local people so as to perceive and become acquainted with the social and environmental conditions there.

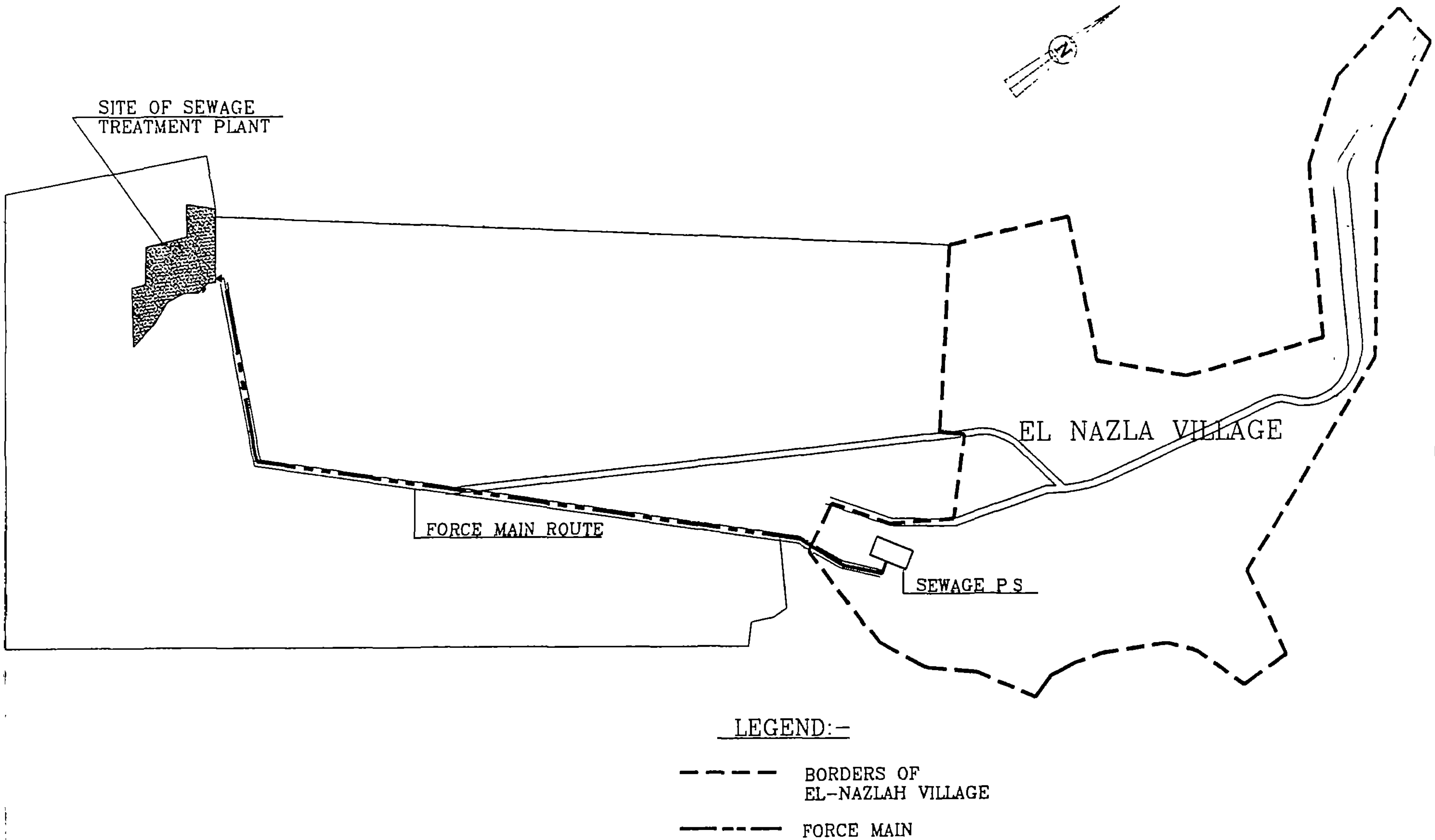


Figure 2.2 General Location of El Nazlah Village and Site of S.T.P.

Most of the streets in El Nazlah village tend to be very narrow and the topography of the village is non-uniform with considerable changes in levels. The existing potable water network provides 90 per cent of the existing houses with water through private household connections. Only about 30 per cent out of the 90 per cent served have modern fixtures (taps, showers, water closets, etc.) and the rest have only a single water tap located inside the house. Of the total population, 10 per cent get their water needs through eight standpipes scattered over the quarters of the village. Drainage from the standpipes is a source of nuisance to the inhabitants because excess water flows either to the valley, forming ponds that are unacceptable environmentally, or to the surrounding drains. Before the project, sewage was mostly disposed of locally into septic tanks constructed of stones and cement mortar with earth floors. Nightsoil from septic tanks was removed at intervals of no more than three months, and probably discharged into one of the nearby drains, for a fee of LE 7 each time. The frequency of removing nightsoil varied according to social status, from once per week for relatively high-income residents to once per three months for low-income residents. The two sewers of 200 mm and 300 mm in diameter in low-level areas were constructed mainly to reduce the level of the groundwater table but, in addition, collected sewage from some premises and discharged it to the valley.

Local residents are working either as farmers or potters and their income is mostly very low. Two types of houses are distinguished in the village. New houses on the northern side of the village are built of red bricks and have concrete roofs. The height of such houses ranges between 7 and 8 m and most are two storey buildings. Old houses located to the south of the main road (Tabhar Road) are built of clay bricks and are mainly two storey.

In brief, the social and environmental conditions in the village are considered to be very poor. Sewage is reaching underground water, causing contamination of the groundwater and raising its level due to the impermeable nature of the soil. The required frequency of emptying septic tanks has been increasing and has become a financial burden on the residents, who are already suffering from their low income. This sometimes results in neglecting the emptying of septic tanks, which ultimately causes flooding of some quarters with sewage and can be a health hazard. There is the potential for infection of children running barefoot in the streets.

3. SUPPORTING STUDIES

3.1 General

In order to develop the engineering design for the sewage treatment plant project, many supporting studies were carried out concerning all conditions and elements that are involved in the project. These studies included mainly the following:

- Present and projected population
- Present and future water consumption and wastewater flow
- Sewage characteristics
- Soil investigation and surveying.

Dr. A.A. Warith, local consulting engineers conducted the required studies before preparing the project design report. A brief description of these studies is presented hereafter.

3.2 Population Studies

3.2.1 The 1988 Population of El Nazlah Village

The population in El Nazlah village at the start of the project was estimated by three different methods:

i) Field survey through selection of population samples. This survey was conducted by the local consultants and the 1988 population by this method was estimated to be about 10760.

ii) Census performed by the Central Organization for Mobilization and Statistics, COMS. According to COMS the population in 1988 amounted to about 10682.

iii) Field survey conducted by World Health Organization (WHO). This survey indicated that the 1988 population was about 9846.

From these results it was concluded that the populations determined by the local consultants and COMS were close and, therefore, the average value of the two estimates was considered as the 1988 population, amounting to 10700. Details of these results are given in the consultants' report to WHO (Warith, 1988).

3.2.2 Projected Population

The future projected population can be determined by the following main computational and graphical methods:

- Arithmetic method
- Geometric method
- Annual growth rate method
- Graphical extension method.

Based on the computed figures and using the above-mentioned methods, the local consultants recommended the population estimates shown in Table 3.1 for design up to the year 2010.

TABLE 3.1 RECOMMENDED POPULATION FOR DESIGN

Year	Population
1995	12700
2000	14000
2005	16000
2010	17000

3.3 Water Consumption and Sewage Flow

3.3.1 Present Water Consumption

Determination of the daily per capita water consumption is one of the basic criteria required for design of sewerage systems. The total daily water consumption at any time can be determined by multiplying the per capita consumption at that time by the projected population.

Since sewerage system projects are usually designed to serve for at least 20 years, prediction of anticipated consumption rates within the design period is essential. This prerequisite can be achieved by introducing assumptions for forthcoming increase rates to apply to the current consumption rate. The local consultants determined the present per capita water consumption by applying the method of direct measurement of flow. Accordingly, the short-term consumption rate up to the year 1995 was estimated to be 65 l/cap.day.

3.3.2 Future Water Consumption

Future water consumption rates were based on an increase in average consumption rate of 10 per cent of the rate of population increase. Table 3.2 presents the recommended future water consumption rates in El Nazlah village up to the year 2010.

TABLE 3.2 FUTURE WATER CONSUMPTION IN EL NAZLAH VILLAGE

Year	Average Water Consumption Rate l/cap.day
1995	65
2000	80
2005	80
2010	100

3.3.3 Sewage Flow Rates

The ratio of sewage flow to consumed water quantity ranges between 70 and 90 per cent.

The local consultants recommended a ratio of 80 per cent for design. Accordingly, the future sewage discharge rates, up to the year 2010, were as shown in Table 3.3.

TABLE 3.3 FUTURE SEWAGE FLOW IN EL NAZLAH VILLAGE

Year	Average Flow Rates of Sewage l/cap.day
1995	52
2000	64
2005	64
2010	80

3.4 Sewage Characteristics

Accurate information on sewage characteristics can only be obtained by monitoring the sewage for reasonably long periods of time, taking into account daily and seasonal variations. Composite samples should be taken for analysis during the monitoring period in order to obtain average daily characteristics.

Owing to the short time available to develop the project, such monitoring was not feasible. However, WHO provided the local consultant with available information on the characteristics of sewage at El Nazlah village, along with other design criteria prepared by Gloyna (1988). The BOD_5 was estimated to be 750 ± 150 mg/l.

This information was supplemented by conducting further sampling and analysis of the sewage by the local consultants. The results of the analyses of collected samples are given in Table 3.4 and showed that the BOD_5 of the sewage varied between 402 and 684 mg/l with an average of 523 mg/l. The sampling was carried out in the summer month of August, which is known to be the month of maximum water consumption. Since El Nazlah village did not then have a sewerage system or sewage pumping station, adequate sampling was not possible. Sewage samples were collected from a manhole

TABLE 3.4 CHEMICAL AND BIOCHEMICAL INVESTIGATION OF WASTEWATER SAMPLES AT EL NAZLAH, FAYOUM, AUGUST 17, 1988

No.	Parameter	Unit	Sample I	Sample II	Sample III
1	Colour	-	-	-	-
2	Odour	-	Putrefied	Putrefied	Putrefied
3	Dissolved Oxygen	mg/l	Nil	0.25	0.34
4	pH value	-	8.34	7.89	8.03
5	Conductivity	µmhos	2368	1725	1520
6	BOD_5	mg/l	684	483	402
7	COD-Dichrom.	mg/l	766	649	576
8	Sludge volume	%	8.45	5.64	2.63
9	Sludge weight	mg/l	11035	9405	4952
10	Floating matter	mg/l	4340	2115	986
11	Suspended solids	mg/l	215	164	123
12	Total dissolved solids	mg/l	1514	1140	1017
13	Oil and grease	mg/l	22.44	36.71	35.85
14	Total hardness	mg/l	526	411	347
15	Calcium hardness	mg/l	340	258	253
16	Magnesium hardness	mg/l	166	153	94
17	Calcium (Ca^{++})	mg/l	136	103	101
18	Magnesium (Mg^{++})	mg/l	48	44	27
19	Sodium (Na^{+})	mg/l	218	154	182
20	Poatassium (K^{+})	mg/l	39	26	28
21	Chloride (Cl^{-})	mg/l	181	178	133
22	Sulfate ($SO4^{-}$)	mg/l	96	135	102
23	Silica (SiO_2)	mg/l	18	12	12
24	Phosphate (PO_4)	mg/l	15	23	18
25	Ammonia (NH_4)	mg/l	75	38	38
26	Nitrite (NO_2)	mg/l	6.5	8.4	8.2
27	Nitrate (NO_3)	mg/l	38	29	31
28	Phenol	mg/l	Nil	Nil	Nil
29	Detergents	mg/l	-	-	-
30	Zinc (Zn)	mg/l	3.60	1.25	1.84
31	Copper	mg/l	0.85	0.65	1.4
32	Iron (Fe^{+++})	mg/l	3.28	1.68	1.72
33	Manganese (Mn^{+++})	mg/l	0.74	0.20	0.35

on an existing sewer providing drainage for a mosque in addition to some scattered houses. It seems that the first sample was taken before people were using the facilities of the mosque and the other two samples were taken thereafter. This explains the high BOD_5 value (684 mg/l) of the first sample compared with the other two samples, which had BOD_5 values of 483 and 402 mg/l, respectively. The first sample was taken as being representative of the average conditions in summer months. Since the annual average BOD_5 was likely to be slightly higher than in summer months, a factor of 1.15 was used to adjust the BOD_5 value. For design purposes, a BOD_5 value of 800 mg/l was agreed with WHO.

3.5 Soil Investigation and Surveying

A complete soil investigation report was prepared by The Engineering Consulting Center (SASECC). The investigated sewage treatment plant site has an area of approximately 15000 m^2 and was levelled agricultural land near El Nazlah village. Seven boreholes, each 8.0 m depth, were drilled in the locations shown on Fig. 3.1.

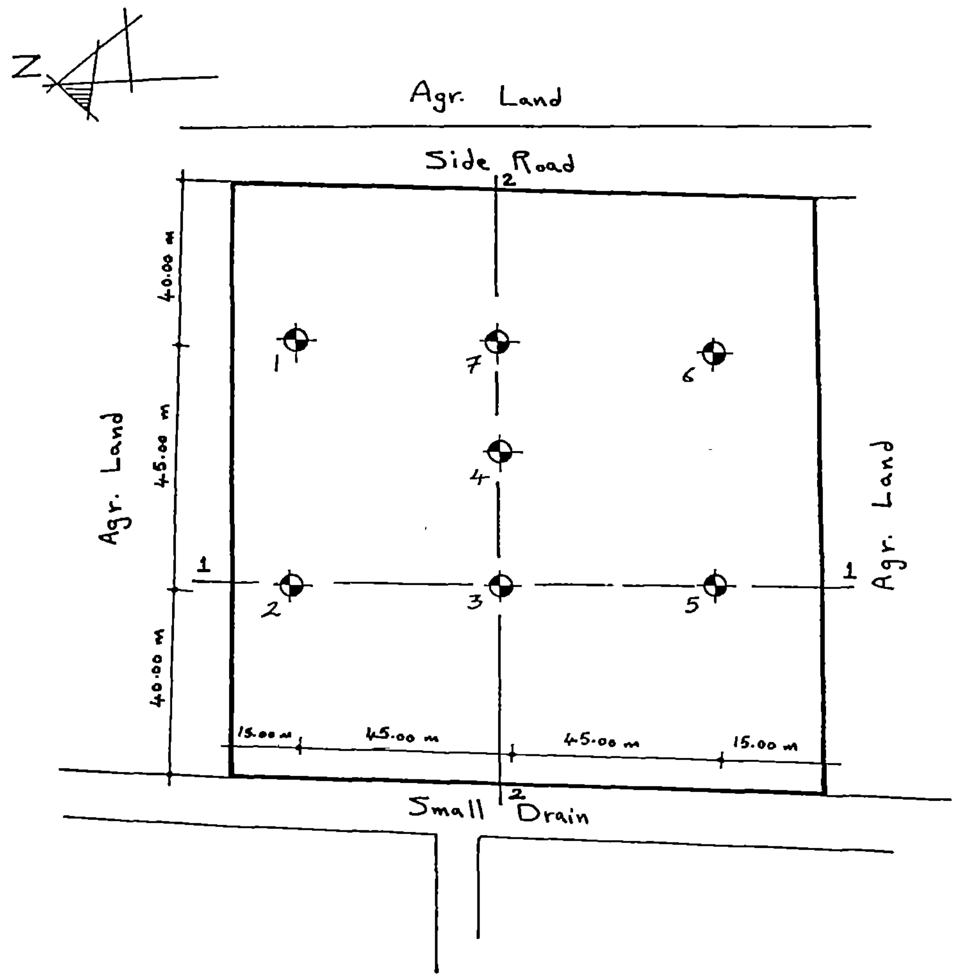


Figure 3.1 Borehole Locations - Al Nazlah, Fayoum Governorate

The primary investigation of the extracted soil samples showed that the site materials were homogeneous and consisted of light brown/grey fissured silty clay with traces of sand and, occasionally, traces of fine calcareous material.

The groundwater level was found to be 2 m below the ground surface in boreholes 2 and 5, at 3.50 m depth in boreholes 3 and 6 and at approximately 1.0 m depth in boreholes 1 and 4. A groundwater level was not indicated in borehole 7. Accordingly, it was recommended to have the foundation level at approximately 1.5 m below the ground surface or at the groundwater level.

Chemical analysis of the groundwater at the site revealed that a high chloride content (17,500 mg/l) was present. This high concentration makes the groundwater highly corrosive and aggressive to underground structures. Therefore, the material of pipes was recommended to be chosen so as to be resistant to chloride and relatively high salinity (10,609 mg/l) levels.

Site survey work was carried out by Dr. A.A. Warith consulting engineers. Natural ground levels over the sewage treatment plant site and at the boundaries were determined. Fig. 3.2 shows the layout of the site for the sewage treatment plant, together with determined ground levels.

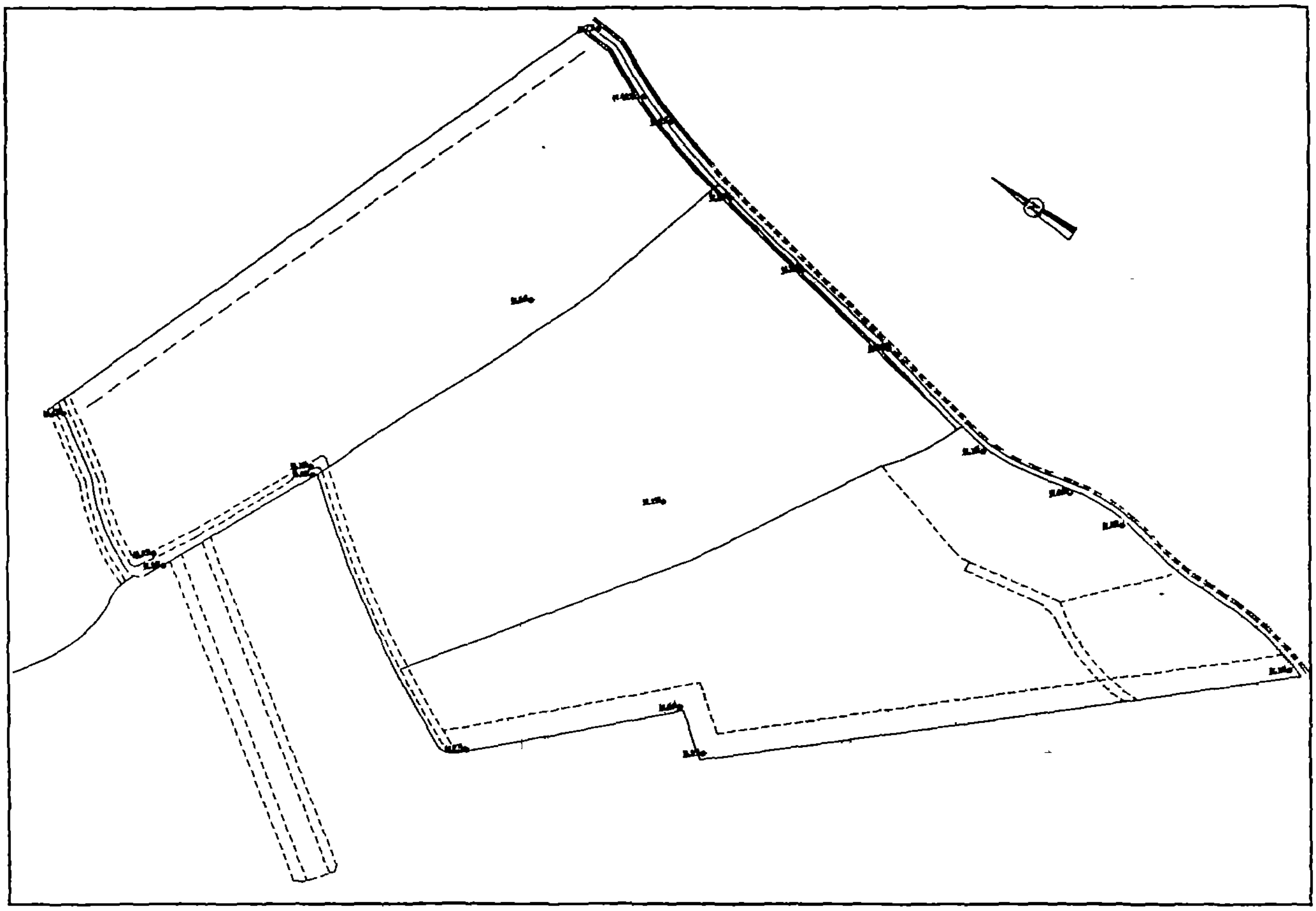


Figure 3.2 Ground Levels at the Sewage Treatment Site

3.6 Basic Design Criteria

The basic design criteria given in Table 3.6 were provided by WHO for the design of stabilization ponds at El Nazlah village.

TABLE 3.6 BASIC DESIGN CRITERIA

Population	10,000
Average annual growth rate	2.5%
Water consumption	70 ± 10 l/cap.day
Wastewater inflow	80% of water consumption
BOD_5	750 ± 150 mg/l
Average atmospheric temperature	15°C
Approximate length of collection network	4.4 km
Average infiltration rate	8 m^3/km.day
Sludge accumulation	0.04 m^3/capita
Available land area	21,000 m^2
Soil characteristics	As in SASECC Report
Design period	10 years

Additional design considerations:

A village of 5,000 persons nearby El Nazlah may aquire wastewater collection system within five years and may be linked to El Nazlah system.

4. PRELIMINARY DESIGN STUDIES

4.1 Preliminary Design Review

The Hespanhol (1988) report provides a complete analysis of an anaerobic pond design, a facultative pond system in series with an anaerobic pond, and a facultative pond system operating as an independent unit. These pond designs for Mahalet Demena Village, were considered worthy of consideration by Prof. Gloyna and the basic concept, with few modifications, was incorporated into his recommendations for El Nazlah (Gloyna, 1988). At the time of Prof. Gloyna's preliminary review, input data as to loadings were limited and fine tuning of design was not considered worthwhile.

Prof. Gloyna's comments, summarized in the next sections, reflect his experience, with an admitted conservative bias. The objective was to increase treatment efficiency, reduce costs and meet governmental regulations on water quality.

4.2 Anaerobic Facultative Pond System

Savings in cost, as well as BOD removal and operational efficiency, might be possible if the following design was used:

a. Use only one anaerobic pond (same volume) and thereby reduce costs in excavation, pond lining and piping, and removal of two Parshall flumes and one walkway.

b. Modify the configuration of the first set of ponds in the facultative system. The Parshall flume in the By-Pass line serving this first set of facultative ponds can be eliminated. This recommendation is justified on the basis that this first facultative pond may be mostly anaerobic at the time the ponds reach maturity. At any rate, the three series connected ponds will provide more efficient sedimentation, pathogen removal, and treatment.

c. Remove the cross dikes between the second set and the third set of facultative ponds. Savings will be possible because of the reduced lining and piping costs.

4.3 Aquatic Macrophytes

The larger aquatic macrophytes hold promise for purification of wastewater because the plants accumulate nutrients, remove soluble compounds from the wastewater and furnish substrate for a large variety of both microscopic and macroscopic organisms required in the pollution control process.

There is a growing body of knowledge available describing the use of emergent, floating and submersed aquatic plants for the renovation of wastewaters. Nature has employed these plants for purposes of purification in the wet lands since the beginning of urban development. The concept has been of long-term academic interest, but actual utilization of aquatic plants on an engineered basis is only beginning to develop into various stages of experimentation and early development.

A review of various candidate aquatic macrophytes for emergent, floating and submersed systems is discussed in the following sections.

4.3.1 Emergent Vegetation

Recent literature describing the engineered use of emergent vegetation for wastewater treatment appears to have had its origin in 1950 at the Max Planck Institute (Seidel et al., 1976). Additional literature in using filter-type, artificial-marsh, wastewater treatment systems has been reported by researchers in several countries. (Kok, 1974, and Greiner et al., 1982, of the Netherlands; Vaucaulaux, 1978, of France; and Small, 1979, and Spangler et al., 1977, of the USA).

Candidate species of emergent vegetation include:

- Common reed (Phragmites communis Trin.)
- Bulrush (Scripus locustri L.)
- Reed (P. australis - used by de Jong, 1976)
- Soft stem bulrush (S. nalidus Vahl. - preferred by Spangler)
- Cattail (Typha spp. - Linde et al., 1976)
- Yellow flag (Iris pseudacorus L. - Dinges, 1982)
- Pickeral weed (Ponterderia cordata L. - Dinges, 1982)
- Giant cane (Arundaria gigantea, Walt, Muhl. - Correll, 1972)

Seidel et al. evaluated over 200 emergent plant species but finally recommended using the common reed (P. communis Trin.) and the bulrush (S. lacustri L.). The reed may grow to a height of about 5 m while the bulrush usually grows to heights of 2-3 m. Both plants seem to tolerate sludges and industrial waters. Reeds and bulrushes develop underground fleshy rhizomes. Reeds have jointed stems and rooting may occur at the nodes. Seidel maintains that bulrushes have specific properties which make the plant more suitable, but others disagree (Greiner, 1982).

Researcher de Jong (1976) suggests that reed plants require less maintenance as compared to other types. However, bulrushes may demand a higher market value. Reeds have the ability to survive in water depths of about 0.5 m. Similarly, reeds can survive dry weather periods. Apparently, these plants promote aeration and increase permeability. Interestingly, other marsh plants can also contribute to the stabilization process without competing with the reeds and bulrushes.

Based on three to five years of Flevoland (Netherlands) experience the crop of bulrushes can bind 300-500 kg N/ha and 50/75 kg P/ha during a growing season.

Similarly, 150-300 kg N/ha and 20-40 kg P/ha can be removed by collecting the above-ground parts of the plant. Of major significance is the fact that the gross purification of wastes treated was 99.9 per cent and 96 per cent, respectively, for BOD_5 and SS.

This purification level produced less seepage, about 9 mm/24 hr. The untreated waste was diluted on 1:1 basis with fresh water.

Based on this information, parallel treatment ditches can be designed as part of the proposed experimental treatment plant. The design assumptions used herein are as follows:

- water depth	0.4 m
- residence time	5 days
- hydraulic load	average flow
- supplementary water supply	none

4.3.2 Floating Aquatic Plants

The floating plants utilize atmospheric oxygen, carbon dioxide and nutrients. The nutrients are mostly derived from soluble substances in the wastewater.

Candidate species for possible use in wastewater treatment include:

- Hyacinth (Eichornia crassipes)
- Duckweed (Family of Lemnaceae)
- Fern (Family of Salveniaceae)
- Rooted/Floating (Myriophyllom brasiliense and Paspalom fluitans)

Water hyacinths, the largest of floating plants and perhaps the most productive macrophyte, has received much consideration for use in polishing ponds. The hyacinth grows rapidly in the enriched wastewater and, under ideal conditions, the plants will attain a height of 1.2 m. The maximum dry biomass of mature hyacinth growing in wastewater ponds is about 3,000 g/m^2 (30 t/ha). Hyacinth water content is about 90 per cent (Dinges, 1982). The hyacinth biomass has been known to double every seven days. The root system is relatively short, about 10 cm, but the roots provide a large surface area for microbial growth. The root system seems to become more extensive with reduced nutrient levels. The major limitation of hyacinths is sensitivity to freezing and saline conditions.

Extensive experimentation and development of hyacinth cultures in the USA for waste treatment have provided much information. Hydraulic loading is probably a more critical factor as compared to organic loading. A high velocity through the basin will carry a significant amount of pond debris. Also, the effluent from a hyacinth pond will likely be anaerobic and reaeration will be required before discharge. Detention time in a hyacinth basin is usually five days or more and operating depth varies between about 0.4 m to 1.83 m. Human faecal coliform bacteria, BOD_5 and TSS levels should be very low in the effluent of a properly designed hyacinth polishing pond (BOD_5 and TSS of less than 10 mg/l).

Surface loading may be greater than 10 $g/m^2.d$ of BOD_5. Removal of nitrogen (N) and phosphorus (P) may be about 80 per cent and 44 per cent, respectively. One hectare of harvested plants might produce 30,000 m^3 of methane. Also, hyacinth ensilage with 4 per cent corn or citrus pulp has produced a readily acceptable cattle food. Dry hyacinth as cattle food has not been acceptable. A variety of hyacinth harvesters have become available on the market.

Submersed Plants

The use of controlled cultures of submersed plants for polishing action is in the early stage of development. Therefore, there will be no further discussion on this topic.

4.4 Preliminary Design

A design for the El Nazlah village sewage treatment plant was proposed by Prof. Gloyna. Consideration was given to the following design requirements:

- limited space: 21,000 m^2,
- aquatic-weed demonstration,
- low-cost facility,
- easy to operate and maintain.

The treatment system proposed by Hespanhol was modified. Experimental reed-bulrush facilities were added; internal dikes and related equipment were deleted, and estimated immediate requirements were used as the design basis rather than future population projection requirements.

The design basis was as follows:

Population	- 10,000 (Hespanhol used 15,000 with 80 per cent adjustment)
BOD_5	- 800 mg/l
Effluent use	- None - Discharge into return-flow drainage canal (this may change when it is recognized that effluent may be useful for irrigation)
Chlorination	- None
Site	- Unusable agricultural land (excessive salt on site will require attention for aquatic-weed unit)

Aquatic-weed	- Reed-Bulrush	
	water depth	0.4 m
	residence time	5 days
	supplementary water	none
	volume (of total)	30 per cent
	width	5 m
	dam (roadway)	3 m

Pond system - Anaerobic, Intermediate and Facultative (three ponds in series - see details in Table 4.1 and Section 4.5)

Alternatives - Seven alternative treatment systems may be evaluated. Also, papyrus and cane may be studied as alternatives to reed and bulrush.

Efficiency - 85-95 per cent BOD_5 removal (filtered), 50-100 mg/l SS (mostly algae) and very high removal of pathogens.

There were uncertainties in the available data. For example, the organic load would remain questionable until the impact of a fully usable water and sewerage system became available.

Flow could be diverted to the aquatic-weed basins from all waste stabilization ponds. The modified plan resulted in a volumetric saving of 18 per cent; a net surface saving of 18 per cent, excluding driveways in reed-bulrush basins. There might not be savings in space requirements if the driveways (dam areas) of the aquatic-weed basins are included. Details are provided in Table 4.1.

A schematic layout of the proposed facility, without regard to geographical features, is presented in Fig. 4.1. Also, Prof. Gloyna's design computations are provided in Section 4.5.

The anticipated hydraulic detentions in anaerobic, anaerobic-facultative and facultative ponds, respectively, are 5, 13 and 21 days. Each aquatic-weed basin would provide a detention of five days. The detention suggested by Hespanhol for an equivalent 12,000 population and flow was 37 days. The surface areas required for the anaerobic, anaerobic-facultative and facultative ponds, respectively, were 1,000 m^2, 4,800 m^2 and 1,200 m^2. The reed-bulrush basins required 4,500 m^2 plus a roadway (dam) area of about 36,000 m^2. The total for the modified designs was 21,100 m^2 (17,500 + 3,600) exclusive of required service areas.

If no additional land could be obtained, it was suggested, on an experimental basis, that the anaerobic detention be reduced to three days, the depth of the intermediate pond increased to 2 m (with proportionate decrease in surface area) and the dam between the aquatic-weed basins reduced to 2 m. This change would provide about 2,500 m^2 of space.

TABLE 4.1 COMPARISON OF WASTE STABILIZATION POND DESIGNS

Unit	Hespanhol L m	W m	D m	Area m2	Vol m3	Gloyna L m	W m	D m	Area m2	Vol. m3	Remarks
AWSP (a)											
#1	24.5	24.5	5	600	3000	49	24	5	1200	6000	No dike
#2	24.5	24.5	5	600	3000						
FWSP (b)											
#1	58	58	1.6	6700(d)	10,670	96	50	1.6	4800(e)	7700	No dike
#2	58	58	1.6	6700	10,670	144	50	1.6	7200(f)	11,500	No dike
#3	58	58	1.6	6700	10,670	-	-	-	-	-	
SUBTOTAL				21,300	38,000				13,000	24,200	
AWB (c)											
#1	-	-	-	-	-	300	5	0.4	1500	600	
#2	-	-	-	-	-	300	5	0.4	1500	600	
#3	-	-	-	-	-	300	5	0.4	1500	600	
SUBTOTAL									4500	1800	
TOTAL				21,300	38,000				17,500	24,200	

Surface saving (Net) $\frac{21,300 \times 17,500}{21,300} \times 100 = 18\%$. Vol. saving = $\frac{38,000 - 26,000}{38,000} = 32\%$

" " (Gross) $\frac{21,300 - 21,000}{21,300} \times 100 = 0\%$

(a) AWSP = Anaerobic Waste Stabilization Pond
(b) FWSP = Facultative Waste Stabilization Pond
(c) AWB = Aquatic Weed Basin
(d) Rounded Numbers
(e) Reduce vol. by 10 per cent to compensate for flow diverted to A.W.B. Remove cross dikes
(f) Reduce vol. by 20 per cent to compensate for flow diverted to A.W.B. Remove cross dikes

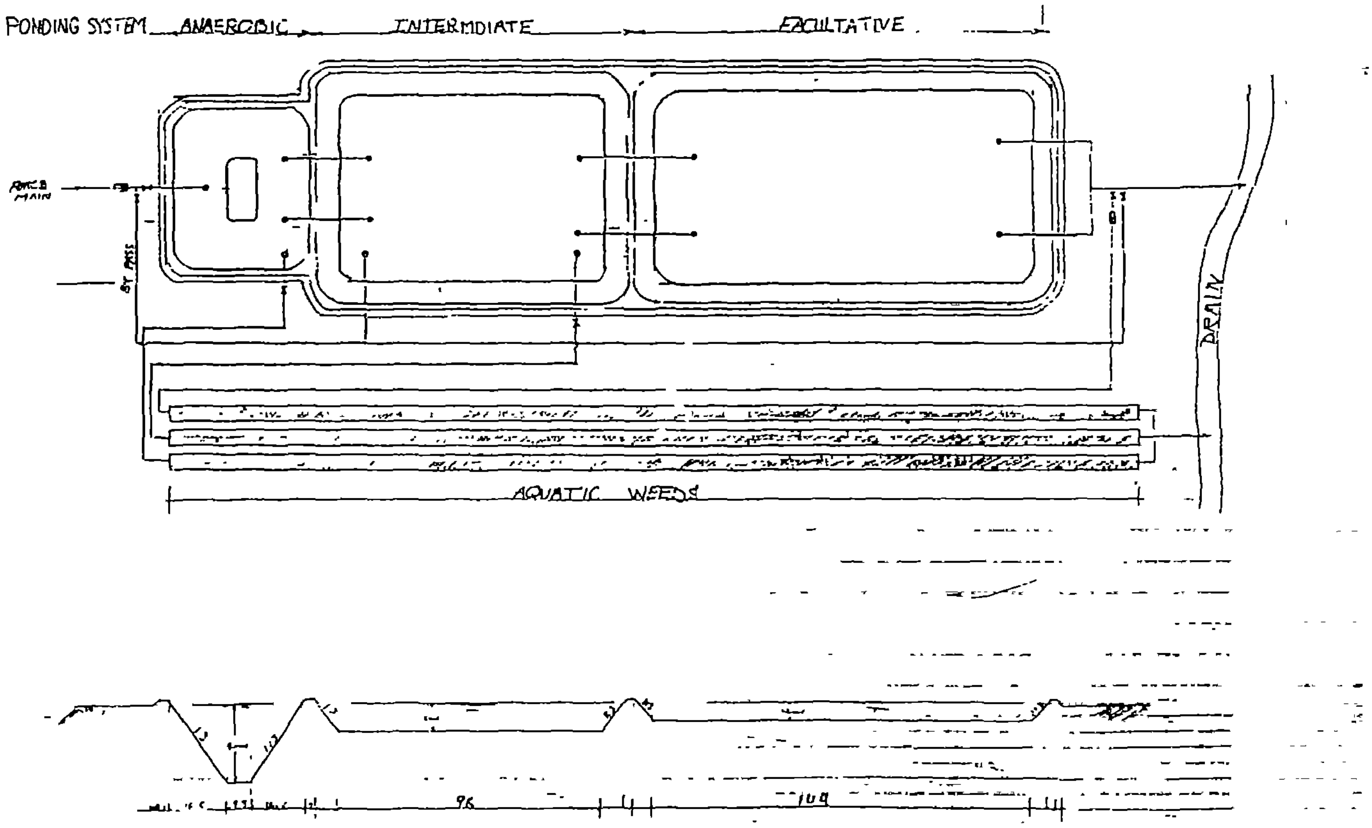


Figure 4.1 Scheme of Proposed Treatment Plant at El Nazlah Village, Fayoum Governorate

4.5 Recommendations

Based on a review of the available technical documents, an analysis of the proposed designs and projected training requirements, the following recommendations were made by Prof. Gloyna.

i) A fully operational waste stabilization pond system (WSPS) in conjunction with a novel, emergent aquatic macrophyte system, should be implemented as the demonstration facility for El Nazlah village, Fayoum Governorate. Detailed site layout and facilities design should proceed. To provide most flexibility in a demonstration unit, it was recommended that a modified WSPS be used (one anaerobic, one anaerobic-facultative and one facultative series-connected pond system). This represented a slight modification of the previous designs developed for other areas. Internal dikes were removed to reduce land requirements and costs. Designs were conservative because the available data describing loadings were not available. Based on the loading estimates and the quality of effluent required, the detention for the anaerobic, intermediate, facultative and aquatic-weed basins, respectively, were 5, 13, 21 and 5 days.

ii) Also, for demonstration purposes, it was recommended that three aquatic-weed basins (reeds and bulrushes) be incorporated into the overall treatment facility. Experimental sections (50 m each) of cane and papyrus were suggested as part of the aquatic-weed facility. Flexibility should be provided in influent connections to each of the aquatic-weed basins. Initially, the aquatic-weed basins should be capable of receiving ten per cent of the effluents from each anaerobic pond, intermediate pond and facultative waste stabilization pond. Ultimately, the three aquatic-weed basins might receive the effluent from any WSPS pond or the overall system.

iii) It was recommended that the demonstration plan involve the evaluation of seven alternative modes of wastewater treatment: anaerobic plus aquatic-weed; intermediate plus aquatic-weed; facultative plus aquatic-weed; the three individual units comprising the WSPS; and the overall WSPS. The capacities of the modified intermediate pond (anaerobic-facultative pond) and the facultative pond, respectively, could be reduced by 10 per cent and 20 per cent as a result of the addition of the aquatic-weed basins. The actual characteristics of the facultative ponds would depend on the organic and volumetric loadings ultimately placed on the pond system. There was some flexibility in the relative size and shape of the intermediate pond and the final facultative pond, but the overall detention and surface area should remain the same. An 18 per cent saving of land area in the ponds could be accomplished by removing all internal diking between various pond units and adding three aquatic-weed basins. However, if the dike areas between the aquatic-weed basins were considered, the total land requirements were about equal with a design similar to that proposed by Hespanhol.

iv) The layout of the treatment plant must accommodate future expansion requirements by increasing the size of any unit (anaerobic, facultative, or aquatic-weed). Space must be provided for an operator's room (records) and equipment storage facility. Access roads must be provided to accommodate motorized vehicles.

v) The elevation of the effluent of the treatment system should be placed at a sufficient level to permit wastewater reuse for irrigation and adequate drainage of the built-up, aquatic-weed basins.

vi) A training programme for engineers and operators as outlined should be provided prior to the initiation of treatment operations.

4.5.1 General Design Criteria

Population	10,000
Water consumption	80 l/day (80 per cent to sewer)
BOD_5	800 mg/l
Temperature (Average coldest month)	15°C
Sewer, length	4.4 km
Infiltration	8 m^3/day.km
Sludge accumulation	0.04 m^3/caput

4.5.2 Anaerobic Pond Design

Sewage flow	= (10,000 x 80 x 0.80)	= 640,000 l/d = 640 m^3/d
Infiltration	= 4.4 x 8	= 35 m^3/d
TOTAL FLOW	= 675 m^3/d	
Detention	= 5 days (est. 90 per cent helminth and 50 per cent BOD_5 removal)	
Sludge volume	= (0.04 x 10,000) x 4 years	= 1,600 m^3
TOTAL VOLUME	= (675) 5 + 1,600	= 5,000 m^3
Depth	= 5 m	
Surface area	= (5,000)/5	= 1,000 m^2
BOD_5 load	= 800 x 675 x 10^{-3}	= 540 kg BOD_5.d
Loading rate	= (540 x 1,000)/5,000 = 540/0.1	= 110 kg BOD_5/m^3.d = 5,400 kg BOD_5/ha.d

4.5.3 Facultative Pond Design

Calculate volume and area of single pond, although two ponds will be used in series. Also, normally the facultative pond would be followed by a maturation pond with one to five days' detention. This is a demonstration facility, and the loadings are not well defined. Therefore, the intermediate pond will be the smaller of the two, because it may serve as a second anaerobic pond.

Sewage flow #1	= (675 - 10%)	= 608 m^3/d
#2	= (675 - 20%)	= 540 m^3/d
Average sewage	= (608 + 540)/2	= 574 m^3/d
BOD_5 load	= (574 x 800) 0.5	= 230 kg/BOD_5.d
Depth	= 1.6 m	
Loading rate	= 20 Ta - 60 kg/ha.d	
Loading rate	= 20 x 15-60	= 240 kg/ha.d
Loading rate (Hespanhol/modification)	= (240) 0.80	= 192 kg/ha.d
Area	= 230/192	= 1.20 ha = 12,000 m^2
Volume	= 12,000 x 1.6	= 19,200 m^3

Similarly, using the Gloyna equation:

t_o = 3.5 (uniform/y warm temp.) Vol. = 19,000 m^3 (use)

t_o = 7.0 (significant seasonal fluctuation) Vol. = 38,000 m^3

4.5.4 Ponds 2 and 3 Design

Intermediate Pond (anaerobic-facultative)

Length	= 96 m
Width	= 50 m
Depth	= 1.6 m
Area	= 4,800 m^2
Volume	= 7,700 m^3
Detention	= 13 days

Facultative Pond

Length	= 144 m
Width	= 50 m
Depth	= 1.6 m
Area	= 7,200 m^2
Volume	= 11,500 m^3
Detention	= 21 days

4.6 Preliminary Design of El Nazlah Sewage Treatment Plant

Professor Pescod carried out the preliminary design for the El Nazlah stabilization ponds in July 1988 following terms of reference issued by WHO Eastern Mediterranean Regional Office.

4.6.1 Basic Design Criteria

WHO recommended the use of stabilization ponds for sewage treatment at El Nazlah village because of their suitability for warm developing countries. The main characteristics of pond systems are as follows:

- Easy construction, operation and maintenance,
- Quick implementation of construction work,
- Relatively low construction cost,
- Low operation and maintenance costs,
- No need for highly-skilled labour, which may not be available in the local market,
- Reasonable efficiency achieved, which allows for disposal of treated sewage into surface drains.

The basic design criteria in Table 3.6 were provided by WHO.

4.6.2 Design Period

A design period of ten years was used, in accordance with the design criteria.

4.6.3 Design Population

The 1988 population, as indicated in Table 3.6, was 10,000, and a 2.5 per cent average annual growth rate was assumed. Hence,a the design population for El Nazlah village was:

$$
\begin{aligned}
P_{10} &= P_o\,(1 + r)^{10} \\
&= 10{,}000\,(1 + 0.025)^{10} \\
&= 10{,}000\,(1.025)^{10} \\
&= 10{,}000 \times 1.280 \\
&= \underline{12{,}800}
\end{aligned}
$$

In addition, within five years a village near El Nazlah with a current population of 5,000 might be linked to the sewage treatment plant. Thus, the ultimate population which the plant might have to accommodate after ten years is 12,800 + 6,400 = 19,200.

However, in view of the uncertainty in respect of the nearby village population it was recommended that the plant should be designed to accommodate the predicted population in El Nazlah village after ten years, with allowance being made for a possible expansion after five years to accommodate the inflow from the additional population in the nearby village. Hence,

design population = 12,800
and for extension after five years = 19,200

4.6.4 Design Flow

Maximum water consumption = 80 litres per caput day (lcpd), with sewage flow 80 per cent of water consumption, as indicated in the given design criteria (Table 3.6).

Thus, for El Nazlah village, maximum sewage flow expected in ten years

$$= 12{,}800 \times 80 \times 0.80 \text{ l/d} = \underline{819.2 \text{ m}^3/\text{d}}.$$

Infiltration given in the design criteria (Table 3.6) is 8 m^3/d per kilometre (km) along an approximate length of 4.4 km, giving total infiltration = 35.2 m^3/d.

Thus, total maximum inflow to El Nazlah village STP for design = 855 m^3/d.

Allowing for a similar level of infiltration in the nearby village sewerage system, the combined flow from the two villages, the ultimate for design = 855 + 427 = 1282 m^3/d.

4.6.5 Design Organic Load

The given design criteria (Table 3.6) suggest a wastewater BOD_5 of 750 ± 150 mg/l. At maximum flow, it is unlikely that the sewage will have the maximum BOD_5 concentration. For similar conditions in Jordan with similar water consumption, sewage strength averages about 800 mg/l. Therefore, for design at El Nazlah a sewage strength of 800 mg/l BOD_5 at maximum flow was adopted.

Thus, design organic load for el Nazlah village STP:

$$= \frac{855 \times 800}{10^3}$$

$$= \underline{684 \text{ kg BOD}_5/\text{d}}$$

and the ultimate design organic load for the two villages

$$= \underline{1026 \text{ kg BOD}_5/\text{d}}$$

4.6.6 Summary of Recommended Design Criteria

Criterion	Unit	El Nazlah Village	El Nazlah + Nearby Village
Design period	Years	10	10
Design population	No.	12,800	19,200
Design flow	m^3/d	855	1,282
Design organic load	kg BOD_5/d	684	1,026

4.6.7 Recommended Pond Configuration

To facilitate pond maintenance, two parallel trains of ponds were recommended for immediate construction. Because of the high organic strength of the sewage, two anaerobic ponds in series were recommended for each train, followed by one or more facultative ponds, as required. In addition, the terms of reference called for a final macrophyte pond.

After five years, if the nearby village was connected to the El Nazlah system, a third train of ponds identical to the other two trains could be installed.

4.6.8 Anaerobic Ponds' Design

The given design criteria (Table 3.6) suggest an average atmospheric temperature of 15°C, presumably in the coolest months. This is higher than the average air temperature of 9°C in the coolest month in Amman, Jordan, where a retention time of about five days in an anaerobic pond achieves a minimum BOD_5 removal of 50 per cent with an influent BOD_5 concentration about 800 mg/l. This removal is less than might have been expected using published information, such as Mara (1976) who suggested 70 per cent removal for five days' retention. In Amman, a second anaerobic pond achieves little further removal during the coolest months.

In view of the similarity of the sewage strengths at El Nazlah and Amman, and taking into consideration the higher ambient temperature in El Nazlah, it was recommended that two anaerobic ponds in series providing a total retention of six days should be adopted and 60 per cent BOD_5 removal assumed. Each anaerobic pond should provide three days' retention and the first pond in the series should accommodate expected sludge deposits, which the given design criteria (Table 3.6) suggest will accumulate at a rate of 0.04 m^3/caput per year. Allowance should be made for pond desludging after five years.

Thus, Primary Anaerobic Ponds volume to accommodate El Nazlah wastewater flow = 3 x 855 = 2,565 m^3.

Additional volume to accommodate sludge accumulation	= 12,800 x 0.04 x 5 = 2,560 m^3
Therefore, total volume of Primary Anaerobic Ponds	= 5,125 m^3
Required volume of anaerobic Pond 1 in each of two trains	= 2,563 m^3

Although a depth of 5 m is acceptable for anaerobic ponds, considering the shallow groundwater situation at the site (The Engineering Consulting Centre SASECC, 1988), it is likely that the ponds will have to be constructed mainly above ground. Assuming that 1 m excavation is acceptable, an embankment 3.6 m high would provide a pond depth of 4 m, allowing for 0.6 m freeboard. An embankment height of 3.6 m is probably as high as one would wish to go with an engineered soil structure under the conditions of rural Egypt.

Accepting that a 4 m liquid depth is achievable, each Anaerobic Pond 1 will require a mid-depth area of 641 m^2, or 16 m x 40 m.

Anaerobic Pond 1 volumetric organic loading with full sludge accumulation

$$= \frac{684 \times 10^3}{2 \times 1{,}283}$$

$$= 266 \text{ g } BOD_5/m^3.d$$

Anaerobic Pond 1 volumetric organic loading without sludge accumulation

$$= \frac{684 \times 10^3}{2 \times 2{,}563}$$

$$= 133 \text{ g } BOD_5/m^3.d$$

Both these volumetric loading levels are acceptable for anaerobic ponds.

Anaerobic Pond 1 retention without sludge accumulation

$$= \frac{3 \times 2563}{1283}$$

$$= 6 \text{ days}$$

The Secondary Anaerobic Ponds' volume to provide three days' retention

$$= 3 \times 855$$
$$= 2{,}565 \text{ m}^3$$

No provision is made for sludge accumulation in these secondary ponds. Thus, required volume of Anaerobic Pond 2 in each train = 1,283 m^3. Again, accepting a 4 m liquid depth, Anaerobic Pond 2 in each train will require a mid-depth area of 321 m^2, or 16 m x 20 m.

Assuming 60 per cent BOD_5 removal in the anaerobic pond, organic load to facultative pond will be 0.40 x 684 = 274 kg BOD_5/d. After five years, if the nearby village is connected into the El Nazlah sewerage system, additional capacity will be required. An identical train of ponds will be required to accommodate the additional 50 per cent load.

4.6.9 Facultative Ponds' Design

The facultative pond following Anaerobic Pond 2 in each train will receive a flow of 428 m^3/d, without allowing for evaporative loss, and an organic load of 137 kg BOD_5/d. Influent wastewater concentration will be approximately 320 mg/l.

For an ambient air temperature of 15°C, the allowable facultative pond loading is of the order of 250 kg BOD_5/ha.d (McGarry and Pescod, 1970). However, because the facultative pond receives effluent from the anaerobic pond a loading rate of only 80 per cent of the permissible loading should be adopted for design.

Thus, facultative pond design loading = 0.80 x 250 = <u>200 kg BOD_5/ha.d</u>
Pond area required at mid-depth = 137/200 = 0.695 ha = <u>6850 m^2</u>
Adopting a facultative pond depth of 1.6 m, the volume of the facultative pond in each train will be <u>10,960 m^3</u>.
Retention time in each facultative pond = 10,960/428 = 25.6 days.

This makes no allowance for evaporative losses, which are likely to be at least 15 per cent of the flow through this type of treatment system. The actual theoretical retention time in the facultative pond will be nearer 30 days.

At the organic loading recommended and with this level of retention time, 80 per cent removal of BOD_5 can be expected in the facultative pond. Thus, facultative pond effluent BOD_5 will be about 65 mg/l plus the BOD_5 of the suspended algae.

4.6.10 <u>Macrophyte Ponds</u>

A macrophyte pond will reduce the soluble BOD_5 and remove algae from the facultative pond effluent. However, the decision on which type of macrophyte pond system would be most suitable for El Nazlah was expected to require further consideration following discussions in Egypt.

The first choice to be made was between floating and emergent macrophytes, because the design would be different for these alternatives. If a floating macrophyte system was preferable, the species of macrophyte would have to be carefully selected. Among possible species were water hyacinth (<u>Eichhornia</u> <u>crassipes</u>), water lettuce (<u>Pistia stratiotes</u>) and duckweed (<u>Lemna</u> <u>spp</u>.). Among emergent macrophytes species which might be chosen were cattails (<u>Typha</u> <u>spp</u>.), bullrushes (<u>Scripus</u> <u>spp</u>.), reeds (<u>Phragmites spp</u>.) and rushes (<u>Juncus</u> <u>spp</u>.). It was recommended that indigenous species should be selected and consideration given to design and operating complexity and to macrophyte harvesting.

The area required for the macrophyte pond would depend on the system chosen and, at the preliminary design stage, only a nominal allowance was made in the plant layout. Effluent from a macrophyte pond would probably meet an effluent quality standard of 20 mg/l BOD_5 and 20 mg/l suspended solids but the national effluent quality standards of 10 mg/l BOD_5, 15 mg/l COD and 1 mg/l organic nitrogen were not feasible for any reasonably appropriate treatment system for rural Egypt.

4.6.11 Ponds Layout

The soil investigation report (The Engineering Consulting Centre SASECC, 1988) provided for the El Nazlah site indicated that a land area of 15,000 m^2 is available, with dimensions 125 m x 120 m. The 125 m dimension appeared to be fixed by the side road and small drain locations, whereas the 120 m dimension seemed to be bounded by agricultural land on each side.

Comparing the areas of land required to accommodate the anaerobic and facultative ponds (3.06 ha) with the site area (1.5 ha) indicated that additional land would be required if the wastewater from the population in El Nazlah was to be treated satisfactorily, but not to the national effluent quality standards. Furthermore, an additional 1.5 ha of land would be required for the third train of ponds if the nearby village was connected into the system.

Figure 4.2 shows a possible pond layout utilizing minimum land. consideration would have to be given to the possibility of acquiring additional adjacent land or to adopting an alternative treatment plant design utilizing less land-intensive processes.

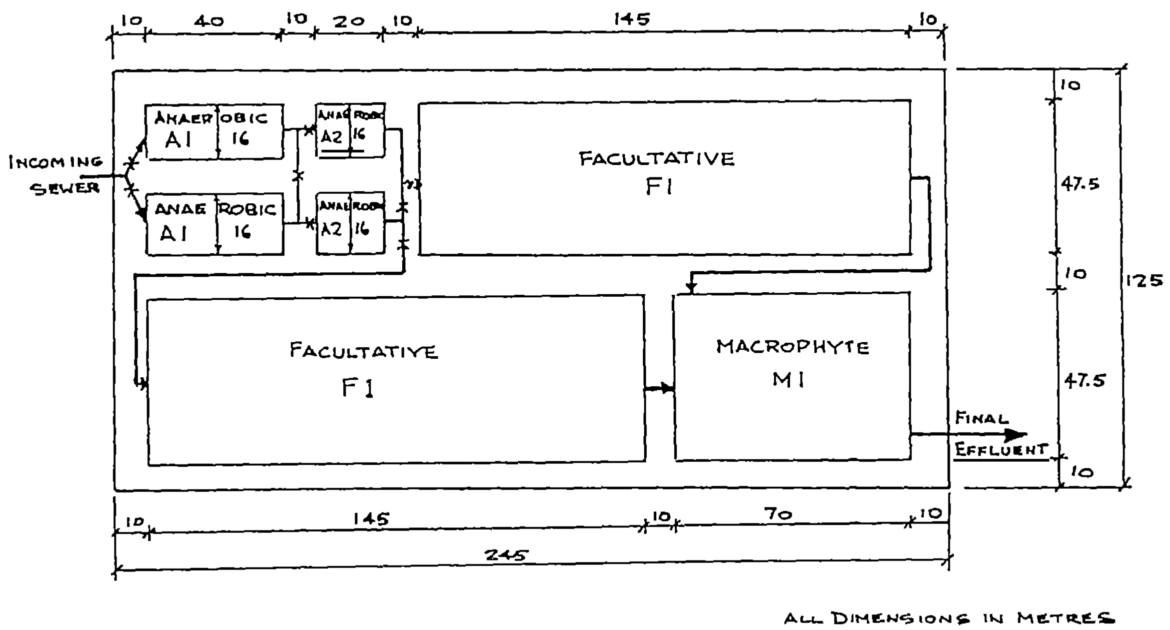


Figure 4.2 Diagrammatic Pond Layout for El Nazlah Village, Fayoum

4.6.12 Effluent Use

It was recommended that the effluent should be used for unrestricted irrigation. The effluent quality was expected to conform with the latest World Health Organization guidelines (Table 4.2) or effluent use in irrigation and would present no health risks to farmers or the consumers of crops.

TABLE 4.2 RECOMMENDED MICROBIOLOGICAL QUALITY GUIDELINES FOR WASTEWATER USE IN AGRICULTURE[a]

Category	Reuse conditions	Exposed group	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100 ml[c])	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	$\leqslant 1$	$\leqslant 1000$[d]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	$\leqslant 1$	No standard recommended	Retention in stabilization ponds for 8–10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[a] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly.
[b] *Ascaris* and *Trichuris* species and hookworms
[c] During the irrigation period.
[d] A more stringent guideline ($\leqslant$200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[e] In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground Sprinkler irrigation should not be used.

4.7 Modifications to Preliminary Ponds Layout

4.7.1 Scaling Down

To accommodate a stabilization pond system, equivalent to the preliminary design of July 1988, on the actual area of land available (approximately 2 ha) required a scaling down of the original system. The original design, for a ten-year future population of 12,800, took up a rectangular land area of approximately 3 ha (125 m x 245 m) while the actual plot of land available was of irregular shape, as indicated in Fig. 3.2.

To accommodate a scaled-down pond system on the site required reduced pond sizes and a reduction in loading was inevitable. Thus, since the relative land areas were in the ratio 2:3, the ponds had to be scaled down by this ratio. However, to incorporate experimental macrophyte ponds on the site, as well as the stabilization pond system, a ratio of 0.6 was suggested. Accordingly, the following basic modifications were proposed by Prof. Pescod in August 1988.

4.7.2 Suggested Stabilization Pond System

Adopting two trains of ponds, as before, each with two anaerobic ponds in series followed by a facultative pond, gave the following area requirements on the basis of a 0.6 scaledown factor:

	Original Area, ha	Adjusted Area, ha	Possible Dimensions
Anaerobic Pond 1	640	384	20 m x 19 m
Anaerobic Pond 2	320	192	10 m x 19 m
Facultative Pond	6850	4030	100 m x 40 m

This system would reach its capacity when a population of 0.6 x 12.800, or 7680, was connected to the sewerage system. Thereafter, either additional land would be required to extend the system using the same technology or more equipment-intensive processes would have to be installed.

In view of the problem with emergent macrophytes in ponds in Egypt it was recommended that the facultative ponds be constructed to a depth of 1.8 m. This would not reduce their area requirement because of the surface loading basis of design.

4.7.3 Embankments

In view of the water table being 1 m below the ground surface, it would not be possible to excavate more than half a metre to construct the ponds. Therefore, the embankments would have to be constructed mainly above ground level, primarily with imported soil.

Adopting 4 m deep anaerobic ponds with 0.6 m freeboard and 0.5 m excavation required embankments 4.1 m high. These must be properly designed as engineering structures and constructed carefully by placing soil in layers of 150-250 mm at optimum moisture content and compacting to at least 90 per cent of the maximum dry density determined by the modified Proctor test. After construction, the embankments must be stable and have a coefficient of permeability, as determined in situ, of less than 10^{-7} m/s. The soil making up the base of the ponds must also have a coefficient of permeability not greater than 10^{-7} m/s or the pond must be lined. In the case of El Nazlah village, consideration would have to be given to lining the bottom and slopes of the ponds, with soil/cement lining probably being cheapest. 8 kg cement per m^2 of soil surface has been used for this purpose.

The area taken up by the embankments would depend on the slope adopted. If a 2:1 slope was feasible (as determined by Dr. A.A. Warith, the local consultants) the arrangement shown in Fig. 4.3 would apply to anaerobic ponds.

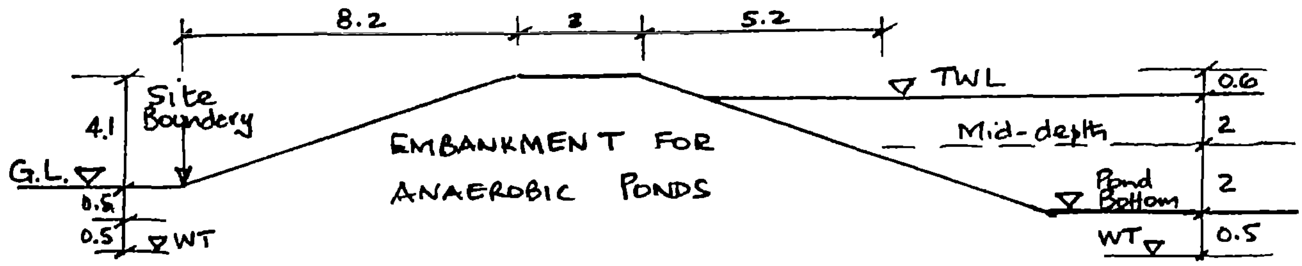


Figure 4.3 Embankment for Anaerobic Ponds

Hence, from the site boundary, the distance to the anaerobic pond mid-depth point would be 16.2 m and between anaerobic ponds the distance to mid-depth points would be 13.4 m.

If the same 2:1 slope was adopted for facultative pond embankments, the equivalent distances to allow for in the layout would be as shown in Fig. 4.4. Thus, from the site boundary, the distance to the facultative pond mid-depth point would be 9.8 m and between facultative ponds the distance to mid-depth points would be 9 m. The minimum distance between a facultative pond and an anaerobic pond would be 11.2 m.

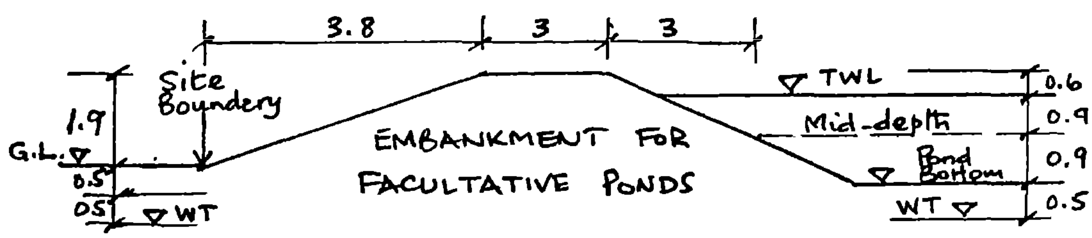


Figure 4.4 Embankment for Facultative Ponds

4.7.4 Ponds' Layout

Allowing for the requisite distances between pond mid-depths and boundaries, to accommodate essential embankments, and utilizing the maximum possible area on the site, a layout as shown on Fig. 4.5 appeared to be reasonable. The irregular shape of the site necessitated adopting irregular shaped facultative ponds but this was unavoidable.

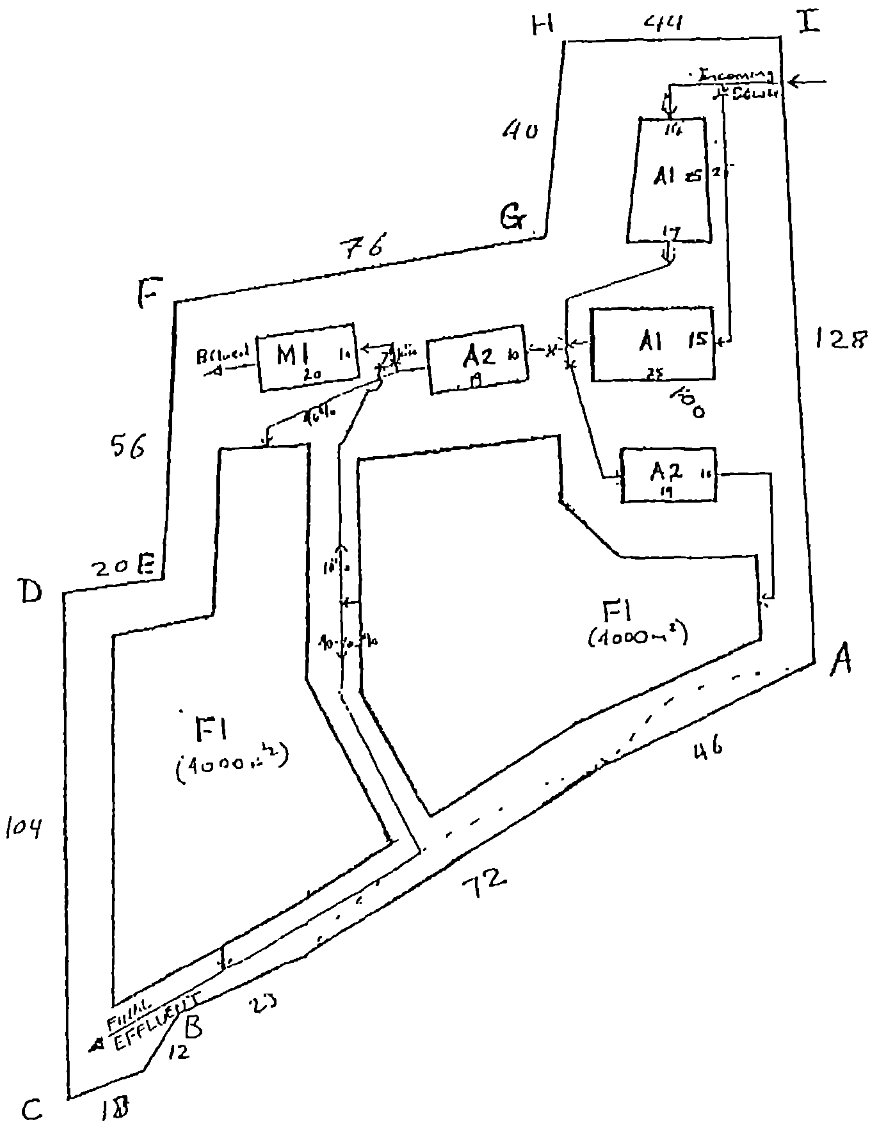


Figure 4.5 Diagrammatic Ponds Layout for El Nazlah Village, Fayoum

The layout shown includes an experimental macrophyte pond to allow the treatment of either anaerobic pond 2 effluent or facultative pond effluent. Not enough area was available to accommodate two macrophyte ponds but one pond could treat the two effluents at different times, providing the necessary information with minimum land use. The local consultant would need to survey the site and develop a precise layout to accommodate the necessary ponds.

4.7.5 Macrophyte Ponds

In view of the fact that sewage treatment using emergent macrophytes was already being studied in Ismaila, Egypt, it was proposed that only floating macrophytes be studied at El Nazlah. Also, because of the widespread use of information available on water hyacinth (Eichhornia crassipes) and the local opposition to extension of this macrophyte in Egypt, it was recommended that either water lettuce (Pistia stratiotes) or the floating macrophyte commonly growing on Egyption canals (other than water hyacinth) be adopted in the experimental studies at El Nazlah.

To reduce the area required for the macrophyte pond, it was suggested that only 10 per cent of the flow from one anaerobic pond 2 or from one facultative pond be diverted to the macrophyte pond. Thus, the flow would be of the order of 42.5 m^3/d. Allowing for a maximum of six days' retention at this flow and a depth of 1.6 m, the macrophyte pond volume would be 255 m^2 and the area 160 m^2. A 20 m x 10 m x 1.6 m macrophyte pond, as shown on Fig. 4.5 would provide about seven and a half days' retention at an inflow of 42.5 m^3/d.

To overcome the possibility of mosquitos becoming a problem in the floating macrophyte pond, it was recommended that mosquito larvae-eating fish, such as Gambusia, Axtyarax, Macropodus, etc., should be tested for their biological control potential.

5. FINAL DESIGN CRITERIA

Dr. A.A. Warith, the local consultants, subsequently adopted the following design criteria for their final design.

5.1 Inlet Units

5.1.1 Inlet Chamber

- Retention time = 10-60 sec.

5.1.2 Approach Channel

- Velocity of flow (v) = 0.6-1.2 m/s
- $b = 2\,d$, $v = (1/n)\,R^{2/3}\,S^{1/2}$

Where,
b = breadth of channel
d = depth of water
n = Manning's roughness coefficient
R = hydraulic radius
s = slope of hydraulic gradient

5.1.3 Bar Screen

- Net area between bars on inclined projection = (2-3) x cross-section of approach channel.
- Inclination angle of bars to the horizontal = 45°-60°.
- Spacing between bars (S) = 3-6 cm for manual cleaning.
- Thickness of bars = 10-19 mm.
- Head loss through bars (h_l) = $1.4\,[(V_1)^2 - (V_2)^2]/2\,g$.

Where,
V_1 = Velocity of flow through bar screen.
V_2 = Velocity of flow through approach channel.

5.1.4 Measuring Weir

$$Q = 3.33\,L\,H^{2.5}$$

Where,

Q	= Max. discharge	(ft^3/sec)
L	= Length of weir	(ft)
H	= Head over crest of weir	(ft)

5.2 Stabilization Ponds

5.2.1 Anaerobic Pond

Retention time (RT)	= 3-6 days
Efficiency of treatment (E_a)	= 40-55 per cent
Depth of water in pond	= 3-5 m
Allowable volumetric loading	= 0.1-0.3 kg BOD_5/m^3.day
Allowable surface loading	= 1000-6000 kg BOD_5/ha.day
Retention time for accumulation of sludge	= 3-4 years
Depth of sludge	= 0.5-1.0 m

Efficiency (E_a) = $L_e/L_i = 1/[(K_T\ (E_a)^n\ R_T + 1)] \times 100$.

Where,

L_e = Effluent organic load from pond (mg/l)
L_i = Influent organic load to pond (mg/l)
R_T = Retention time (days)
K_T = First order soluble BOD_5 removal rate constant at temperature T °C = $K_{20} \cdot \theta^{(T-20)}$
K_{20} = 6.0 day^{-1} at 20°C
θ = Temperature constant = 1.085
T = Average temperature in winter (°C)
n = Constant, equal to 4.8.

5.2.2 Facultative Pond

Retention time	= 15-30 days
Depth of water in pond	= 1-2 m
Efficiency of treatment	= 80-90%
Organic surface loading	= 200-250 kg BOD_5/ha.day
Efficiency (E_f)	= $L_e/L_i = [1/(1 + K_T \times R_f)] \times 100$

Where,
L_e = Effluent organic load from pond (mg/l)
L_i = Influent organic load to pond (mg/l)
R_f = Retention period (days)
K_T = First order soluble BOD_5 removal rate constant at temperature T °C = $K_{20} \cdot \theta^{(T-20)}$
K_{20} = 1-2 day^{-1}
θ = Temperature constant = 1.085
T = Average temperature in winter (°C).

5.2.3 Maturation Pond

Retention time	= 3-7 days
Efficiency (E_m)	= 60-70%
Depth of water in pond	= 1.0-2.0 m.

5.3 Experimental Macrophyte Ponds

Depth of water = 0.5 m (for emergent macrophytes) or 1.6 m (for floating macrophytes).

Retention time = 5 days.

6. FINAL DESIGN AND PLANT DESCRIPTION

6.1 General

The local consultants, Dr. A.A. Warith, prepared the final design of the sewage treatment plant for El Nazlah to meet the stated objectives of establishing a conventional stabilization pond system. The design took into account the need to dispose of the treated effluent into the nearest drain. Therefore, the quality of the treated effluent was guaranteed to meet Egyptian Law 48, 1982, regarding discharge of treated effluent into public drains. According to this law, effluent BOD_5 and suspended solids should not exceed 60 and 50 mg/l, respectively.

The design reviewed in this Manual is compatible with the engineering drawings and specifications prepared for the tender documents.

6.2 Selected Design Configuration

After reviewing available data and reports, including the soil investigation report, and following frequent and intensive discussions with the WHO project personnel, the consultants summarized their main findings and results of discussions in the following key issues, which were incorporated in the design:

i) Although the available area for the treatment plant site was relatively large (about 4.5 acres) for treatment systems such as activated sludge or biological filters, for conventional waste stabilization ponds the available area was not sufficient to accommodate the treatment units required for the future needs of the village.

ii) It was decided to use two anaerobic ponds in parallel in order to allow diversion of the total flow to one of them while desludging the other. This arrangement would also facilitate maintenance in any of these ponds. Using two anaerobic ponds also followed the suggestion of Prof. Pescod. However, one facultative pond only was recommended to save the area of a dividing embankment and increase the volume of the pond.

iii) Owing to significant differences in groundwater levels within the site (1 m to more than 3.5 m below ground level), it was decided to locate the deep ponds (anaerobic ponds) where the boreholes showed lower groundwater levels. Other shallow units were designed to have their bed level at or slightly below the original ground level, to reduce the cost of construction to a minimum.

iv) In order to keep the cost of construction to a minimum, it was decided to use earth embankments for the boundary walls of the ponds, because this was found to be the least cost option.

v) Earth embankments could be constructed either using gravelly sandy soil or clay. Since the former was more likely to be available and is also commonly used for such earthwork construction, it was recommended that this material should be used for the construction of earth embankments for the ponds at El Nazlah. The classification of the used material should be according to the specifications of ASSHTO-M-145, or equivalent. The supplied soil must be compacted by a vibrating steel roller to obtain at least 95 per cent of the maximum dry density according to item DZ049 of the ASTM specification, or equivalent.

vi) It was recommended that internal sealing of the earth embankments as well as the bottom of the ponds should be accomplished using soft polyethylene sheets, of thickness 300 micron (locally available), to prevent leakage of sewage and contamination of groundwater resources. The polyethylene sheet was to be protected by a 20 cm thick layer of clay soil supported by concrete hollow slabs.

vii) External protection of earth embankments was to be similar to the internal protection, using hollow concrete slabs on a 20 cm thick clay layer but excluding the sealing liner. This protection was necessary to prevent intruders from damaging the embankments or extracting soil from them, especially if no security fencing was to be provided.

viii) It was agreed with the WHO project personnel that macrophyte ponds were to be included only as experimental pilot units receiving a small fraction of the total sewage flow (3-10 per cent). Moreover, it was decided to include two macrophyte ponds, one receiving effluent from the anaerobic ponds and the other receiving effluent from the facultative pond. Each macrophyte pond was designed to be operable either with an emergent or with a floating aquatic plant system.

ix) As a result of the irregular boundaries of the treatment site, pond configurations were also irregular to achieve best utilization of the land.

x) All pipes carrying sewage or treated effluent that were to be constructed underground should be made of PVC, which is resistant to corrosion against both sewage as well as soil containing a high chloride content and relatively high salinity.

xi) Penstocks were recommended as regulation devices wherever possible, to facilitate inspection and maintenance of interconnecting pipes, especially for pipes carrying raw sewage or effluent containing high suspended solids content. However, occasionally that was not possible, due to pressure head limitations and the need to lower the bed level of some ponds, because it would have significantly increased the cost of construction.

xii) It was recommended that an electromagnetic flow meter with recorder should be installed on the force main at the treatment site to provide full information on sewage flow. In addition, flow meters to monitor precisely the flow rate to the macrophyte pond during the experimental period were also proposed.

6.3 Design Basis

Design Year	= 1995
Population at year 1995	= 12,350
Population of area served by first phase sewerage system	= 9,670
Design population (connected to STP)	= 8,200
Water consumption	= 65 lpcd
Sewage flow	= 80% of water consumption
Infiltration rate	= 0.35 m^3/d per cm diam. per km
Sludge accumulation	= 0.04 m^3/cap. per year
Concentration of organic matter (BOD_5) in raw sewage	= 800 mg/l
Average temperature in winter	= 15°C
Available area of treatment plant site	= 19,200 m^2
Area available for construction of treatment units	= 17,900 m^2
Flow rate from pumping station to sewage treatment plant	= 15 l/sec.

Design flow for inlet units (inlet chamber, screen, etc) will be taken as 15 l/s

Sewage flow = [8200 x 65 x 0.8]/1000 = 426.40m^3/d

Infiltration flow = 0.35 (16 x 4.2 + 20 x 1.1 + 25 x 0.61) = 36.60 m^3/d

Total sewage flow = 426.40 + 36.60 = 463 m^3/d.

6.4 Design of Treatment Units

6.4.1 Inlet Chamber

Flow rate from pumping station is 15 l/sec

Water level = 9.15 m

Invert level = 8.45 m

Longitudinal sectional area of chamber

= [(1.10 + 0.50)/2] x 0.60 + 1.1 x 0.20 = 0.70 m^2

Chamber width = 0.2 m

Volume of chamber = 0.70 x 0.2 = 0.14 m^3

Retention period = volume/peak flow rate

= 0.14/0.015 = 9.30 ≡ 10 sec

6.4.2 Design of Screen

Q_{peak}	= 0.015 m^3/sec
Spacing between bars	= 3 cm
Water depth	= 0.18 m
Assume no. of openings	= 4
Total space between bars	= 4 x 0.03 = 0.12 m
Total width of bars	= 20 - 12 = 8 cm
Width of bar	= 8/5 = 1.6 cm = 16 mm
Velocity upstream of screen	= 0.015/(0.18 x 0.2)
	= 0.42 m/sec

Velocity through screen = 0.015/(0.18 x 0.12)
= 0.70 m/sec

Losses through clean screen
= 1.4 $[(0.7)^2 - (0.42)^2]/(2 \times 9.81)$ = 0.02 m = 2 cm

Allowance was made for a head loss up to 30 cm through the screen between cleanings.

6.4.3 Design of Weir

Q = 15 l/sec (peak flow from sewage pumping station)
= 0.015 m^3/sec = 0.53 ft^3/sec
Q = 3.33 L $kH^{1.5}$
Take width = 20 cm
0.53 = 3.33 [0.20/0.3048] $H^{1.5}$
$H^{1.5}$ = 0.24
H = 0.38 ft = 12.5 cm ≡ 13 cm

6.4.4 Design of Anaerobic Pond

5 days retention period is used
Flow = 463 m^3/d
Volume of pond = 463 x 5 = 2,314.80 m^3
Volume of sludge = 0.04 x 8200 x 3 = 984 m^3
Total volume = 2314.80 + 984 = 3,298.8 m^3
BOD_5 loading = 800 x 463/1000 = 370.37 kg BOD_5/d
Volumetric loading = 370.37/2314.80
= 0.16 kg BOD/m^3.d
i.e. < 0.3, > 0.1
Depth = 4 m
Surface area at mid-depth = 3,298.8/4 = 824.70 m^2
= 824.70/2 = 412.35 m^2
Surface loading = 370.37 x 10^4/824.70 = 4,490 kg BOD_5/ha.d
i.e. < 6,000, > 1,000

To calculate the effluent BOD_5 from the anaerobic pond the following relationship, given by Vincent et al. (1963), was used.

$$Le = L_i/[K_T (L_e/L_i)^n R + 1]$$

Where,
L_e = effluent BOD_5 (mg/l)
L_i = influent BOD_5 (mg/l)
K_T = rate coefficient = 6.0 at 20 °C
n = constant = 4.8
R = retention period (days)
K_T = $K_{20} \times 1.085^{(T-20)}$
Since T = 15 °C for El Nazlah village
K_{15} = $6 \times 1.085^{(15-20)}$ = 3.99
L_e = $800/[4 (L_e/L_i)^{4.8}$ c 5 + 1] = 420 mg/l

6.4.5 Design of Facultative Pond

To obtain an acceptable surface loading rate, the empirical procedure developed by McGarry and Pescod (1970) was used:

$$S = 20\ T_m - 60$$

Where,

S	=	Max. surface loading rate (kg BOD_5/ha.d)
T_m	=	Average temperature (°C)
S	=	20 (15) - 60 = 250 kg BOD_5/ha.d

It was assumed that 3 per cent of the total flow received by the anaerobic ponds would pass through one of the macrophyte ponds.

Flow rate to the facultative pond	= 0.97 x 463
	= 449.07 m^3/d ≡ 449 m^3/d
Surface area	= [(420 x 449)/(1000 x 240)]
	= 0.7858 ha = 7858 m^2
Assuming depth of pond	= 1.60 m
Volume of pond	= 7858 x 1.60 = 12,572.8 m^3
Retention period	= 12,572.8/463 = 27.16 days

To estimate the BOD_5 of the effluent from the facultative pond the empirical formula derived by Gloyna (1971) was used:

$$L_e = L_i/(K_T\ R_f + 1)$$

Where,

L_e	=	effluent BOD_5 (mg/l)
L_i	=	influent BOD_5 (mg/l)
R_f	=	retention period (days)

Where, K_T is the BOD_5 reduction rate constant in the pond, which varies with temperature according to the equation:

$$K_T = K_{35} \times 1.085^{(T-35)}$$

Where,

K_{35}	=	1.20
K_T	=	$1.2 \times 1.085^{(15-35)} = 0.2$
L_e	=	420/(0.23 x 27.16 + 1) = 58.0 mg/l

6.4.6 Design of Maturation Pond

Flow rate to maturation pond = 0.97 x 463 = 449 m^3/d

Available area for maturation pond is about 1360 m^2

Assuming depth of water	= 1.40 m
Volume of pond	= 1360 x 1.40 = 1904 m^3
Design retention period	= 1904/449 = 4.2 days

6.4.7 Design of Macrophyte Ponds

Each of the two ponds was designed to provide a retention period of five days with a depth of either 0.5 m or 1.6 m.

i) Floating Macrophyte Pond

Flow	= 10/100 x 463 = 46.3 m^3/d
Volume of pond	= 46.3 x 5 = 231.45 m^3
Assume depth	= 1.6 m
Surface area at mid-depth	= 231.45/1.60 = 144.60 m^2

ii) Emergent Macrophyte Pond

Volume of pond	= 144.60 x 0.5 = 72.30 m^3
Accommodated flow	= 72.3/5 = 14.46 m^3/d
Accommodated flow as per cent of total flow	= 14.46/463 x 100
	= 3.1% ≡ 3%

6.5 Description of Selected Design

WHO recommended the use of stabilization ponds as an appropriate system for treatment of sewage in El Nazlah village due to their suitability for developing countries. The local consultants finalized the most appropriate option of the stabilization ponds system that suited the land area available for the treatment units at El Nazlah village. A brief description of each component of the recommended system is given in the following sections and a more detailed description of the plant is included in Appendix A of this Manual.

6.5.1 Anaerobic Ponds

These ponds were designed to be 4 m in depth to allow for settling of suspended solids. The organic load was expected to be reduced in these ponds by about 50 per cent, due to both the settling of part of the suspended organic matter and the decomposition of part of the soluble organic matter by the action of anaerobic bacteria.

Effluent from anaerobic ponds usually contains a low concentration of suspended solids which can easily be treated in subsequent units. A relatively large depth was allowed to accommodate deposited sludge for a period of not less than three years. In addition, two ponds were recommended to allow for the maintenance of one while the other received the full sewage flow. Cleaning of these ponds was recommended to be effected using a submersible sludge pump fitted with a flexible hose on the delivery side connected to a tanker for sludge haulage to sludge drying beds or landfill. A boat could be used for operation of the submersible sludge pump used to remove sludge from the pond bottom.

6.5.2 Facultative Pond

This pond was designed to be 1.6 m in depth. It should be aerobic for a great part of its depth but will be anaerobic near the pond bottom. A shallow pond depth was selected to allow for the growth of aerobic bacteria, which oxidize the organic matter at a rate higher than anaerobic bacteria, and this was possible at El Nazlah where the available area for the treatment works was relatively large. Moreover, the small depth is suitable for growth of algae, which provide the oxygen required for aerobic oxidation of organic matter. The efficiency of this facultative pond in oxidizing organic matter was expected to be from 85-90 per cent.

6.5.3 Maturation Pond

This pond was designed to be 1.4 m in depth. It operates as an aerobic pond over its full depth due to the small imposed organic load. Aeration of the pond is achieved as a result of atmospheric reaeration through the surface and photosynthetic oxygen production by algae growing in the pond. As the concentration of suspended solids is relatively small in this pond sunlight will readily penetrate the full depth and therefore will contribute to the disinfection process and destroy pathogenic bacteria.

Owing to the lack of appropriate applications of stabilization pond treatment systems in Egypt and because of insufficient data and knowledge of such applications elsewhere under similar climatic conditions, the local consultants considered the maturation pond as an experimental component that might need further investigation after implementation. Within the first year of operation, it was expected that this pond would act as a maturation pond to improve effluent quality. Over that period, monitoring of the effluent from the facultative pond would take place and effluent quality would be compared with allowable standards for discharge into public drains. If the effluent quality from the facultative pond, after monitoring for sufficient time, proved to be adequate for direct discharge into public drains the maturation pond would no longer be needed as such. Thus the pond could be used either as a fish (aquaculture) pond or it could be added to the facultative pond to increase system capacity and hence treat more flow of sewage using the same system with only slight modification. The modification required would be mainly removal of the part of the embankment separating the maturation and facultative ponds.

6.5.4 Macrophyte Ponds

These ponds were designed to accommodate both floating and submergent aquatic plants. Therefore, each pond was designed to operate at 0.5 m and 1.6 m water depth. One of the two ponds will receive the effluent from the anaerobic pond and the other the effluent from the facultative pond. The flow rate diverted to each of the ponds may vary between three and ten per cent of the total flow handled by the overall treatment plant, depending on the type of aquatic weed (Fig. 6.1). The objective in establishing the macrophyte ponds was to carry out experiments under local conditions to evaluate the performance of these ponds and make recommendations for their potential use in the future.

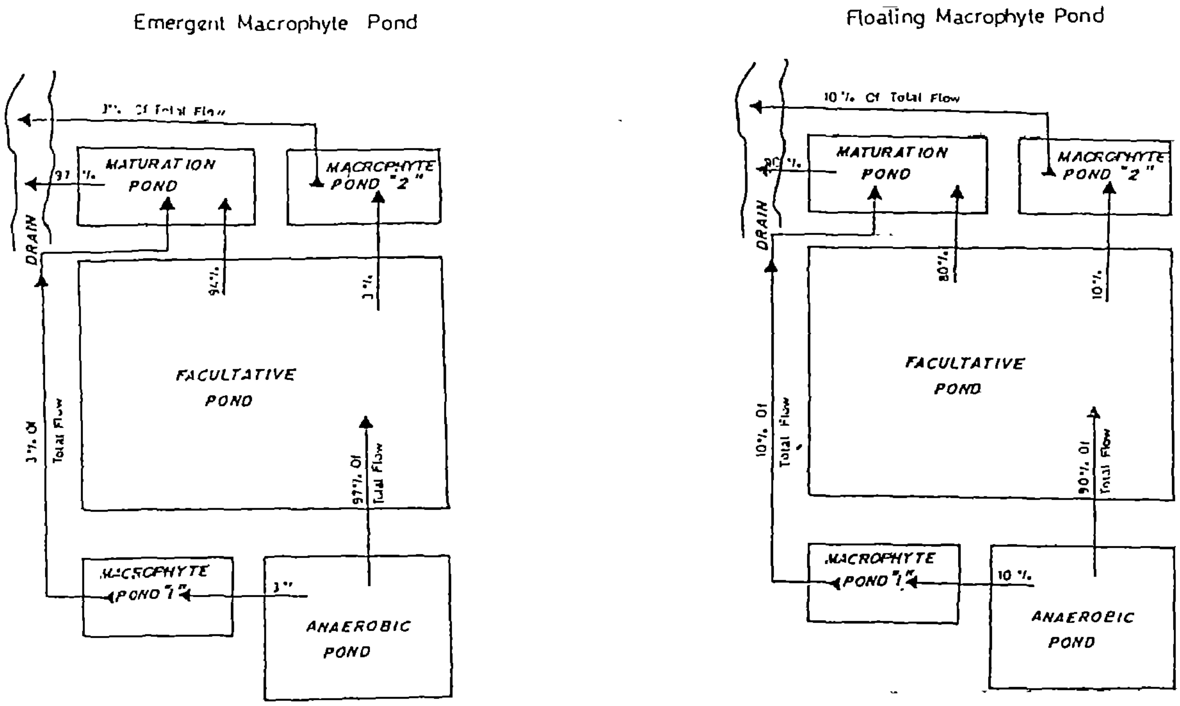


Figure 6.1 Schematic Diagrams Showing the Flow Distribution Among Various Treatment Units for Both Emergent and Floating Macrophyte Types

6.5.5 Plant Layout and Construction

Fig. 6.2 shows the layout of the treatment units. A brief description of the form of construction of the required works for the different treatment units is presented in the following sections:

i) Inlet Chamber

The inlet chamber was to be constructed from reinforced concrete, with length 110 cm, width 20 cm, height 165 cm and water depth 80 cm.

ii) Screen

The screen was to be inclined 60° to the horizontal and would include five steel bars each 16 mm thick with 3 cm spacing between adjacent bars.

iii) Flow-measurement Weir

The flow-measurement weir was to be made of galvanized steel plate 5 mm thick, 20 cm width and 10 cm height. A scale for head measurement was to be located over the weir channel 50 cm from the weir.

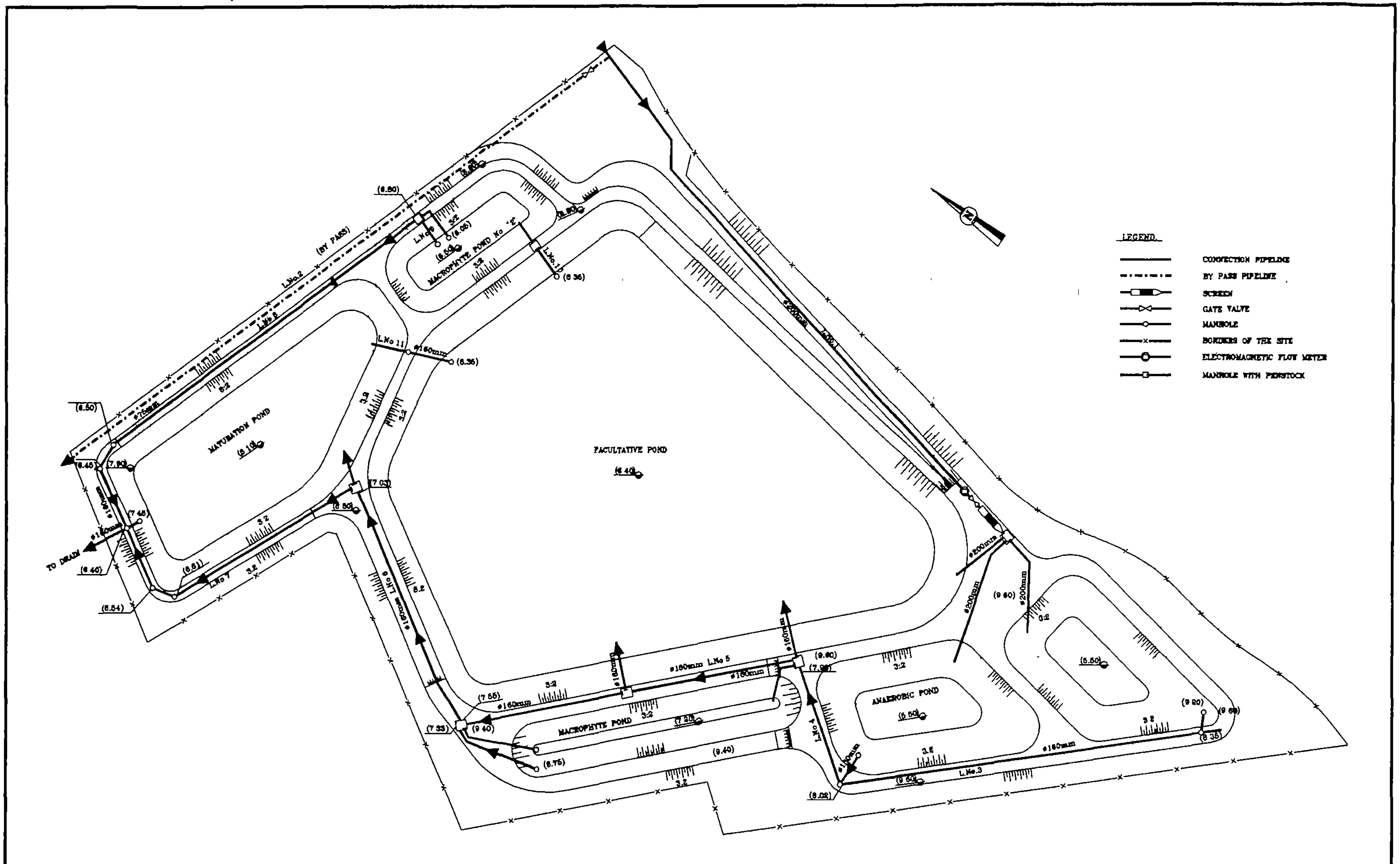


FIGURE 6-2 GENERAL LAYOUT FOR SEWAGE TREATMENT PLANT

iv) Anaerobic Ponds

Two anaerobic ponds were to be constructed using earth embankments with a slope of two horizontal to one vertical on an area of about 825 m^2 at mid water depth. A layer of 15 cm thick fine sand topped by 15 cm of gravel was to be laid above a polyethylene lining sheet. Water depth would be 4 m. All internal slopes of the ponds were to be supported by hollow concrete blocks and the external slopes would be supported with pitching or by hollow concrete blocks.

v) Facultative Pond

The facultative pond was to be constructed using earth embankments with a slope of two horizontal to one vertical on an area of about 7860 m^2 at mid water depth. A layer of 15 cm thick fine sand topped by 15 cm of gravel was to be laid above a polyethylene lining sheet. Water depth would be 1.6 m. All internal slopes of the pond were to be supported with hollow concrete blocks and the external slopes would be supported with pitching or hollow concrete blocks.

vi) Maturation Pond

The maturation pond was to be constructed using earth embankments with a slope of two horizontal to one vertical on an area of about 1600 m^2 at mid water depth. A layer of 15 cm thick fine sand topped by 15 cm of gravel was to be laid above a polyethylene lining sheet. Water depth would be 1.4 m. All internal slopes of the pond were to be supported with hollow concrete blocks and the external slopes would be supported with pitching or hollow concrete blocks.

vii) Macrophayte Ponds

Two ponds were to be constructed for experimentation, one of them to receive part of the effluent from the anaerobic pond and the other to receive part of the effluent from the facultative pond. The depths of water in these ponds were either 0.5 m or 1.6 m, in order to allow for their operation as either emergent or floating macrophyte systems. Each pond was to be constructed using earth embankments with a slope of two horizontal to one vertical on an area of about 145 m^2 at mid water depth. A 15 cm layer of fine sand topped by 15 cm of gravel was to be laid above a polyethylene lining sheet. All internal slopes of the pond were to be supported with hollow concrete blocks and the external slopes would be supported with pitching or hollow concrete blocks.

vii) Inter-connecting Pipes

The sewage treatment plant would receive influent flow through a 200 mm force main designed by the local consultants, Dr. A.A. Warith. Effluent from the maturation pond would be discharged into an adjacent drain which discharges in turn into the local main drain. 200 mm, 160 mm, and 75 mm PVC pipes were to be used to connect the different ponds in the plant.

ix) Roads

The plant was to be provided with a paved earth embankment of 4 m width for access to the anaerobic ponds. This will allow for vehicle manoevring. The plant would be surrounded by a wire fence and provided with an entrance gate of 4 m width. An area of about 120 m^2 was allowed for administration offices and stores.

6.6 Effluent Disposal and Reuse Options

Effluent quality and its disposal or reuse options depend on the degree of treatment given to the raw sewage. Often, the policy for effluent disposal and/or reuse controls and governs the selection of technology and unit processes for the treatment plant in order to achieve the goals set by the policy makers with due regard to present laws and regulations.

From the viewpoints of economy and resource conservation, irrigation use of the treated effluent from the El Nazlah treatment plant seemed to be appropriate. However, according to the local consultants' terms of reference, the final design of the treatment works should consider disposal of treated effluent to the drain nearest to the treatment site. Consequently, their design considered this obligation in preparing the tender documents. The quality of treated effluent suitable for discharge into public drains, according to Egyptian Law 48, 1982, should contain no more than 60 mg/l BOD_5 and 50 mg/l suspended solids. Accordingly, the treatment plant works were designed to cope with the stated standards of the law and the local consultants guaranteed the required effluent quality.

On the other hand, it was recognized that the effluent quality might be suitable for use in irrigation. However, monitoring the quality of the treated effluent was recommended before considering its use for irrigation. It was recommended that the monitoring programme should include analysis of the effluent for conventional parameters such as BOD_5, COD, ammonia, total nitrogen and phosphorus, suspended solids, and grease as well as faecal and total coliforms. The California Department of Health Services (CDHS) water quality standards regarding bacterial count for different levels of treatment and types of use of the treated effluent were provided by the local consultants, as in Table 6.1. It was recommended that toxic micro-pollutants (heavy metals and toxic organic substances) should be checked intermittently. The recommended maximum concentrations of trace metals in irrigation were provided as in Table 6.2. Attention was also drawn to the technological aspects of the irrigation system, which may also impose some limitations on the maximum allowable levels of pollutants. For instance, plugging potential has to be considered for drip irrigation systems, as in Table 6.3.

TABLE 6.1 WASTEWATER RECLAMATION TREATMENT AND QUALITY CRITERIA FOR IRRIGATION AND IMPOUNDMENTS

Treatment Level	Coliform Liimits	Type of Use
Primary		Surface irrigation of orchards and crops vineyards - Fodder, Fiber and seed crops
Oxidation and	≥ 23 coliforms/100 ml	Pasture for milk producing animals - Landscape impoundment - Landscape irrigation (golf courses, cemeteries)
	≥ 2.2 coliforms/100 ml	Surface irrigation on food crops - Restricted recreational impoundment
Oxidation, coagulation, clarification, filtration and disinfection	≥ 2.2 coliforms/100 ml	Spray irrigation for food crops - Landscape irrigation (parks, playgrounds) Non-restricted recreational impoundment

Source: Crook (1985)

TABLE 6.2 RECOMMENDED MAXIMUM CONCENTRATION OF TRACE METALS IN IRRIGATION WATER

Element	For Water Used Continuously on all Soil (mg/l)	For use up to 20 years on Fine-Textured Soils at pH 6.0-8.5 (mg/l)
Cd	0.01	0.05
Cr	0.10	1.00
Cu	0.20	5.00
NI	0.20	2.00
Pb	5.00	10.00
Zn	2.00	10.00
Be	0.10	0.50

Source: Camp, Dresser and McKee Inc. (1980)

TABLE 6.3 PLUGGING POTENTIAL OF IRRIGATION WATER USED IN DRIP IRRIGATION SYSTEMS

Type of Problem	Potential Restriction on Use		
	Little	Slight to Moderate	Severe
Physical			
Suspended Solids (mg/l)	< 50	50-100	> 100
Chemical			
pH	< 7	7-8	> 8
Dissolved solids (mg/l)	< 500	500-2000	> 2000
Manganese (mg/l)	< 0.1	0.1-1.5	> 1.5
Iron (mg/l)	< 0.1	0.1-1.5	> 1.5
Hydrogen Sulphide (mg/l)	< 0.5	0.5-2	> 2
Biological			
Bacterial population (max no/ml)	< 10000	10000-50000	> 50000

Source: Wescot and Ayers (1985)

6.7 Sludge Disposal Options

Disposal of sludge, either wet or dry, is one of the main problems at sewage treatment works. Combinations of physical, chemical and biological processes are employed in handling sludges. The objective of processing sludge is to extract water from the solids and dispose of the dewatered residue hygienically.

Unfortunately, the site of the sewage treatment plant at El Nazlah village does not provide any space for sludge handling and/or disposal. Therefore, sludge handling and/or disposal should take place off site. On the other hand, it is fortunate that desludging (sludge removal) will only be required once every three years.

The total amount of sludge to be expected at the works is made up of the quantities of solids coming down the sewer, plus the solids estimated to be produced in the biological decomposition of organic matter, minus the solids lost in the effluent. In 1968, a very extensive investigation by the Water Pollution Research Laboratory in England (Bolitho, 1973) indicated that the average quantity of sewage sludge dry solids was 0.0785 kg/capita day, regardless of the type of sewage treatment. At works where no treatment was given, other than preliminary processes and primary sedimentation, the sludge solids were 0.0545 kg/capita day. The average moisture content of such sludge was 92.5 per cent, giving about 0.726 litres of sludge/capita day. Of the dry solids, 72.2 per cent were volatile matter, or about 0.04 kg/capita day.

The estimated sludge accumulation in the anaerobic pond of the proposed sewage treatment plant at El Nazlah village is less than these figures. This is because the settled solids will undergo anaerobic decomposition that will reduce their volume and, in addition, the longer detention period in such ponds (five days) will concentrate the solids and reduce the sludge water content resulting in further volume reduction of sludge. Accordingly, the yearly sludge accumulation rate in the anaerobic pond was taken as 0.04 m^3/capita, following the recommendation of Prof. Gloyna. Based on this criterion, the quantity of sludge expected to accumulate in three years and which will require handling, is expected to be of the order of 984 m^3. The estimated water content of this sludge would be approximately 90 per cent (10 per cent solids).

In developing countries, sewage sludge should be disposed of at least cost, whilst safeguarding public health, avoiding environmental damage and considering the value of sewage sludge as a resource. In view of these guidelines and because of the intermittent production of sludge at El Nazlah, only two options seem to be available.

The first option is to haul the sludge by tanker trucks and dispose of it after dewatering on the drying beds of the nearest treatment plant. In this case, the treatment plant at Fayoum would be the closest treatment site. The Fayoum treatment plant is about 40 km from the site of the treatment plant at El Nazlah village. The produced sludge in this case should be collected in summer time when the drying beds of Fayoum plant are underloaded and can accommodate additional sludge quantity. In addition, it should be organized for the sludge to be transported in batches, each batch being delivered 15 days after the previous one. The local consultants proposed that one quarter of the total sludge quantity be transported in every batch ($1/4 \times 984 \equiv 240$ m^3). This quantity would require only about 850 m^2 of drying beds. Lime stabilization was, however, recommended to ensure that the sludge would not putrify and create odours or pose any health hazard when reused or disposed of. Rehabilitation of the treatment plant in Fayoum had been carried out by the local consultants at the end of 1985, when the number of sludge drying beds had been increased from 20 to about 120 beds. Implementation of the rehabilitation works started as of 1986 and would be completed by early 1989. Moreover, a new treatment plant, for which mechanical equipment has already been supplied, was planned to be constructed in the very near future. This new plant is supposed to serve the Fayoum Governorate up to the year 2020.

The second option is to locate a nearby site to which sludge could be hauled and where it could be disposed of in earth lagoons. In such lagoons the organic solids would be stabilized by anaerobic and aerobic decomposition. A sludge lagoon must be located away from highways and dwellings, to minimize possible nuisance from objectionable odours, and should be fenced to keep out unauthorized persons. Government desert land is available not far from the site of the treatment plant of El Nazlah village (10-20 km) and, therefore, the potential for obtaining a suitable site for sludge lagooning is high. Such a lagoon should be relatively shallow (1-1.5 m) and, once the sludge is dry, it could be removed and placed in a landfill. Lagoon drying time could be extended to two years before removal in order to free the sludge of pathogens (Healy, 1984). In this case, lagooned sludge could be applied to land used to grow crops for human consumption (cooked) or to park flowerbeds. Then, only precautions to protect groundwater from potential contamination would be necessary.

The location for the lagoon should be a natural depression of area about 1100 m^2 and a cheap polyethylene sheet (EL $5/m^2$) could be used as a liner.

It was recognized that the selection of any option would require further assessment, including cost analysis and study of topographic maps to identify a suitable site for sludge lagooning. Costing of the first option would need to take into account the transportation cost of sludge to Fayoum treatment plant and the cost of the lime needed for sludge stabilization, accepting that dewatering of sludge on drying beds at Fayoum treatment plant would be free of charge. Costing of the second option would need to take into account the transportation cost of sludge to the site of the lagoon, the cost of the required polyethyline sheet, accepting that the government would make the land available free of charge.

6.8 Future Development and Expansion Requirements

It was recommended, in implementing a treatment system in a country for the first time, to proceed in consecutive phases. In the meantime, it would be wise to consider, during the planning phase, reserving additional area (adjacent to the available land dedicated to serve the first phase) for the potential expansion of the treatment plant.

The stabilization pond system proposed for El Nazlah village was designed to handle a sewage flow of 463 m^3/d, serving a population of 8,200 (approximately 77 per cent of the present population and about 85 per cent of the population to be served by the sewerage system that will be implemented in the first phase development). The available site for the treatment plant occupies an area of 19,200 m^2 (4.5 acres) which means per capita area requirements of about 19,200/8,200 = 2.35 m^2/capita or the equivalent of about 41.5 m^2/m^3 of daily sewage flow.

The population in the year 2010 (after about 20 years) is expected to be 17,000, which will result in an average sewage flow of about 1360 m^3/d (excluding infiltration).

Accordingly, the area requirements to serve future expansion could be determined as follows:

i) Based on population growth

Required area = 17000 x 2.35
≅ 40000 m^2 (9.5 acres)

ii) Based on flow projections

Required area = 1360 x 41.5
≅ 56500 m^2 (13.5 acres)

For planning purposes, it is more appropriate to consider the area requirements based on the flow projection. This means that the area requirements for future expansion up to the year 2010 necessitate trebling the available site. This area, however, excludes the area required for sludge handling and/or disposal which has previously been addressed and, most probably, will be off site. The area requirement could also be revised based on the results of the investigations which will be conducted to evaluate the performance of the macrophyte ponds.

Therefore, acquiring additional land for future expansion should be decided after the full assessment of the experimental results is completed and the proper design criteria for macrophyte pond systems, under local conditions, are established.

7. BILL OF QUANTITIES AND COST

7.1 General

The final bill of quantities corresponding to the various works and unit prices in 1989 Egyptian pounds (LE) is given in Appendix B.

7.2 Final Cost Estimates and Cost Per Capita

Design cost (approximate)	=	15 000.00 LE
Supervision cost	=	22 500.00 LE
Construction cost	=	590 065.77 LE
Total Cost*		627 565.77 LE

The design population for the El Nazlah STP was 8200.

Therefore, cost per capita = 627 565.77 LE/8200
= 76.53 LE/cap

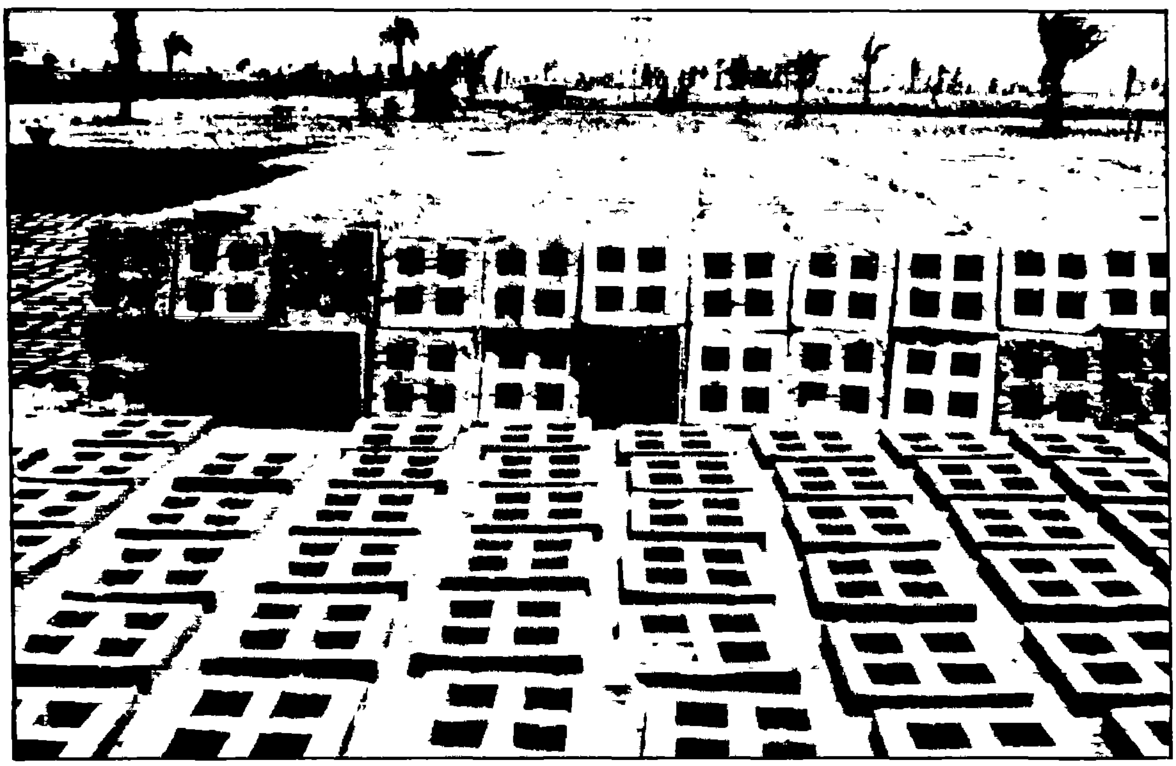
(*Administrative cost is not included)

8. CONSTRUCTION DRAWINGS AND PHOTOGRAPHS

8.1 General

This chapter includes the photographs of the El Nazlah treatment plant, taken at various stages of its construction. However, the construction drawings used for the construction of the ponds are given in Appendix C.

SITE OVERALL GRADING



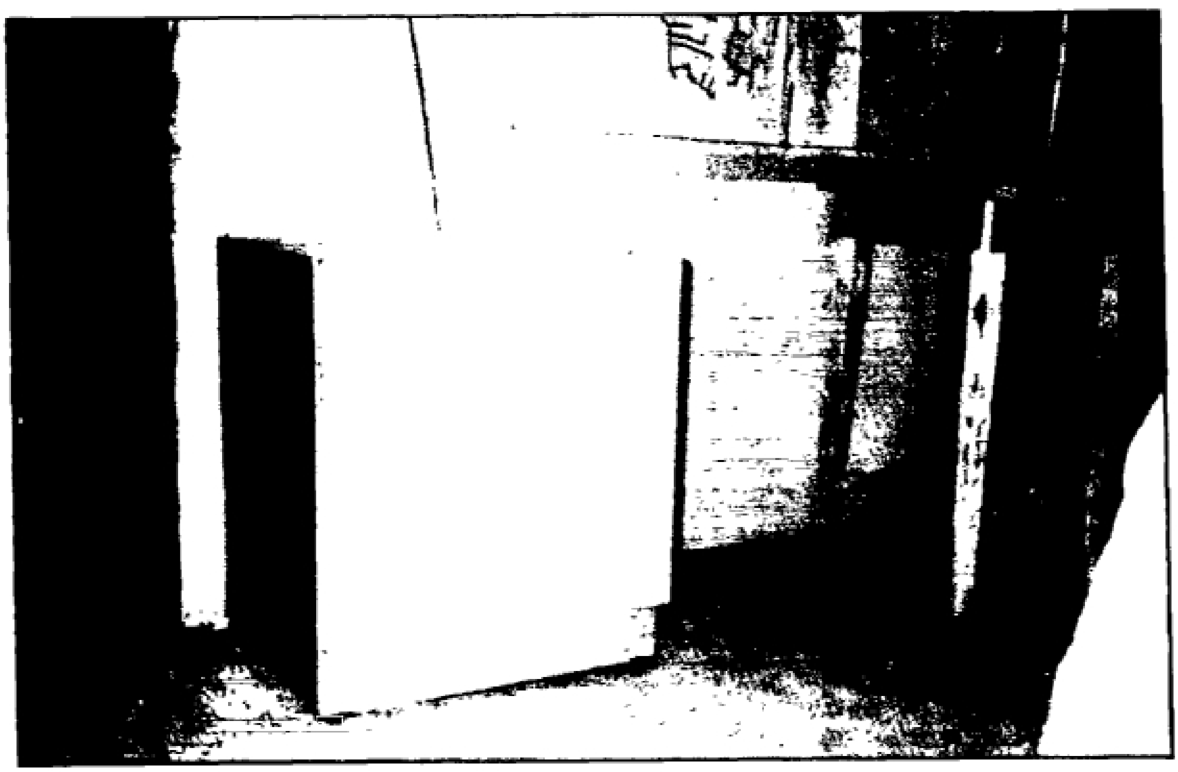
FABRICATION OF HOLLOW CONCRETE PANELS

EMBANKMENTS EXECUTION IN WELL COMPACTED LAYERS.

EMBANKMENTS EXECUTION IN WELL COMPACTED LAYERS

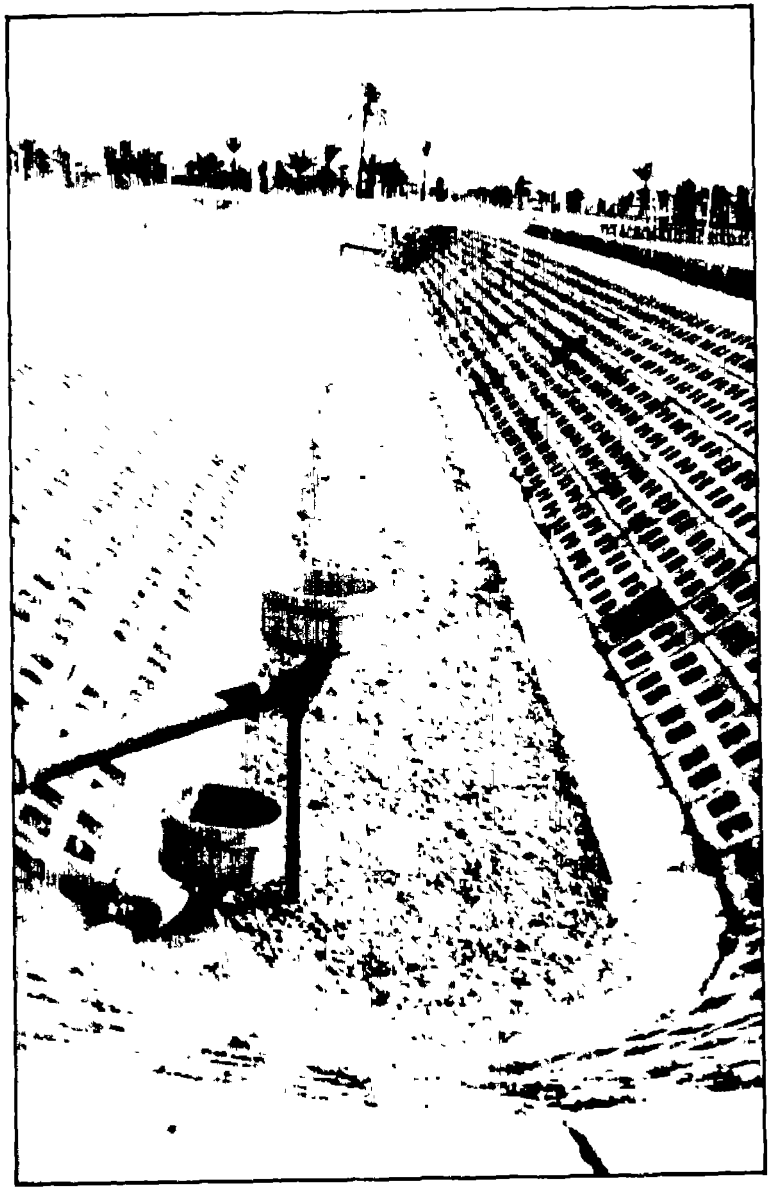
COMPACTION TESTS FOR EMBANKMENT LAYERS

SITE LABORATORY - SAND CONE TEST PROCEDURE

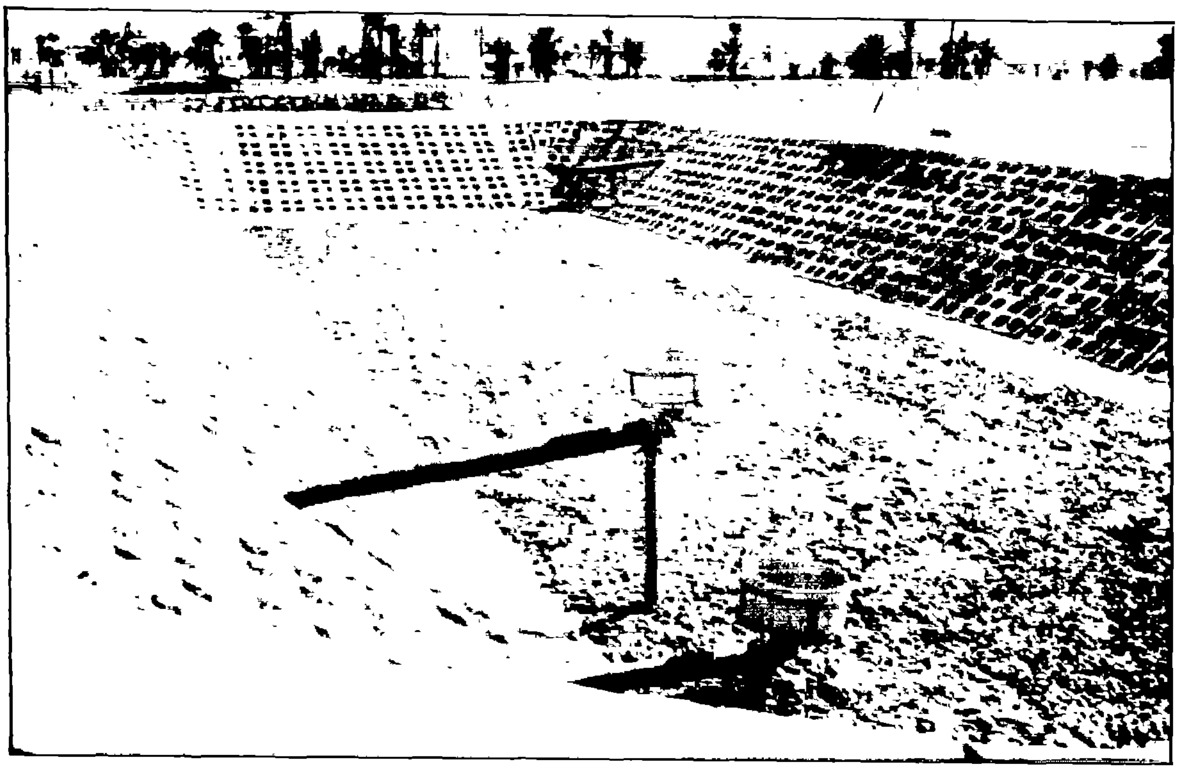


EMBANKMENTS OUTSIDE PITCHING

MACROPHYTE POND No. 1

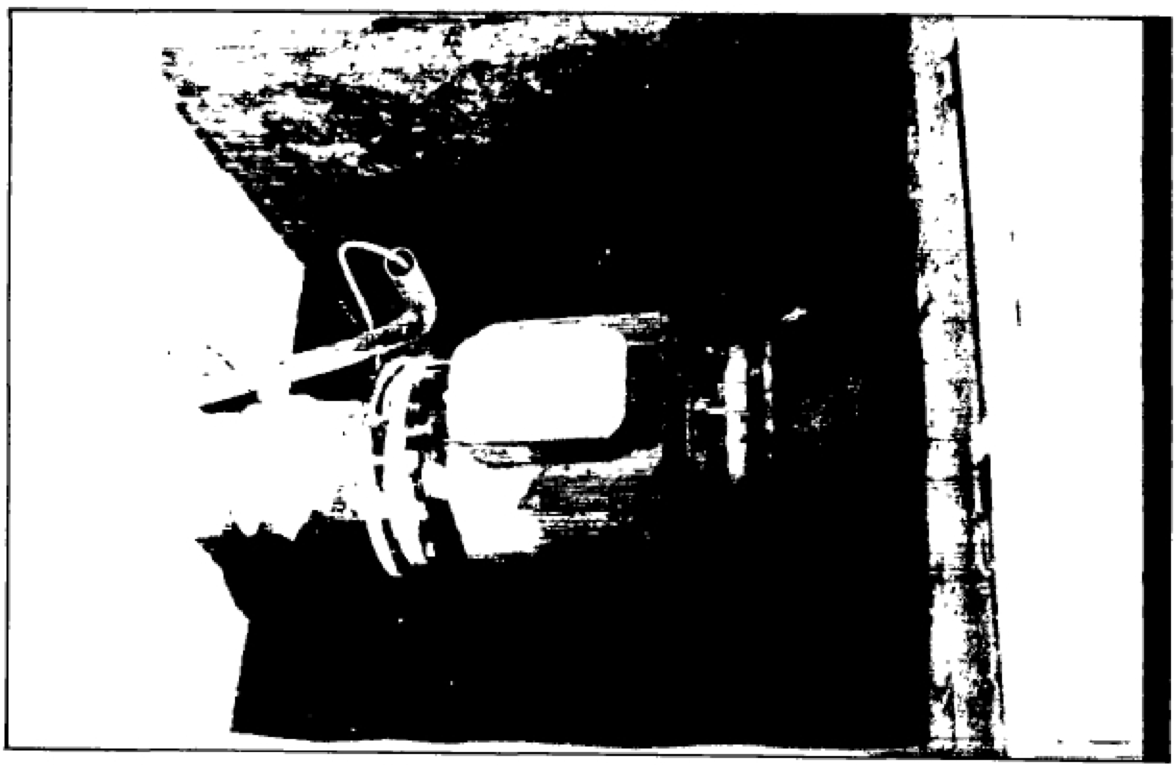


MACROPHYTE POND No. 2

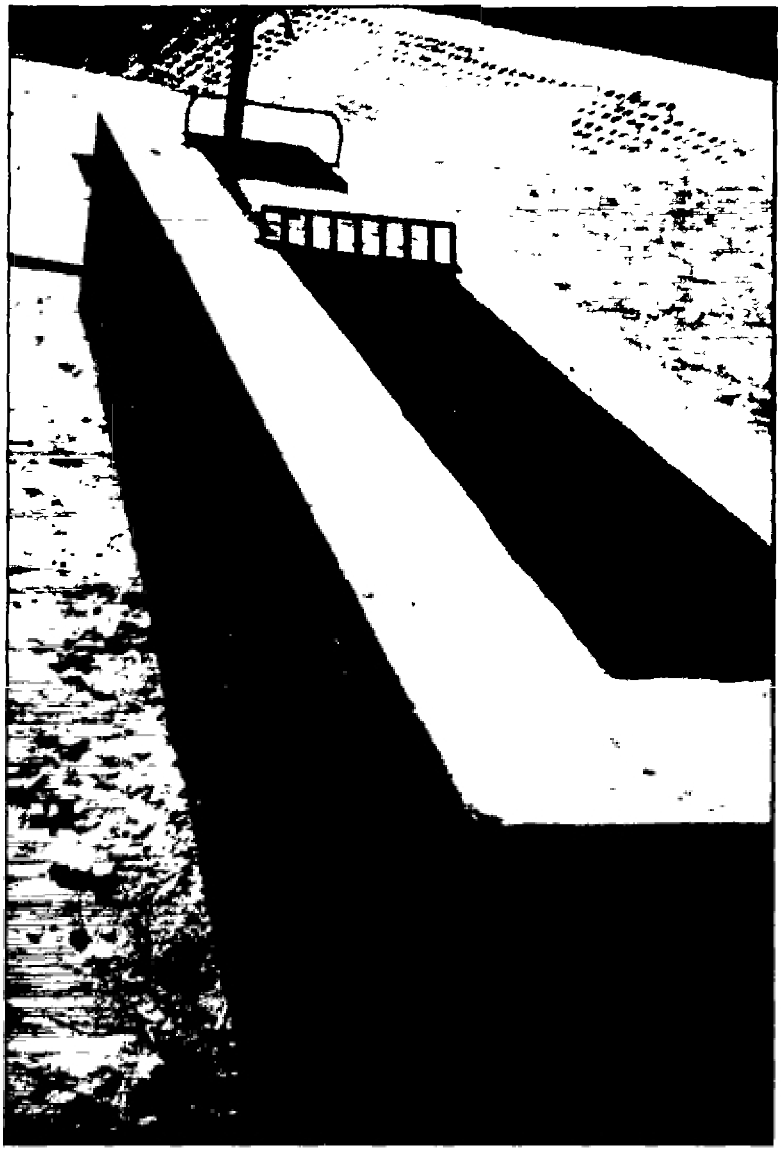


WHO PROJECT MANAGER IN SITE VISIT.

DISTRIBUTION CHAMBER & PENSTOCKS



ELECTRO MAGNETIC FLOWMETER



INLET SCREEN & FLOW MEASUREMENT WEIR

9. OPERATION AND MAINTENANCE

9.1 Introduction

This Chapter is based on a Manual prepared specifically for the El Nazlah Sewage Treatment Plant (STP), Fayoum Governorate. It covers the basic operation and maintenance procedures required to ensure the satisfactory performance of the treatment processes and also attempts to identify potential problems which might arise and to suggest possible solutions.

A companion 'Treatment Process Performance Monitoring Manual' was also prepared and is included as Chapter 11: the El Nazlah STP monitoring requirements are covered there. This operation and maintenance manual will not include monitoring details but will refer to monitoring results and their use in plant operation.

9.2 Plant Layout and Description

Appendix A contains a plant layout diagram (Fig. A1) and a simplified description of the treatment processes at El Nazlah STP. This will assist plant operators to understand the basic mechanisms of the unit processes and the parameters which affect their performance.

9.3 Responsibilities of the Operators

The treatment plant operators at El Nazlah STP have the responsibility to operate and maintain the plant to achieve the best possible effluent quality at all times. They also have important health and safety and environmental responsibilities.

Sewage contains pathogenic (disease-causing) viruses, bacteria, protozoa and helminths (worms) as well as chemical substances which might be hazardous to health. Operators must observe strict rules of hygiene if they are to be free from infection. These will include hand washing after working around the plant and certainly before eating and drinking or preparing food. Visitor must also be asked to wash hands after walking around the plant.

With ponds containing sewage, the treatment plant site is also hazardous from the point of view of a person falling into the reactors and risking drowning or, at least, contamination. Operators must prevent the general public from entering the site and must restrict visitors to those duly authorized. Life-saving equipment must be available at all times for use in case of emergency.

Any sewage treatment plant will release odours at certain times. The El Nazlah STP includes an anaerobic treatment stage (AP) and will be more likely to create odour on a regular basis, especially during hot weather. This is unavoidable but good housekeeping around the plant, following the instructions contained in this Chapter, will minimize problems caused by odour generation. Thus screenings, scum and sludges removed from any of the processes must not be allowed to stand around to decompose and attract flies and vermin. Scum should be removed from the ponds as it forms so as to prevent the encouragement of fly or mosquito larval development.

Finally, the operators must maintain the site of the STP in as neat and tidy a condition as is possible. Vegetation must be regularly cut down and grass mowed so that the site looks well maintained at all times. All rubbish, screenings, scum and sludges must be buried on site or stored in a container until transferred to a solid waste disposal site.

Good operation and maintenance will go a long way to minimizing the nuisance to nearby residents. The public relations role which operators play must be taken seriously and public complaints given due consideration.

9.4 Start-up Procedures

The anaerobic ponds (AP) should first be allowed to fill with raw sewage one at a time. However, mid-way during this filling process, supernatant from the first anaerobic (AP) pond being filled should be pumped into the facultative pond (FP) until the depth of liquid in the facultative pond reaches about 50 cm. This should then be allowed to stand, to develop algal biomass, until the level of liquid in both anaerobic ponds reaches the overflow weirs, when it will discharge into the facultative pond. By this time, an inoculum of appropriate species of algae will have built up and the facultative pond activity will be ready to start.

With further regular inflow into the anaerobic ponds, the level in the facultative pond (FP) will gradually increase until it reaches the overflow weir level. Thereafter, further inflow will overflow as effluent (FE) into the maturation pond (MP). No special arrangement is necessary for start-up of the maturation pond, which should be allowed to fill up naturally and, eventually, overflow.

During periods when experiments are being carried out on the macrophyte ponds (MaP1 and MaP2) flow will be diverted to these ponds from the anaerobic pond (AP) and from the facultative pond (FP) and subsequent flows to the facultative pond (FP) and the maturation pond (MP) will be reduced accordingly. Appropriate indigenous species of floating macrophytes will be placed on the surface of the macrophyte ponds once they have filled to overflow level.

9.5 Routine Operation

9.5.1 Magnetic Flow Meter, FM

Since the magnetic flow meter (FM) does not have any parts in the flowing sewage, routing operation simply requires the pipe associated with the flow meter to be kept clean and free from obstructions. At El Nazlah, it would be unlikely for any large objects to block the metering pipe, because of the screening and pumping, but biological growths could foul the channel. The magnetic flow meter is equipped with a self-cleansing mechanism and should not require operator attention.

9.5.2 Inlet Screen, S

Gross solids in the raw sewage will already have been removed by the screens at the main pumping station in El Nazlah village. Nevertheless, the inlet screen(S) at the treatment plant, with a bar spacing of 3 cm, will accumulate material and will require regular cleaning. If the screen is not cleaned regularly, the liquid level will rise on the inlet side and could eventually overflow and by-pass the screen. This is an undesirable and unnecessary situation and must be avoided by the operators.

To prevent excessive build up of debris on the screen, the operator must remove accumulated solids from the screen, using a suitable rake, at least once each day and at any other time when it is noticed that the liquid level is building up on the inlet side of the screen as a result of screen blockage. The operators will soon become accustomed to the amount of screenings produced each day and will arrive at the most appropriate timing for the cleaning procedure.

Screenings removed from the screen should be stored in a suitable container until buried in a trench on-site or transported to a suitable solid waste disposal landfill. Since screenings will contain pathogenic microorganisms, care must be taken by the operators to avoid direct contact with these solids until they are covered in a safe repository. The screenings will also contain degradable organic matter and will create odours if left around for long periods, especially in hot weather. Therefore, screenings should be disposed of on a daily basis and if this is a routine operational procedure, fly nuisance will be minimized. Should the screenings be stored in a container for longer periods, the container should be covered to prevent fly and odour problems.

9.5.3 Anaerobic Ponds, AP

Influent raw sewage (RS) from the pumping station will discharge intermittently to the treatment plant and, after passing the screen(S) and magnetic flow meter (FM), will enter the anaerobic ponds (AP). During times when inflow is entering an anaerobic pond, the pond will overflow effluent (AE) to the next stage of treatment.

Treatment in an anaerobic pond is achieved through the action of bacteria under anaerobic conditions, that is in the absence of dissolved oxygen. Any settleable solids in the sewage will settle out and form a sludge on the bottom of the pond. This sludge will decompose anaerobically and at temperatures above 15°C will release gas, mainly composed of methane (CH_4) and carbon dioxide (CO_2), which will rise to the surface in tiny bubbles. Under hot summer conditions, the evolution of gas will be more intense and some odour will be apparent, although it will not normally be obnoxious. All sewage treatment plants have a characteristic odour and the El Nazlah STP will be no exception.

Anaerobic ponds perform without much operator attention but in the case of the El Nazlah STP the operators must make every effort to minimize unnecessary odour production. It is natural in anaerobic ponds for gas to be released from the bottom sludge and emerge at the pond surface. Through time, anaerobic ponds tend to accumulate surface scum which, if not removed, can completely cover the surface of the pond. Although this scum will not adversely affect treatment in the anaerobic pond, it has a tendency to create additional odour as faecal material decomposes and to encourage the development of flies and mosquitos. Consequently, for environmental reasons, it is recommended that the operators remove any scum formed.

The scum will tend to accumulate in the downwind corner or end of the ponds and can be removed using a wire-mesh skimmer on a long handle. Operators should remove the scum at least once each week and place it in a container for disposal along with screenings. The only other regular task of the operators is the removal of any accumulated solids in inlet and outlet pipes, chambers, etc. Apart from carrying out these routine operational procedures and the monitoring tasks indicated in the 'Monitoring Manual' (especially sludge accumulation), the operators can rely on the anaerobic ponds to carry out their function of settling out and decomposing organic solids and anaerobically degrading soluble and colloidal organics.

9.5.4 Facultative Pond, FP

Effluent from the anaerobic ponds (AP) will overflow, during times of sewage pumping, into the facultative pond (FP). In this pond remaining soluble and colloidal organic matter will be broken down by aerobic and facultative bacteria under aerobic conditions, near the surface of the pond, which are maintained through the photosynthetic production of oxygen by algae during daylight hours. Because of the algae, the facultative pond should look green in colour when operating satisfactorily.

Any settleable solids in the facultative pond, including dead bacteria and algal cells, will form a layer of sludge on the bottom of the pond. This layer will go anaerobic and anaerobic bacteria will break down organic solid matter with the release of gas, mainly comprised of methane and carbon dioxide. Intermediate products of the anaerobic breakdown will be released as soluble organics to the supernatant layer where they will be broken down by aerobic and facultative bacteria under aerobic conditions.

As in the case of the anaerobic ponds (AP), the facultative pond (FP) will normally operate without any operational intervention by the operator. The operator will have to remove any accumulated solids from inlet and outlet pipes, chambers, etc. and remove any scum accumulating on the surface of the pond, for disposal with screenings. In addition, a careful check will have to be maintained on sludge accumulation in the facultative pond, according to the instructions in the 'Monitoring Manual'.

9.5.5 Maturation Pond, MP

Effluent from the facultative pond (FE) will overflow, during times of sewage pumping, into the maturation pond (MP). In this pond, suspended biomass in the facultative pond effluent (FE) will settle out and form an anaerobic layer on the bottom, where it will be further broken down by anaerobic bacteria. Soluble and colloidal organic matter in the facultative pond effluent or released from the bottom sludge into the supernatant will be broken down by aerobic and facultative bacteria under aerobic conditions, as in the facultative pond. However, because the organic loading on the maturation pond (MP) will be much less than on the facultative pond (FP), the bacterial activity and the algal photosynthetic activity will be much less in the maturation pond (MP). The maturation pond will serve as a polishing pond for the facultative pond effluent (FE) and will contribute to faecal coliform (FC) removal. Sludge accumulation in the maturation pond (MP) will be much less than in the facultative pond (FP).

The maturation pond will also operate normally without operational intervention by the operator. The operator will have to remove any accumulated solids from inlet and outlet pipes, chambers, etc. and remove any scum accumulating on the surface of the pond, for disposal with screenings. In addition, sludge accumulation will have to be checked as for the facultative pond but the rate of accumulation in the maturation pond is expected to be less.

9.6 Routine Maintenance

9.6.1 Magnetic Flow Meter, FM

A magnetic flow meter will not normally require maintenance, unless it fails to register flows when the pipe section containing the flow meter must be disassembled for inspection.

9.6.2 Inlet Screen, S

A bar screen is a very robust piece of equipment and will not normally require any maintenance attention.

9.6.3 Anaerobic Ponds, AP

Anaerobic ponds formed by earth embankments require regular embankment maintenance. Grass and other forms of vegetation will tend to grow on the embankments, particularly on the inner slope near the water surface, and must be regularly cut. Grass can be grown intentionally on the embankments by seeding and regular watering with facultative pond water (FP). This will give the impression of a neat, orderly maintained, pond if the grass is regularly cut and trimmed. It will also minimize soil erosion on the embankments and lead to their easier maintenance. Overgrown grass or vegetation on embankments gives a very bad impression to nearby residents and leads to a lack of confidence in the ability and industry of the operators.

Earth embankments are also vulnerable to attack by rodents and other burrowing animals. If this occurs at El Nazlah, the operators must repair any damage caused by such activity, immediately filling in the holes and tracks which might be created. Occasional application of rodenticide might be necessary if the problem becomes unmanageable otherwise. The embankments should be regularly inspected for any signs of animal attack or habitation and appropriate action taken.

The other routine maintenance function associated with the maturation pond (MP) will be to prevent the development of rooted or floating macrophyte (aquatic plant) growth in the pond. Rooted (or emergent) forms of aquatic plants, such as reeds, tend to grow in shallow areas of the pond and must be regularly cut down. Otherwise they reduce the open area of the pond, making the treatment plant look overgrown with vegetation, and encourage fly and mosquito proliferation. The cane plant is seen to grow widely in canals in Egypt and is likely to be the indiginous species which causes most problems, although other rooted macrophytes could also develop. Floating macrophytes, such as the water hyacinth, might develop anywhere on the surface of the pond and should be removed whenever noted during inspection. No growth of macrophytes should be allowed to obstruct the surface of the maturation pond and interfere with the transfer of sunlight to algae in the pond.

9.6.4 Facultative Pond, FP

The facultative pond, being formed by earth embankments will require the same embankment maintenance as described for the anaerobic ponds. Being a larger pond, the facultative pond embankment will be much longer and constitute a major maintenance problem. Unlike the anaerobic ponds, the facultative pond contents will tend to allow macrophytes to grow and these will also contribute to the extent of maintenance.

Rooted or emergent forms of aquatic macrophytes, such as reeds, tend to grow in shallow areas of ponds containing aerobic contents. These must be prevented if possible and regularly cut down if and when they occur. Otherwise, they reduce the open area of the pond, making the treatment plant look overgrown with vegetation, interfere with the algal photosynthesis and encourage fly and mosquito proliferation. In addition to emergent macrophytes, floating macrophytes might develop anywhere on the surface of the facultative pond, particularly when they are being used in the experimental macrophyte ponds. No growth of macrophytes should be allowed to obstruct the surface of the facultative pond and all forms of aquatic plant should be cut down and removed at regular intervals.

9.6.5 Maturation Pond, MP

The maturation pond, which is also an earth embankment, will require the same embankment maintenance as the facultative pond. In addition, being primarily an aerobic pond, it will be subject to the potential growth of emergent and/or floating macrophytes and must receive the same maintenance attention as the facultative pond.

9.6.6 Macrophyte Ponds, MaP1 and MaP2

These ponds, being formed by earth embankments, will require the same embankment maintenance as the facultative and maturation ponds. However, because they are specifically designed to experiment with floating macrophytes, these species should not be removed in routine maintenance. Emergent macrophytes, on the other hand, should receive the same attention as in the facultative and maturation ponds and be removed whenever they occur. Removal of the floating macrophyte under experimentation will not be a routine maintenance function but will form part of the scientific study monitoring programme.

9.6.7 Access Roads and Perimeter Fence

Operators at El Nazlah also have the responsibility of ensuring that the sewage treatment plant access roads and perimeter fence are properly maintained. Regular inspection of roads and fencing will identify any deterioration of the road surface or the security of the perimeter fence. The need for repairs can then be reported to the appropriate authority and, hopefully, suitable action will be taken. At regular intervals, the fencing will require painting and this need should also be reported so that the required materials can be supplied.

9.7 Possible Operating Problems and Solutions

9.7.1 Anaerobic Ponds, AP

i) Objectionable odour

Excessive odour released by an anaerobic pond is likely to be due to one or more of the following causes:

- organic and/or hydraulic loading in excess of the design loading
- the presence of toxic substances in the influent, inhibiting the normal reactions in the pond and/or creating odour themselves
- a sudden temperature drop
- low influent pH.

To remedy odour problems, the following actions are possible:

- recirculation of maturation pond effluent to the anaerobic pond, to create a surface layer of oxygen-rich water; because of the need for pumping, this solution is not generally recommended but might be necessary for short periods to overcome critical conditions.
- stop removing scum to assess the effects of allowing such a cover to form; there may be a trade-off between odour control and fly and mosquito nuisance
- reduce the inflow to the anaerobic pond, by by-passing part to the aerated pond, until a plant extension is built
- lime addition is sometimes necessary, if anaerobic pond pH is not in the normal operating range of 6-8, but in general chemical addition is not recommended, particularly chlorination.

ii) Mosquitos and other insects

Mosquitos, flies and other insects might appear as a result of one of the following factors:

- the exposure of screenings, scum, grass cuttings and organic debris for long periods on site
- the accumulation of a scum layer on the pond surface.

To overcome these potential problems, the operation and maintenance procedures recommended should be followed on a routine basis. If, for odour control purposes, a scum layer is allowed to develop and found to encourage insects, the scum should be sprayed regularly with facultative or maturation pond effluent. Occasionally, an insecticide might have to be sprayed onto the scum layer but great care should be taken to avoid pesticides entering the liquid wastewater in the pond.

9.7.2 Facultative Pond, FP

i) Colour change

Under normal operating conditions, a facultative pond will be loaded at an organic loading rate within its design limit and should generally look green in colour. This will be the condition at all times of year, although algal species will change from time to time. If the colour of the facultative pond changes to grey, or even pink, this is a sign of overloading under the environmental conditions at that time. A grey colouration will indicate that algae are not able to photosynthesize under the loading conditions and the greater part of the pond contents (FP) is anaerobic. Sometimes, organic overloading of a facultative pond produces a pink colouration, which is due to the presence of purple sulphur bacteria thriving when sulphate is reduced, under anaerobic conditions, with the production of sulphide.

If a major colour change is noted in the facultative pond, dissolved oxygen measurements should be made between noon and 2 p.m. at several points in the pond and at several depths at each sampling point. Should these DO measurements indicate that the majority of the pond depth (say more than 90 per cent) is anaerobic, then the loading on the facultative pond must be reduced. The organic loading on the facultative pond should be checked by measuring the daily inflow to the pond and the average concentration of BOD_5 in the inflow. In addition, the depth of sludge should not be allowed to accumulate beyond 0.5 m. At El Nazlah, the organic loading on the facultative pond should not exceed 240 kg BOD_5/ha d.

If, on checking, the facultative pond loading is found to be less than this limit, then a cause for colour change other than excessive organic loading must be suspected. This cause could only be toxic materials in the inflow which inhibit or prevent the growth of algae. In the case of El Nazlah sewage, this would be very unlikely but if it does occur analyses of the inflow will have to be carried out to identify potential toxic components. Non-biodegradable synthetic detergents can sometimes have an adverse effect on algae in facultative ponds. Should the cause of pond colour change be identified as a todic component of the sewage, the source of the toxic discharge must be found and the discharge prohibited.

ii) Foaming

In countries where non-biodegradable (hard) synthetic detergents are still produced, their presence (particularly alkyl benzene sulphonates) in sewage often causes problems of foaming in sewage treatment plants. This foaming can be excessive in plants using mechanical or diffused aeration but is generally only slight in stabilization pond STP's. Foaming may occur at any point of high turbulence and in the facultative pond this will be at the entrace. A drop over a weir on overflowing effluent from the anaerobic ponds is likely to create foam which will be transferred to the surface of the facultative pond near the inlets.

It is highly unlikely that foaming will be a serious problem at El Nazlah but if some foaming occurs, and if some remedial action is necessary, simply spraying the foam with pond water will be sufficient. Such action could be accomplished using a portable pump with a spray nozzle on the discharge but would be necessary only when a serious problem with foam arose.

iii) Scum formation

As a second stage of treatment at El Nazlah, it is unlikely that floatable materials in the raw sewage will pass through thè anaerobic ponds to the facultative pond. However, any scum allowed to accumulate on the surface of the anaerobic pond might overflow into the facultative pond. In addition, algal mats sometimes occur on the surface of a facultative pond as a consequence of an algal bloom, producing a dark-green scum. Incorporated into any scum which forms on the surface of a facultative pond will be organic matter and bacteria, with the potential to create odorous decomposition products. Under the overloading conditions already mentioned, purple sulphur bacteria might also be incorporated into scum mats, giving them a pinkish colour. Non-biodegradable synthetic detergents in the inflow might also contribute foam to scum mats. On occasions, portions of the anaerobic bottom layer of sludge in facultative ponds is raised to the surface with the release of gas bubbles. Scum will tend to be blown by the wind and accumulate in downwind corners or end of the facultative pond.

To overcome scum problems, surface mats must be either broken up and reintroduced into the pond contents (FP) or physically removed from the pond. Algal mats or floating bottom sludge may be sprayed with a jet of water or wastewater from a hose (fed by a portable pump if pond water is used) directed onto the floating scum. This will either cause the scum to sink to the pond bottom or to mix with the pond contents. Where scum accumulates in pond corners, it can be removed with a wire-mesh skimmer on a long handle and disposed of as recommended.

iv) Objectionable odour

If odour is released by the facultative pond at Mit Mazah, it is likely to be caused by one of the following:

- organic overloading
- excessive sludge accumulation
- long period of low temperature and cloud cover
- presence of toxic material
- short-circuiting
- lack of wind-induced mixing

Organic overloading will only occur if the design load for the plant is exeeded and this will result in a drop in dissolved oxygen concentration in the pond and a reduction in pH. If sludge is allowed to accumulate to more than half the pond depth, this is likely to create the same conditions as organic overloading because anaerobic intermediate products will be released from the bottom sludge into the pond water. If such overloading creates conditions which give rise to objectionable odour then the only remedy is to reduce the organic loading by reducing inflow or organic strength or by desludging. Change of influent loading will require additional pretreatment whereas desluding can be carried out at any time. Sludge monitoring as recommended and regular desludging should prevent the build up of bottom sludge to the point where it would create organic overloading.

Low temperature and cloudy skies will reduce photosynthetic oxygen production and sometimes cause dissolved oxygen to be absent from the pond contents, even during the day. This condition should not be allowed to coincide with a high level of sludge accumulation, which would severely stress the oxygen balance in the pond. Recirculation of pond effluent to the influent has been recommended as a possible solution to this problem but is of doubtful value in practice. Floating surface aerators or diffused aeration (if available) could be installed for the period concerned to overcome this temporary overloading problem.

Short-circuiting must be checked through tracer monitoring studies (as described in the 'Monitoring Manual') and overcome by appropriate siting of inlet and outlet and by baffling, if found to be significant. Wind access to the ponds must not be reduced by the use of solid fencing or tree planting around the perimeter.

v) Mosquitos and other insects

Insect breeding in maturation ponds is primarily associated with emergent macrophyte growth and with scum formation. Varying the water level will expose to sunlight those parts of the plants to which larvae attach themselves and so cause them to dry out and die. This can be an effective measure against larval development. For longer term control, larvivorous fish, such as Gambusia, Lebistes, Tilapia and Chinese Grass Carp, can be introduced into the maturation pond if the dissolved oxygen is at a suitable level. Insecticide spraying on the embankment could be adopted to overcome excessive occasional infestation with insects but care must be taken to prevent pesticides entering the pond liquid contents.

9.7.3 Maturation Pond, MP

Technically, the same operating problems could occur with the maturation pond as described for the facultative pond. However, because the maturation pond is the third stage of treatment and primarily carrying out an effluent polishing function, problems caused by overloading will only arise if there is a failure of the anaerobic and/or facultative ponds.

Consequently, if any of the operational problems created by excessive overloading do occur, rather than look for causes within the maturation pond, the performance of the anaerobic and facultative ponds should be investigated. Problems of foaming, scum formation and insects should be dealt with as described for the facultative pond.

9.7.4 Macrophyte Ponds, MaP1 and MaP2

i) Macrophyte growth limitation

If the macrophyte introduced into a floating macrophyte pond fails to increase the surface cover in a few weeks, a cause for the growth limitation must be sought. At El Nazlah, with the macrophyte ponds receiving anaerobic and facultative pond effluents, there will be no shortage of the major nutrients, N and P. However, although most unlikely, a lack of a minor nutrient (such as iron) could limit macrophyte growth. More likely, though, would be the presence of a toxic material in the sewage. In view of the ability of floating macrophytes to accumulate heavy metals, these toxic elements would have to be present in the sewage at a very high level to be inhibitory. Toxic organic compounds would be the most probable cause of macrophyte growth limitation if any were present in the El Nazlah sewage at a sufficiently high concentration.

Should macrophyte growth limitation be observed at El Nazlah, the raw sewage should be analyzed for toxic materials to try to identify any major element or compound in high concentration. Once a toxic inhibitory material was identified, its source would have to be investigated and its discharge prohibited. Such a toxic material would almost certainly also affect algal growth and cause problems in the facultative pond.

ii) Objectionable odour

If odour is released by one of the macrophyte ponds at El Nazlah during an experimental study the cause is likely to be anaerobic conditions due to excessive organic loading. Floating macrophyte ponds have been known to create odours at organic loadings in excess of 440 kg BOD_5/ha d and some of the experimental loadings suggested in the El Nazlah STP Monitoring Manual exceed this level.

The solution to objectionable odour caused by organic overloading is, clearly, to reduce the loading level. Since the purpose of the experimental programme is to identify optimum operating conditions for Fayoum macrophyte ponds, it is essential to exceed the practical limit of organic loading in some tests. Another solution which has been adopted where high organic loadings have been applied to minimize land usage is diffused aeration of floating macrophyte ponds. This is unlikely to be necessary in the context of the El Nazlah experimental ponds or any future full-scale macrophyte ponds in Egypt.

iii) Mosquitos and other insects

The presence of floating macrophytes on the pond surface may give rise to an increase in population of mosquitos and other insects in the area. Anaerobic conditions in the pond apparently increase the probability of insect problems.

Strategies that have been used to control this problem include:

- maintaining aerobic conditions in the pond contents (MaP1 and MaP2)
- frequent harvesting of the macrophytes
- diffusion of oxygen into the pond

- step-feed of influent with recycle of effluent
- application of insecticides
- stocking ponds with insect-controlling fish, for example *Gambusia afinis* to control mosquitos.

In the case of the experimental ponds at El Nazlah it is unlikely that any of these techniques will be necessary. Any insect problems which arise are likely to occur during the tests at high organic loadings, which can be short-lived. Information on pond loadings which give rise to insect problems is useful in deciding on a suitable design loading. Should insect problems arise at all loadings in the experimental ponds, consideration will have to be given to insect control strategies, with a view to arriving at the most appropriate technique for Egypt. The techniques involving aeration, insecticides and fish would only be applied at the full-scale if the other approaches were not found to be effective.

9.8 Record Keeping

Apart from the extensive records which must be kept when a system monitoring programme is being carried out, as detailed in the 'Monitoring Manual', operators should routinely prepare a plant inspection and maintenance record. This is most easily recorded on a weekly record form and the recommended version for El Nazlah operators is included at the end of this Chapter.

The operator should enter his observations as appropriate but the following descriptions might be usefully applied for some of the parameters:

Weather Conditions:

Sunshine	- bright	(no clouds, intense sunshine)
	- sunny	(occasional clouds)
	- dull	(overcast or cloudy)
Rainfall	- dry	(no rainfall)
	- drizzle	(fine rain)
	- moderate	(intermittent rain)
	- heavy	(continuous rain or heavy storm)
Wind	- calm	(no detectable air movement)
	- breeze	(gentle wind)
	- moderate	(windy)
	- strong	(violent wind)

Access Road

Condition	- potholes
	- ridges
	- vegetation
	- location

Maintenance - filled holes
- graded surface
- cut out vegetation
- resurfaced

<u>Fencing</u>

Condition
- holed
- collapsed
- corroded
- location

Maintenance - repaired hole
- re-erected fence
- painted

<u>Observations</u>

Colour
- green
- brown/grey
- pink/red
- black
- clear
- milky

Odour
- not noticeable
- slight
- moderate
- objectionable

Embankments - erosion
- rodent damage
- vegetation

Inlet)
Outlet)
- clear
- blocked
- growth

Water level - high
- normal

Insects
- mosquitos
- flies
- other
- few
- many
- low

EL NAZLAH SEWAGE TREATMENT PLANT
FAYOUM GOVERNORATE

Weekly Inspection and Maintenance Record Form

Date: ....   Operator: ....

Weather Conditions: Sunshine .... Rainfall .... Wind ....

Pumping Station: Start times .... Stop times ....

Access Roads: Condition .... Maintenance ....

Fencing: Condition .... Maintenance ....

Treatment Plant Site: Condition .... Maintenance ....

Screen (S): Condition .... Upstream Water Level .... Maintenance ....

Magnetic Flow Meter (FM): Channel condition .... Maintenance ....

Meter reading ....

Observations	Anaerobic Ponds (AP1)	(AP2)	Facultative Pond (FP)	Maturation Pond (MP)	Macrophyte Ponds (MaP1)	(MaP2)
Colour						
Odour						
Scum						
Foam						
Floating macrophytes						
Rooted macrophytes						
Embankments						
Inlet						
Outlet						
Water level						
Insects						
Maintenance						
Other Observations						
Sludge Accumulation						

10. MANAGEMENT

Though a wastewater stabilization pond is a simple installation which does not require skilled manpower on the site during operation, some technical, financial and administrative support is necessary.

10.1 Training

The operator must receive training in the routines he is supposed to perform. If he has sufficient education, or the capacity to learn more advanced subjects, he could take an elementary short course on the pond treatment process. He should be informed of his responsibilities, particularly regarding public health, so that he will feel that he is playing an important role and will approach his job with care and attention.

10.2 Financial Aspects

Pond operation and maintenance are very important. This implies that a budget must be made available to cover regular expenses, such as tools, protective garments, repair materials, flashlight batteries, printed matter, toilet paper, medicines, insect repellants and other minor items, as well as for paying the operator, energy costs, etc. The salary paid to the operator should definitely be more than that of a normal manual worker in view of the responsibilities he is expected to assume.

Although the running costs will be low, the success of the whole operation depends on the responsible agency providing the resources on a continuing basis. Once the capital investment in a wastewater stabilization pond system has been made, it is folly to risk project failure through lack of operating funds.

10.3 Administrative Aspects

On the governmental side, the agency concerned should establish a department to be responsible for the administration of wastewater collection, transport and treatment facilities. Operator supervision is an essential function of such a department, for the operator cannot be expected to work in a vacuum.

Pond performance evaluations should also be carried out by the department, so that future designs will take advantage of findings. This department should organize the operator's training courses and activities and, in time, set up a control or research laboratory. Without effective administrative and technical backup, the wastewater stabilization pond installation is likely to become less and less efficient until it ceases to be effective. This deterioration can happen in a short time.

The community served should be required to pay towards the service, and community self-help should be encouraged, from the time of planning, during construction, and as part of maintenance and operation. Community involvement, following appropriate education of the public, is beneficial in every way and can markedly reduce running costs, as well as public nuisance, like trespassing, since the dangers are understood.

11. TREATMENT PROCESS PERFORMANCE MONITORING

11.1. Introduction

This Chapter is based on a Manual specifically prepared to provide a comprehensive programme for monitoring the performance of sewage treatment processes at the El Nazlah Sewage Treatment Plant (STP), Fayoum Governorate. Since it is WHO's intention to have this plant serve as a prototype for wider application in Egypt, and because the macrophyte ponds are experimental demonstration units, the monitoring programme is more rigorous than would be the case for routine monitoring of a similar plant under normal conditions. The results from a year or more of monitoring under the conditions laid down in this Chapter will provide a sound basis for assessment of the treatment processes under a wide range of operational and climatic conditions.

The Manual attempted to provide simple explanations of the principles of sampling and analysis as well as recommendations on the detailed sampling programme. This is necessary because of the lack of experience with STP monitoring in Egypt and the likely inexperience of the staff carrying out the programme.

11.2 Plant Layout and Description

Appendix A contains a plant layout diagram (Fig. A1) and a simplified description of the treatment processes at the El Nazlah STP. This will assist plant operators and monitoring contractor's personnel to understand the basic mechanisms of the unit processes and the parameters which affect their performance.

11.3 Abbreviations used in the Manual

The following abbreviations are used throughout this Chapter.

STP - Sewage treatment plant
RW - Raw wastewater
AP - Anaerobic pond contents
FP - Facultative pond contents
MP - Maturation pond contents
MaP1 - Macrophyte pond No. 1 contents
MaP2 - Macrophyte pond No. 2 contents
AE - Anaerobic pond effluent
FE - Facultative pond effluent
ME - Maturation pond effluent
MaE1 - Macrophyte pond No. 1 effluent
MaE2 - Macrophyte pond No. 2 effluent
CS - Daily flow-weighted composite sample
GS - Grab sample

BOD_5 - 5-day, 20°C, Biochemical oxygen demand
COD - Chemical oxygen demand
DO - Dissolved oxygen
SS - Suspended solids
pH - The logarithm of the reciprocal of the hydrogen ion concentration
N - Nitrogen
P - Phosphorus
Ca - Calcium
Mg - Magnesium
Na - Sodium

11.4 Sampling Locations and Techniques

11.4.1 Sampling Points

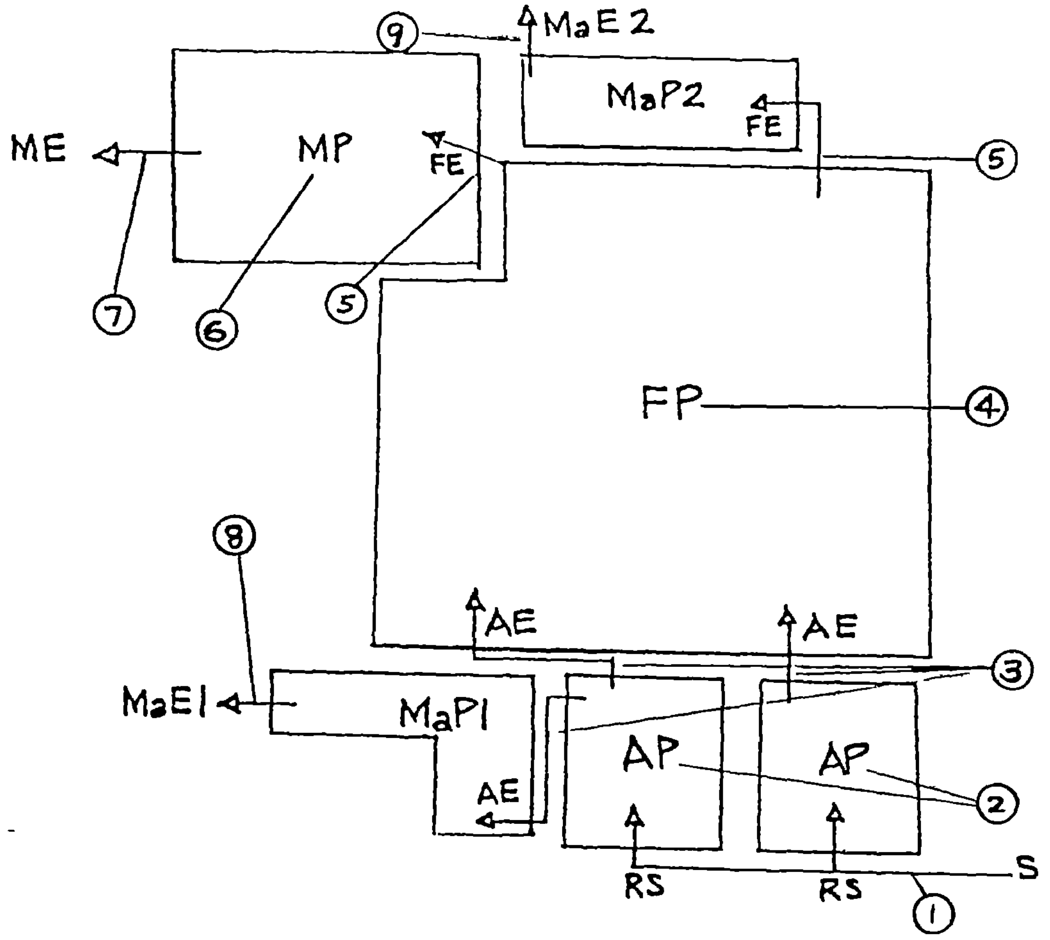
To follow the progress of treatment in the El Nazlah STP a regular programme of sampling and analysis of raw wastewater, unit process contents and unit process effluents is required. Thus, samples must be taken of the raw wastewater (RW) as it enters the anaerobic pond, following screening (S), at Point (1) on the following sampling diagram:

Samples of the anaerobic pond contents (AP) should be taken at approximately a central point in each pond, as indicated by Point (2) on the sampling diagram. The effluent from both anaerobic ponds (AE) should be sampled as it leaves each pond, before it mixes with the contents of the facultative pond (FP) or the contents of macrophyte pond No. 1, as indicated by Point (3) or the sampling diagram.

The contents of the facultative pond (FP) will vary in quality depending on the anaerobic activity in the bottom sludge, the time of year, the time of day and other factors. An approximately central location for sampling, indicated as Point (4) on the sampling diagram, will serve as a representative location for the facultative pond contents (FP) but, on occasions, it will be useful to sample near the inlet end of the facultative pond. Diurnal sampling at different depths at Point (4) at different times of year will provide useful information on the performance of the facultative pond. The effluent from the facultative pond (FE), should be sampled as it leaves the pond, before it mixes with the contents of the maturation pond (MP) or the contents of macrophyte pond No. 2, as indicated by Point (5) on the sampling diagram.

Samples of the maturation pond contents (MP) should be taken at approximately a central point, as indicated by Point (6) on the sampling diagram. The effluent from the maturation pond (ME), which is the final effluent from the El Nazlah STP, should be sampled after it overflows from the pond and before it reaches the receiving drain, at Point (7) on the sampling diagram.

Finally, when macrophyte treatment experiments are in progress, the effluent from macrophyte pond No. 1 (MaE1) and from macrophyte pond No. 2 (MaE2) should be sampled at Points (8) and (9) on the sampling diagram.



Sampling Diagram

11.4.2 Sampling Techniques

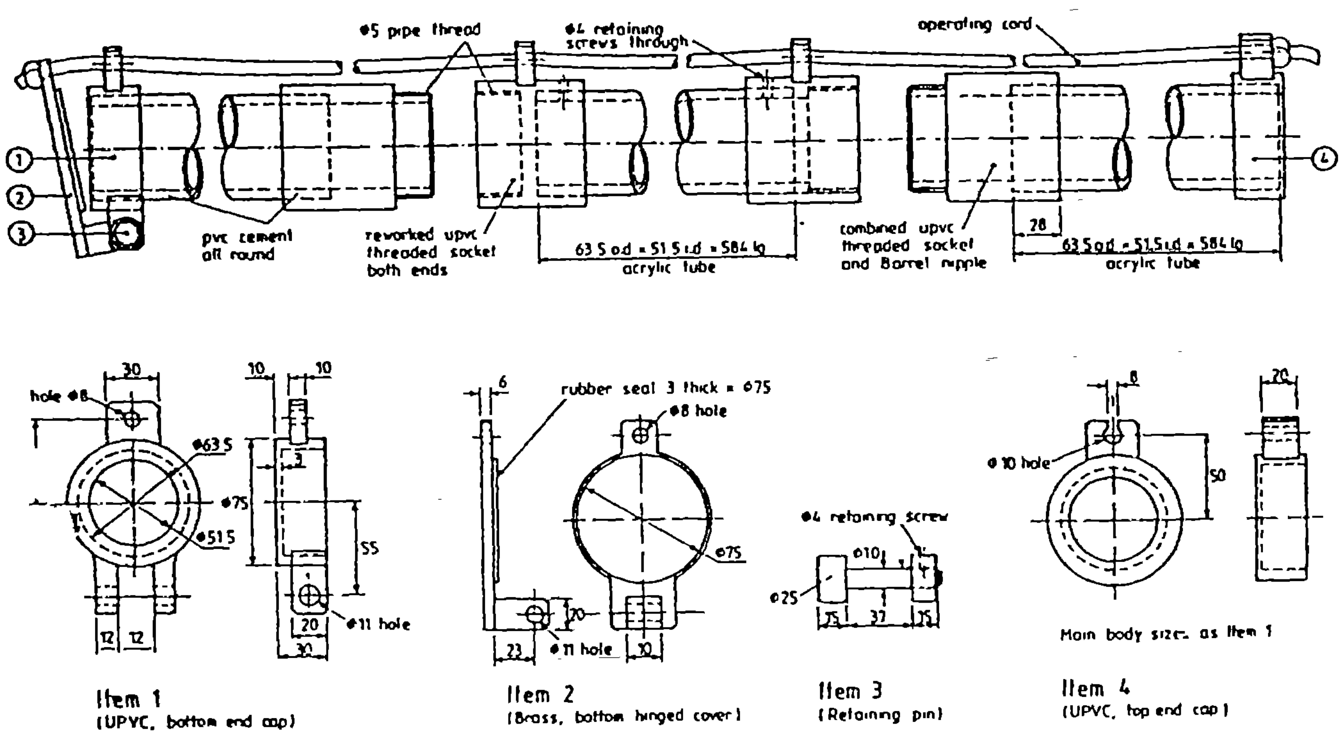
At any sampling point, a sufficient volume of sample must be taken to allow the full range of analyses required to be carried out. Each sample must be fully representative of the material being sampled and the technique adopted should ensure that this is achieved. A single grab sample is only representative of a flowing material at the point of sampling at the particular time the sample is taken.

To assess the spatial variability of a material, grab samples can be taken at different depths and/or different points on the plan area. The time variability of the material can be assessed by taking grab samples, either by hand or automatically, at different time intervals. This gives rise to considerable analytical effort and expense and is only used where conditions are changing significantly from one time period to another. A more common technique is to obtain a time-averaged sample by compositing grab samples taken at regular time intervals so as to produce a single representative sample (for analysis) over the period of time. However, to produce a true average of the material being sampled over the time period, it is necessary to mix samples in proportion to the volume of flow of the material at any time. Mixing of the flow-proportional samples will provide a true-average quality of the material.

In the context of the El Nazlah STP, the samples which will show the greatest diurnal variability will be the raw wastewater (RW), the contents of the facultative pond (FP) and the final effluent (ME). However, as a result of the mixing which will take place in the pumping station sump and the few short pumping periods in a day, the raw wastewater entering the STP will show less diurnal variability than would normally be expected. The anaerobic pond contents will not show significant variability from day to day, because these ponds are not affected by algal action and have a relatively long retention time (5 days). All the processes at El Nazlah will be subject to seasonal variability, mainly caused by temperature change.

The depth of sludge in a pond should be monitored and, to achieve this, the 'white towel' test is the simplest technique. White towelling material should be wrapped around the lower portion of a sufficiently long pole and lowered vertically into a pond until it touches the bottom. When the pole is withdrawn the depth of the sludge layer will be clearly visible because some of the sludge particles will have become entrapped in the towelling.

For certain monitoring analyses, a full depth sample of the water column in a pond is necessary. A pond column sampler is required to take such a sample and the sampler shown below is a suitable design.



Note: The overall length of the sampler (here 1.7 m) may be increased as necessary, and its diameter (here 50 mm) may be altered to 75 mm if required. The design shown here is a three-piece sampler for ease of transportation, but this feature may be omitted. Alternative materials may be used.

Pond Column Sampler

11.4.3 Sample Preservation

Many samples can be analyzed immediately after collection but some may require storage before analysis at a later time or date. Grab subsamples taken to prepare a composite sample for analysis will have to be stored until the final sample of the period is taken.

For analysis no longer than 30 hours after a sample is taken, storage of samples below 4°C is sufficient to prevent significant change of organic composition. Thus samples of raw wastewater, pond contents and effluents can be stored in a low temperature refrigerator for limited periods before analysis. If a suitable refrigerator is not available, samples should be stored in containers packed with ice.

Certain analyses must be carried out at the time of sampling or results will be meaningless. Dissolved oxygen and pH are examples of such analyses.

Samples taken for the purpose of biological organism counting and identification might require preservation using formalin if immediate attention cannot be given to the samples.

11.5 Analytical Techniques

Analysis of samples should generally be carried out according to methods specified in the 16th Edition of 'Standard Methods', 1985 published jointly by the American Public Health Association, the American Water Works Association and the Water Pollution Control Federation. One notable exception to this is the counting of helminths, which should be carried out following one of the procedures given in the World Health Organization's 'Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture', Technical Report Series No. 778, 1989.

A list of necessary equipment and supplies to carry out the monitoring programme is provided in Appendix D.

11.6 Meteorological Data Collection

In assessing the performance of sewage treatment plants, including stabilization ponds, it is essential to relate results to certain meteorological parameters. The following meteorological data should be collected on a routine basis:

Temperature - Ambient air temperature, as well as the temperature of wastewater in the ponds, should be determined at the same point at the same time every day. In the absence of continuous recording of temperature or the provision of a maximum/minimum thermometer, this procedure will allow realistic mean monthly temperatures to be calculated and their variation determined.

Solar Radiation - Without a recording instrument, a rough idea of this parameter can be obtained by recording perceived conditions as follows:

- bright sunlight (clear skies, intense sunshine)
- sunshine (sunny with occasional clouds)
- cloudy (no direct sunshine)

Rainfall - If a standard rain gauge is not available on site, local observations will allow comparison with the rainfall records at the nearest gauging station. Recording the following conditions on a daily or part-day basis will be appropriate:

- no rain (dry)
- some fine rain (drizzle)
- moderate rain
- heavy rain or storm

Wind - If an anemometer is not available on site, local wind conditions can be compared with the nearest meteorological station records by recording daily observations, as follows:

- calm (no detectable air movement)
- breeze (gentle wind)
- moderate wind
- strong wind
- violent wind (hurricane)
- wind direction

Evaporation - Free water surface evaporation can be measured on site if an evaporation pan is installed. Daily readings will be necessary.

11.7 Monitoring Programme

11.7.1 Visual Observations

The operator of the treatment plant should walk around each pond at least once every day and record his observations on a form. At least the following observations should be included on the form:

Observation	AP	AeP	MP	Notes
Colour of pond contents (green, brown/grey, pink/red, milky/clear)				
Odour (absent, slight, severe)				
Surface scum, foam				

Floating aquatic plants

Emerging rooted aquatic plants

State of embankments (erosion, rodent damage, vegetation)

Inlet/Outlet blockage

Wastewater level (high, normal, low)

Presence of insects (flies, mosquitos)

Presence of birds/water fowl

11.7.2 Raw Wastewater

The following characteristics of the raw wastewater should be monitored at the frequency indicated, adopting the sampling system suggested:

Parameter	Sampling	Frequency/Time of Sampling
Flow	(Recorder)	Daily
Suspended solids	Composite	Weekly/Different day each week
BOD_5 (unfiltered)	Composite	Weekly/Different day each week
BOD_5 (filtered)	Composite	Weekly/Different day each week
COD (unfiltered)	Composite	Weekly/Different day each week
COD (filtered)	Composite	Weekly/Different day each week
Ammonia-N	Composite	Weekly/Different day each week
pH	Grab	Weekly/Different day each week
Temperature	Grab	Weekly/DIfferent day each week
Faecal coliforms	Grab	Monthly/Between 08.00 and 10.00 h
Helminths	Composite	Monthly
Total-N	Composite	Monthly
Total-P	Composite	Monthly
Chloride	Composite	Monthly
Electrical Conductivity	Composite	Monthly
Ca, Mg, Na	Composite	Quarterly
Boron	Composite	Quarterly
Sulphide	Grab	Monthly

Composite samples should be 24 hour flow-weighted composited grab samples.

11.7.3 Anaerobic Pond Contents

Monitoring of the anaerobic pond contents (AP) should include the following:

Parameter	Sampling	Frequency/Time of Sampling
pH	Grab	Weekly/One sample between 08.00 and 10.00 h and one between 14.00 and 16.00
Temperature	Grab, mid-depth	Weekly
Dissolved oxygen	Grab, mid-depth	Weekly

11.7.4 Anaerobic Pond Effluent

The anaerobic pond effluent (AE) should be monitored as follows:

Parameter	Sampling	Frequency/Time of Sampling
Suspended solids	Composite	Weekly/different day each week
BOD_5 (unfiltered)	Composite	Weekly/different day each week
BOD_5 (filtered)	Composite	Weekly/different day each week
COD (unfiltered)	Composite	Weekly/different day each week
COD (filtered)	Composite	Weekly/different day each week
Ammonia-N	Composite	Weekly/different day each week
pH	Grab	Weekly/different day each week
Faecal coliforms	Grab	Monthly/Between 08.00 and 10.00 h
Helminths	Composite	Monthly
Sulphide	Grab	Monthly

11.7.5 Facultative Pond and Maturation Pond Contents

The contents of the facultative pond (FP) and the maturation pond (MP) should be monitored as follows:

Parameter	Sampling	Frequency/Time of Sampling
Suspended solids	Grab	Daily
Dissolved oxygen	Grab	Daily/At various points across pond
Sludge deposits	White towel test	Weekly

11.7.6 Facultative Pond Effluent, Macrophyte Ponds Effluents and Final Effluent

The effluent from the facultative pond (FE), the effluents from macrophyte ponds No. 1 (MaE1) and No. 2 (MaE2), and the final effluent (ME) should be monitored as follows:

Parameter	Sampling	Frequency/Time of Sampling
Suspended solids BOD_5 (filtered)	Composite	Weekly/Different day each week
COD (filtered)	Composite	Weekly/Different day each week
Ammonia-N	Composite	Weekly/Different day each week
pH	Grab	Weekly/Different day each week
Faecal coliforms	Grab	Monthly
Helminths	Composite	Monthly

11.7.7 Tracer Studies

At least on two occasions, at different times of year, a tracer study should be carried out to assess the hydraulic retention time in the six ponds. The use of Rhodamine-B as tracer is convenient but requires a fluorometer to measure its concentration.

11.7.8 Diurnal Studies

To assess diurnal changes in pH and dissolved oxygen over the depth of the facultative and maturation ponds, 24 hour studies should be carried out at different times of year (perhaps once a quarter). Grab samples should be taken every 20 cm over the depth of pond at hourly intervals for analysis for pH and dissolved oxygen and, ideally, for algal numbers and species.

11.7.9 Macrophyte Pond Studies

i) Macrophyte species

The two macrophyte ponds are located so as to receive anaerobic pond effluent (in MaP1) and facultative pond effluent (in MaP2) and to operate as floating macrophyte ponds. Locally available floating macrophytes will be investigated for use so as not to introduce foreign species, which might upset the natural ecological conditions. Floating macrophytes which have been used for this purpose elsewhere include: water hyacinch (*Eichornia crassipes*), water lettuce (*Pistia stratiotes*), Pennywort (*Hydrocotyle umbellata*), duckweed (*Lemna, Spirodela* and *Wolffia* spp.), alligator weed (*Alternanthera* spp.) and water fern (*Salvinia* spp.).

ii) Experimental programme

The macrophyte ponds have been designed for a retention time of approximately 5 days at an inflow rate of 46.3 m^3/d and depth of operation 1.6 m. It is also possible to operate at depths down to 0.5 m and the inflow rate can be adjusted so as to provide various retention times. The experimental programme should be designed to assess two or three local species of floating macrophytes in each pond operating over a range of conditions.

For each species, the influence of pond depth and retention time should be assessed over feasible ranges. Three levels of pond depth, say 0.6 m, 1 m and 1.6 m, should be adopted and retention times at these depths also varied so as to give three levels of hydraulic and organic loading. With a surface area at mid depth of 145 m^2, the following retention times should be assessed at the pond depths suggested, when the indicated hydraulic and organic loadings would apply:

Pond Depth,	Inflow, m^3/d	Retention Time, d	Hydraulic Loading, m^3/ha d	BOD_5 Loading, kg/ha Pond MaP1	Pond MaP2
1.6	46.3	5	3100	1280	192
1.6	23.2	10	1550	640	96
1.6	11.6	20	775	320	48
1.0	29.0	5	2000	800	120
1.0	14.5	10	1000	400	60
1.0	7.3	20	500	200	30
0.6	17.4	5	1200	480	72
0.6	8.7	10	600	240	36
0.6	4.4	20	300	120	18

Organic loading rates higher than 440 kg BOD_5/ha d might not be satisfactory, due to anaerobic conditions causing odours, and the above suggested schedule might have to be adjusted as a result of experience during the experimental period.

iii) Macrophyte growth and harvesting

Different floating macrophyte species develop in different ways but growth is influenced by solar energy response, nutrient level and composition in the growth medium (the wastewater), cultural methods and environmental factors, particularly temperature. From initial stocking with the species under investigation, plant growth must be monitored in each macrophyte pond under the conditions of a specific test in the programme.

There are two ways of assessing plant growth and both should be attempted at El Nazlah. The first is to report the percentage of pond surface covered on a regular basis while the second, more useful technique, is to report the plant density in units of wet plant mass per unit of surface area. For example, under normal conditions, loosely packed water hyacinth can cover the water surface at a relatively low plant density of 10 kg/m^2 wet weight or it can reach a maximum density of 50 kg/m^2 wet weight, when growth ceases. The biomass yield of water hyacinth tends to be higher than other floating macrophytes, on an annual basis, but some species can grow faster than hyacinth (for example, duckweed can double the surface area covered in 4 days).

The nutrient assimilation capacity of aquatic macrophytes is directly related to growth rate, standing crop and tissue composition. Water hyacinth has been found (in Florida) to reach a standing crop level of 30 kg (dry weight)/ha and result in a maximum storage of 900 kg N/ha and 180 kg P/ha. Maximum nitrogen removal by water hyacinth has been found to be 5850 kg N/ha year, compared with 1200 kg N/ha year for duckweed.

Harvesting of the aquatic plants is essential to maintain a crop with high metabolic uptake of nutrients. The macrophyte growth rate will dictate the frequency of harvesting and plant density assessment will indicate when harvesting should be carried out. Clearly, when a maximum density is reached, no further growth will occur and harvesting is necessary. Duckweed harvesting might be required once a week under ideal growth conditions, whereas water hyacinth might need harvesting every three to four weeks. Harvested plants are typically dried and landfilled but other treatment processes (such as vermicomposting or biogas production) could be applied. Ground duckweed can be used as an animal feed without air drying. The yield of macrophytes and nutrient removal rates can be calculated if the weight of harvested plants is measured.

iv) Effluent and macrophyte-tissue analyses

When steady-state conditions have been reached in the macrophyte ponds under a particular loading condition, influent and effluent samples should be analyzed for total-N, NH_3-N and total-P. If the raw sewage contains any heavy metal at a significant concentration, the concentration of this metal could also be determined in the influents and effluents. In addition, biomass-tissue should be analyzed for N, P plus any relevant heavy metal at the time of harvesting.

The results for biomass growth and composition should be presented in terms of standing crop (tonnes dry weight/ha), growth rate (tonnes dry weight/ha year), tissue composition (g N/kg and g P/kg) and nutrient removal (kg N/ha year and kg P/ha year) for each macrophyte species.

11.8 Presentation of Results

All data should be presented as tabulations and on disc for computer analysis. The annual report containing the monitoring results should include full details of the sampling procedures adopted. Graphical trends in major parameters should be included in the annual report and attention drawn to the major factors influencing the performance of the five types of unit processes in the El Nazlah sewage treatment plant.

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APPENDIX A

DESCRIPTION OF TREATMENT PROCESSES

1. Plant Layout and Sewage Inflow

The layout of the El Nazlah Sewage Treatment Plant is shown in Fig. A1. It comprises a flow measurement device (FM), an inlet screen (S), two anaerobic ponds (AP), a facultative pond (FP), a maturation pond (MP) and two experimental macrophyte ponds (MaP). All ponds are contained by soil embankments.

Raw sewage (RS) enters the plant through the screen (S) after having been pumped from the pumping station in the village. Because the capacity of the pump is much larger than the present sewage flow, the sewage is pumped intermittently to the treatment plant, with flow entering only a few hours during the day. No night-time flow will reach the treatment plant due to the fact that the pumping station is not manned 24 hours and the pumps are operated manually. This intermittent flow regime will not adversely affect the operation of the treatment processes because of the relatively long retention time in each stage of ponds.

2. Flow Measurement

A magnetic flow meter (FM) is provided on the pumping main to allow measurement of the volume of sewage flow at any time. No obstruction of the pipe in which the flow meter is installed must be allowed, otherwise the flow measurement will not be accurate. An automatic self-cleansing system is incorporated into the magnetic flow meter.

3. The Screen

The screen (S) at the treatment plant entry is of 3 cm bar spacing and will retain only large particles which have passed through the coarse screen at the village pumping station. Nevertheless, solids will accumulate at the screen and if not removed regularly will cause the flow level in the entry channel to rise and, eventually, to by-pass the screen. This by-pass condition should never be allowed to occur and good operation will ensure the removal of screenings on a regular basis to prevent any significant rise in flow level in the inlet channel upstream of the screen.

The screenings will contain putrescible organic matter, pathogenic bacteria and viruses, parasitic helminths (worms) and protozoa which can cause disease. Consequently, they must be handled with due care and disposed of in an approved manner, either by burial in trenches or in a sanitary landfill with urban refuse. Because of their organic content, these screenings should not be left around the site exposed so as to cause odours and create a health risk to plant operators.

4. The Anaerobic Ponds

4.1 Design

This is the first major stage in the treatment process and has been designed to achieve primary treatment, through physical settling of solids, and partial breakdown of organic material under anaerobic conditions. Anaerobic operating conditions (the absence of dissolved oxygen) are achieved in the anaerobic ponds (AP) by designing for a volumetric organic loading of 100 g BOD_5/m^3d or more. The inlet flow to the treatment plant is equally divided between the two anaerobic ponds operating in parallel and for each cubic metre of pond volume the inflow of sewage in one day will contain approximately 100 grams of 5 day, 20°C, biochemical oxygen demand (BOD_5). The BOD_5 of the sewage, an estimator of organic meterial, can be measured in the laboratory to check on the anaerobic pond loading at any time, and this will be one regular measurement in the monitoring programme.

If, for example, the measured BOD_5 of the raw sewage (RS) averaged 800 mg/l over a 8.6-hour total pumping period in a day, when the flow rate to one anaerobic pond (AP) averaged 27 m^3/h, the influent BOD_5 to the pond would be:

$$800 \text{ mg/l } (= g/m^3) \times 27 \text{ m}^3/h \times 8.6 \text{ h} = 185{,}600 \text{ g } BOD_5/\text{day}.$$

With each anaerobic pond volume being 1158 m^3 (excluding sludge storage volume), the volumetric BOD_5 loading on each pond would be 185,600/1158 g BOD_5/m^3d = 160 g BOD_5/m^3d.

Approximately 50 g BOD_5 is released as organic waste per person per day and is contained in the sewage from a community. Since each anaerobic pond is designed to receive 160 g BOD_5/d for each m^3 of volume, about one third of a cubic metre of anaerobic pond volume is provided for each person served. The strength of sewage varies from community to community depending on water use, with a BOD_5 of 800 mg/l being very strong.

4.2 Performance

The volume of inflow to each anaerobic pond (AP) will determine the hydraulic retention time. Thus, for a 8.6-hour per day pumping period with average flow rate of 27 m^3/h discharging into one anaerobic pond, the daily inflow volume would be 232 m^3. With the anaerobic pond volume of 1158 m^3, the hydraulic retention time in the pond under these conditions would be 5 days. In this retention time, approximately 65 per cent of the suspended solids (SS) in the raw sewage (RS) will settle out and 50 per cent or more of the BOD_5 will be removed.

The organic solids which settle to the bottom of each anaerobic pond form a thick sludge which undergoes anaerobic bacterial breakdown. Complex organic materials in the raw sewage and in the sludge will be broken down by bacteria in the absence of oxygen (anaerobic conditions) to produce intermediate organic products (organic acids) and, eventually, methane gas and carbon dioxide, according to the pathways shown in Fig. A2. These reactions will proceed simultaneously at temperatures above 10°C, below which anaerobic action virtually ceases.

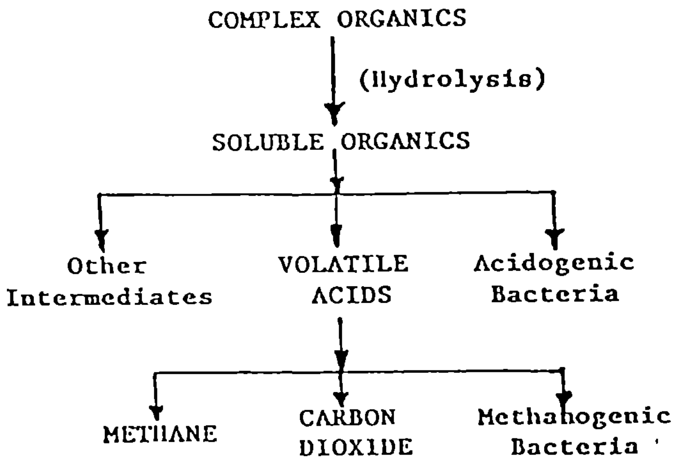


Fig. A2 - Anaerobic breakdown of organic materials in an anaerobic pond

These same reactions occur in the body of the anaerobic pond but at a lower rate because fewer anaerobic bacteria will be present in the water column, compared with the sludge layer. A well-operating anaerobic pond releases gas bubbles from the sludge which carry with them anaerobic bacteria to seed the water column and improve the BOD_5 removal generally. Gas bubbles will be released to the atmosphere at the surface of an anaerobic pond at a rate which will depend on the temperature at any time. Gas release will be highest during the hottest period of the year and some odour can be expected. At a volumetric organic loading of approximately 160 g BOD_5/m^3d, the odour should not be excessive, especially if the sulphate concentration in the raw sewage is less than 100 mg/l.

With gas rising to the surface of an anaerobic pond and sometimes carrying sludge with it, a surface scum will tend to develop on the anaerobic pond surface. This scum layer, if allowed to accumulate, will serve as a breeding ground for flies and mosquitos and so should be removed on a regular basis. Although it is sometimes stated that a scum layer improves the performance of anaerobic ponds, especially during cool weather, the potential environmental disadvantages should be considered at El Nazlah.

Solids settling to the bottom of the anaerobic ponds will accumulate over time, in spite of the organic material being constantly broken down by anaerobic action. The level of sludge, as indicated by the 'white towel' test, should not be allowed to exceed 2 m depth before being removed. Sludge removal can be achieved by vacuum tanker, of the type used to evacuate septic tanks, or by portable pump and hose. Only one anaerobic pond should be desludged at a time, with the whole of the raw sewage flow being diverted through the one still in operation. Since most of the sludge removed will be well stabilized, through anaerobic action, it will be suitable for disposal onto agricultural land, applying the necessary precautions and techniques prescribed for good land disposal practice.

5. The Facultative Pond

5.1 The Treatment Process

Effluent from the anaerobic ponds (AE) will overflow into the facultative stabilization pond (FP), when inflow is pumped to the treatment plant. In this second stage of treatment, aerobic and facultative bacteria will breakdown the remaining colloidal and soluble organic material in the water column (according to Fig. A3) and algae will grow to provide dissolved oxygen for bacterial growth. The carbon dioxide released by bacterial respiration will provide the algae with the carbon source for photosynthesis and a symbiotic relationship will exist according to the diagram of Fig. A4.

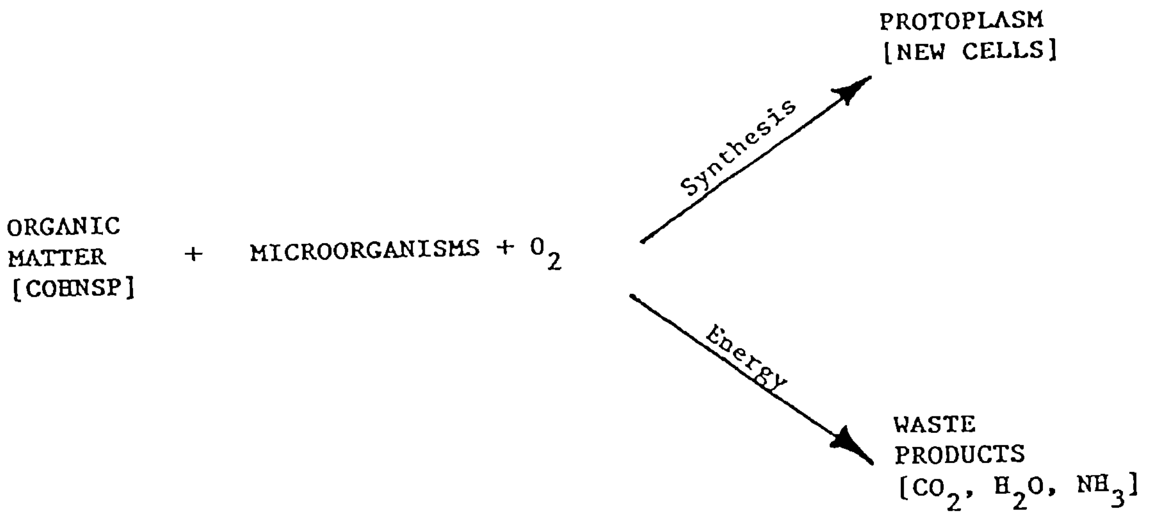


Fig. A3 - Aerobic breakdown of organic matter

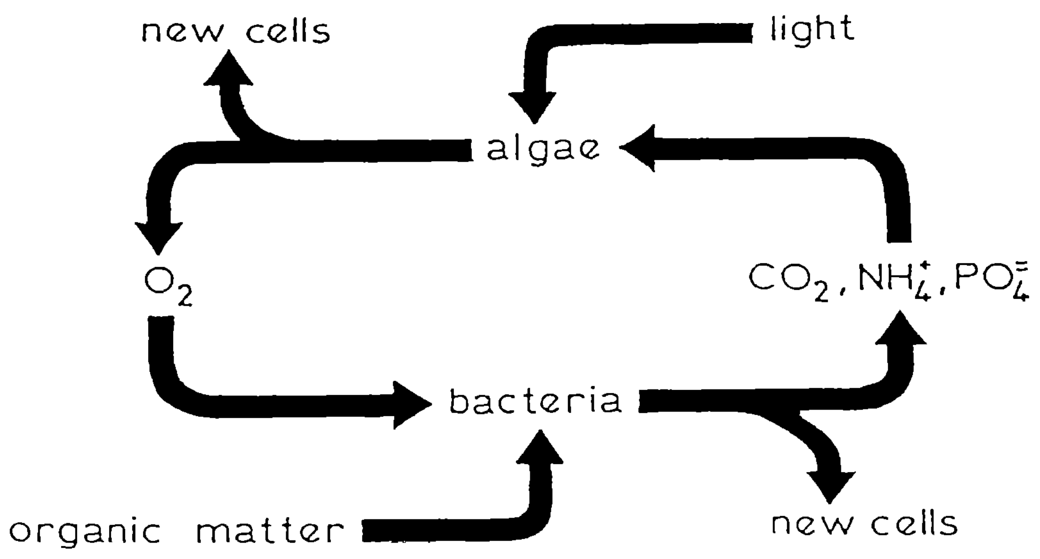


Fig. A4 - Algal/bacterial action in the facultative stabilization pond

Any organic solids, including dead algae and bacteria, which settle out in the facultative pond will undergo anaerobic breakdown in the bottom sludge. Any intermediate organic products of the anaerobic breakdown will be released to the water column and be further broken down by aerobic and facultative bacteria. The result will be a significant improvement in BOD_5 removal as the wastewater passes through the facultative pond.

5.2 Design

The facultative stabilization pond (FP) has been designed to achieve secondary biological treatment of the anaerobic pond effluent (AE) to the extent of a further 40 per cent removal of the original BOD_5 in the raw sewage (RS), equivalent to 80 per cent efficiency. To maintain satisfactory environmental conditions in this pond at all times of year, the facultative pond has been designed for a surface organic loading rate of 240 kg BOD_5/ha d and is expected to remove at least 80 per cent of the colloidal and soluble organic matter (BOD_5) in the effluent from the anaerobic ponds (AE).

Thus, to continue the example, if 50 per cent of the raw sewage BOD_5 is removed in the anaerobic pond treatment stage, the effluent (AE) will contain 400 mg/l BOD_5. Ignoring any evaporative losses, the total inflow volume of 463 m^3/d to the two anaerobic ponds will overflow into the single facultative pond, giving a total BOD_5 load of 185,600 g/d, or 185.6 kg/d. With the facultative pond mid-depth area being 7858 m^2, the surface organic loading on the pond would be 236 kg/ha d.

5.3 Performance

The facultative stabilization pond (FP), being shallow in depth (1.5 m), will be aerobic near the surface at all times but will be anaerobic in the sludge layer and in the lower part of the water column. During the day and night the depth of the aerobic layer in the pond will vary because the production of oxygen by algae (photosynthesis) is dependent on light intensity and ceases during darkness. Use of oxygen by the bacteria is continuous throughout the day and night and, during the night, even the algae respire and consume oxygen. Thus, the dissolved oxygen released to the pond will be greatest during the day near the surface of the pond, where and when light intensity is highest, and pond dissolved oxygen (DO) will vary with depth and time of day.

In addition, the utilization of carbon dioxide (CO_2) by the algae will vary throughout the day and the pH of the pond contents will vary as a result. During the daytime, when dissolved oxygen levels are highest, pond pH will also be highest because algae will be utilizing CO_2 at the highest rate. Dissolved oxygen and pH levels in the pond tend to be lowest at the end of the night, just before dawn. At this time, the surface layer with dissolved oxygen might be quite shallow, especially during the cool period of the year, and the dissolved oxygen concentration in this layer might be quite low (1-2 mg/l DO). By comparison, at the time of maximum depth of aerobic surface layer in the pond, which normally occurs from 1-2 pm in hot weather, the concentration of DO near the pond surface will often be at a level of supersaturation. Pond pH might fluctuate between 6.5 and 9.5, as CO_2 is released and consumed, and the high pH levels are thought to contribute to pathogen die-off.

Dissolved oxygen concentration and pH are two parameters which can easily be measured and will be included in the pond monitoring programme. The facultative pond should never be completely anaerobic at any time of day at any time of year.

The types of algae which predominate in a facultative pond vary naturally with loading and time of year. No special measures are required to encourage or discourage any particular species of algae and it can be assumed that the combination of organisms existing at any particular time are best adapted to the environmental conditions at that time. The effluent from the facultative pond (FE) will contain less than 10 per cent of the original BOD_5 in the raw sewage (RS) in the form of soluble BOD_5 but will contain algae which also register as BOD_5 in the test. Consequently, the facultative pond effluent (FE) should be tested for unfiltered and filtered BOD_5, to allow the separation of BOD_5 caused by suspended algae. Normally, the BOD_5 concentration attributable to suspended algae in a facultative pond effluent (FE) is of the order of 30-50 mg/l. The algae will also show up as suspended solids in the test and might contribute about 50 mg/l SS in the facultative pond effluent.

6. The Maturation Pond

6.1 The Treatment Process

Effluent from the facultative pond (FE) will overflow into the maturation or polishing pond (MP) when inflow is pumped to the treatment plant. This effluent is likely to contain 50-70 mg/l of BOD_5 with suspended algae contributing to this BOD. The processes of solids settlement and biological degradation of organic matter under aerobic conditions, as achieved in the facultative pond (FP), will continue in the maturation pond (MP). However, with a relatively low soluble BOD_5 concentration in the facultative pond effluent (FE), the aerobic bacterial action indicated in Fig. 3 will not be at such a high level as in the facultative pond (FP) and algal growth will not be so great. Settlement of algae transferred from the facultative pond will occur in the maturation pond, resulting in clarification of the effluent from the maturation pond (MP).

6.2 Effluent Quality

Another function of a maturation pond, in addition to clarification and BOD_5 removal, is to improve the removal of pathogens and faecal indicator organisms, as measured by faecal coliform bacteria. Faecal coliforms (and pathogens) die off in all the stages of stabilization pond treatment but maturation ponds are more efficient in achieving reduction than earlier pond stages.

The die off of faecal coliform (FC) bacteria is calculated from the following formula:

$$Ne = \frac{Ni}{1 + K_b R} \qquad (1)$$

where, Ni = Influent number of FC
Ne = Effluent number of FC
K_b = Rate coefficient for FC removal
R = Retention time in pond

For a series of n ponds in series, the overall formula becomes:

$$Ne = \frac{Ni}{(1 + K_{b1} R_1)(1 + K_{b2} R_2).....(1 + K_{bn} R_n)} \qquad (2)$$

Where, K_{bn} = Rate coefficient for FC removal in n^{th} pond
R_n = Retention time in n^{th} pond

The removal rate coefficient for FC is considered to be temperature (T°C) dependent, as follows:

$$K_{bT} = 2.6\ (1.19)^{T-20} \qquad (3)$$

K_b has often been assumed to be a constant rather than to vary, depending on the stage of pond. Recent studies on the Al Samra stabilization pond system in Amman, Jordan (Saqar and Pescod, 19) showed that K_b varied from 0.5 d^{-1} for anaerobic ponds to 0.7 d^{-1} for maturation ponds during the coldest part of the year. For the higher temperature in Fayoum, the following K_b values could be applied:

Anaerobic ponds, $K_{b1} = 0.6\ d^{-1}$
Facultative pond, $K_{b2} = 0.7\ d^{-1}$
Maturation pond, $K_{b3} = 0.8\ d^{-1}$

Applying Eq. 2 to the El Nazlah ponds and assuming Ni = 10^8 FC/100 ml, the maturation pond effluent FC level (Ne) can be calculated:

$$Ne = \frac{10^8}{(1 + 0.6 \times 5)(1 + 0.7 \times 27)(1 + 0.8 \times 4.2)} = \frac{10^8}{4 \times 18.9 \times 3.36}$$

$$= 3.94 \times 10^5 \text{ FC/100 ml}$$

This level of FC contamination would prevent the effluent from being used for unrestricted irrigation but, provided it was free of nematode eggs, it could be used to irrigate industrial and fodder crops. Monitoring will provide information on the actual quality of the final effluent from the El Nazlah Sewage Treatment Plant and whether or not it complies with the WHO (1989) Guideline value of < 1000 FC/100 ml for unrestricted irrigation .

7. Macrophyte Ponds

7.1 The Treatment Process

Two macrophyte ponds (MaP) have been incorporated into the design of the El Nazlah Sewage Treatment Plant as experimental and demonstration units for this type of treatment. Only a small portion of the total flow is to be transferred to these ponds, approximately 3 per cent of the influent flow rate to macrophyte pond No. 1 (MaP1) and 10 per cent of the influent flow rate to macrophyte pond No. 2 (MaP2).

Both ponds will be stocked with floating macrophytes (aquatic plants) which are known to be effective in treating effluents to a high standard, being particularly efficient in the removal of nutrients (nitrogen and phosphorus) and heavy metals. For the El Nazlah macrophyte ponds, indigenous species of floating macrophytes will be tested for their suitability in treating anaerobic pond effluent in MaP1 and facultative pond effluent in MaP2 under different loading conditions. The surface of each pond will gradually be allowed to be covered by growth of the macrophyte chosen for study at any particular time. This will ultimately eliminate algal involvement in the treatment process, through light shading.

7.2 Macrophyte Harvesting

From time to time, and at least once every year, the floating macrophytes covering the whole pond surface will have to be removed, otherwise maximum treatment performance (which occurs when the macrophytes are growing freely) will not be achieved. The crop of macrophytes can be harvested using a boat or, since these ponds are relatively small, from the embankment using wooden rakes. Some macrophytes might be suitable for animal feed but more typically will have to be disposed of. Landfill disposal or burial in trenches are likely to be the most practicable methods but pretreatment in biogas digesters is possible and, if adopted, will produce methane gas as a byproduct.

APPENDIX B

BILL OF QUANTITIES

I T E M	UNIT	QUN.	RATE L.E.	TOTAL L.E.
- Excavation in wet soil	m³	250	8.50	2125
- Excavation in dry soil	m³	4300	3.00	12900
- Backfill with borrow material for formation of embankment	m³	10500	15.00	157500
- Plastic insulation for slopes and bottom of ponds	m³	13000	5.00	65000
- Layer of fine sand with 15 cm thick	m³	1130	3.50	3955
- Layer of gravel with 15 cm thick	m³	1130	9.00	10170
- Supporting of internal and external slopes with hollow concrete blocks 10 cm thick	m²	7750	15.00	116250
- Piping system				
* 75 mm PVC pipes	m	120	20.00	2400
* 160 mm PVC pipes	m	435	28.00	12180
* 200 mm PVC pipes	m	250	30.00	7500
* Manholes	No	9	1200	10800
* Penstock	No	5	2000	10000
- Valves				
* 200 mm diameter	No	2	350	700
* 160 mm diameter	No	7	300	2100
* 75 mm diameter	No	4	175	700
- Construction of offices, store and W.C.	lumpsum		10000	10000
- Construction of screen and inlet chamber	lumpsum		3500	3500
- Supply & erection of magnetic flow meter	lumpsum		11000	11000
- Site lighting	lumpsum		3500	3500
- Dissludging pump	No	1	7000	7000
TOTAL COST				449280

ITEM	DESCRIPTION	PLANNED COST	ACTUAL COST
A	Excavation & Backfill	172525.00	225803.82
B	Concrete Works	119750.00	101309.57
C	Construction & Sanitary Fixtures.	125505.00	151595.96
D	Electrical & Mechanical Works	21500.00	21813.87
E	Adminstration Building	10000.00	-
F	Site Fence.	-	84000.00
G	Prices increase of cement & steel.	-	8542.55
H	Deduction against supervision	-	(-)3000.00
	TOTAL	449280.00	590065.77

The project had a closing cost of 590065.77 L.E. out of the originally planned cost estimate 449280.00 having a difference of 140785.77 L.E. due to variation orders mentioned in the final justification.

ITEMS	DESCRIPTION	UNIT	TENDER QTY	CONT. QTY	ACTUAL QTY	UNIT PRICE	VAR.	% OF VAR.	TENDER AMOUNT	CONT. AMOUNT	ACTUAL AMOUNT	REMARKS
1	EXCAVATION	M3	4300.0	4300	9573.07	3.00	5273.07	12[illegible]	1290[illegible].00	12900.00	28719.21	CO1
2	EXCAVATION IN WET SOIL	M3	250.0	250	1214.41	10 00	964.41	38[illegible]	250[illegible].00	2500.00	12144.10	CO1
4	SAND LAYER OF 15 CM TH.	M3	1135.0	1135	1095.75	9.00	-39.25	-[illegible]	1021[illegible].00	10215.00	9861.75	
5	GRAVEL LAYER OF 15 CM TH.	M3	1135.0	1135	1095.75	17.00	-39.25	-3%	1929[illegible].00	19295.00	18627.75	
6	SANDY-GRAVEL BACKFILLING FOR EMBANKMENT	M3	10500.0	10500	15567.62	12.25	5067.62	48%	12862[illegible].00	128625.00	190708.35	CO1
6	CLAY BACKFILLING UNDER CONC. PANELS	M3	0.0	0	874.51	7.00	874.51		0.00	0.00	6121.57	
7	RFT STEEL	TON	0.5	1	8.90	2000.00	8.40	1680%	1000.00	1000.00	17800.00	
8	RFT CONC. FOR WALLS & FOUNDATION	M3	5.0	5	154.16	140.00	149.16	2983%	700.00	700.00	21582.40	
9	PREECAST HOLLOW CONC. PANELS	M2	6520.0	3200	4262.03	15.00	1062.03	33%	97800.00	48000.00	63930.45	CO1
10	RFT CONC. SLAB 15 CM TH.	M2	1550.0	0	0.00	22.00	0.00		34100.00	0.00	0.00	
11	UPVC PIPES 200 MM DIA.	M	250.0	250	274.35	27.00	24.35	10%	6750.00	6750.00	7407.45	
	160 MM DIA.	M	435.0	435	353.55	22.00	-81.45	-19%	9570.00	9570.00	7778.10	CO1
	75 MM DIA.	M	120.0	120	65.25	15.00	-54.75	-46%	1800.00	1800.00	978.75	CO1
12	CAST IRON VALVES 200 MM DIA.	NO	2.0	2	2.00	330.00	0.00	0%	660.00	660.00	660.00	
	160 MM DIA.	NO	7.0	7	0.00	200.00	-7.00	-100%	1400.00	1400.00	0.00	CO1
	75 MM DIA.	NO	4.0	4	0.00	100.00	-4.00	-100%	400.00	400.00	0.00	CO1
13	ELBOW 90 DEG. 160 MM DIA.	NO	6.0	6	9.00	80.00	3.00	50%	480.00	480.00	720.00	CO1
	75 MM DIA.	NO	8.0	8	0.00	50.00	-8.00	-100%	400.00	400.00	0.00	CO1
	ELBOW 45 DEG. 200 MM DIA.	NO	3.0	3	10.00	100.00	7.00	233%	300.00	300.00	1000.00	CO1
	160 MM DIA.	NO	12.0	12	2.00	80.00	-10.00	-83%	960.00	960.00	160.00	CO1
	75 MM DIA.	NO	4.0	4	0.00	50.00	-4.00	-100%	200.00	200.00	0.00	CO1
	ELBOW 22.5 DEG.160MM DIA.	NO	5.0	5	0.00	80.00	-5.00	-100%	400.00	400.00	0.00	CO1
	TEE 200/200	NO	1.0	1	1.00	120.00	0.00	0%	120.00	120.00	120.00	
	TEE 160/160	NO	5.0	5	0.00	100.00	-5.00	-100%	500.00	500.00	0.00	CO1
	TEE 160/75	NO	2.0	2	0.00	100.00	-2.00	-100%	200.00	200.00	0.00	CO1
	TEE 75/75	NO	2.0	2	0.00	80.00	-2.00	-100%	160.00	160.00	0.00	CO1
14	MANHOLES DEPTH MORE THAN 60 CM	NO	7.0	7	16.00	700.00	9.00	129%	4900.00	4900.00	11200.00	CO1
	MANHOLES DEPTH LESS THAN 50CM	NO	2.0	2	0.00	350.00	-2.00	-100%	700.00	700.00	0.00	
15	CAST IRON PEN-STOCK	NO	5.0	5	12.00	1500.00	7.00	140%	7500.00	7500.00	18000.00	CO1
16	POLYETHYLENE SHEETS 0.3 MM	M2	13000.0	13000	0.00	4.50	-13000.00	-100%	58500.00	58500.00	0.00	CO2
17	STONE PITCHING 40 CM TH. FOR EMANKMENTS	M2	1250.0	0	2995.64	18.00	2995.64		22500.00	0.00	53921.52	CO1
18	PITUMINOUS PAINT 3 COATS ON CONC. SURFACES	M2	15.0	15	12.05	15.00	-2.95	-20%	225.00	225.00	180.75	
19	SITE LIGHTING	L.S	1.0	1	1.00	20000.00	0.00	0%	20000.00	20000.00	20000.00	
20	INSTALL ONLY MAGNITIC FLOW METER	L.S	1.0	1	1.00	1000.00	0.00	0%	1000.00	1000.00	1000.00	
21	ADMINSTRATION BUILDING	L.S	1.0	1	0.00	24428.00	-1.00	-100%	24428.00	24428.00	0.00	CO1
5/2	PLAIN CONCRETE	M2	0.0	0	41.61	80.00	41.61		0.00	0.00	3328.80	CO2
22/2	RENDERING	M2	0.0	0	32.62	9 00	32.62		0.00	0.00	293.58	
33/2	CAST IRON PIPES 100 MM DIA.	L.M	0.0	0	27.90	30.00	27.90		0.00	0.00	837.00	
39/2	SITE LIGHTING SWITCH- BOARD	L.S	1.0	1	0.40	1250.00	-0.60	-60%	1250.00	1250.00	500.00	
	TOTALL						3279.07		472438.00	366038.00	497576.53	
	TOTALL AFTER REDUCTION 5%								448816.10	347736.10	472697.70	
22	SUPPLY AND INSTALL SITE FENCE	L.M	0.0	600	600 00	140.00	0.00	0%	0.00	84000 00	79000.00	
	***TOTAL WITHOUT V.O.								448816.10	431736.10	551697.70	
	TOTAL AFTER ADDING CO NO 1 (130000 LE)									561736.10		CO1
-	POLYETHYLENE SHEET 1MM TH.	M2	0.0	0	1429.52	20.00	1429.52		0.00	0.00	28590.40	CO3
-	STEEL SCREEN &WEIR	L.S	0.0	0	1.00	900.00	1.00		0.00	0.00	900.00	CO3
-	OUTLET WEIR (B.R.B.PIPES PIECES)	NO	0 0	0	9.00	216.25	9.00		0.00	0.00	1946.25	CO3
-	ELE. CABLE FOR MAGNITIC FLOW METER	L.M	0.0	0	102.50	13.55	102.50		0.00	0.00	1388.88	CO3
	TOTAL AMOUNT OF EXECUTED WORKS								448816.10	561736.10	584523.22	
	AMOUNT DUE TO PRICES INCREASING OF CEMENT &STEEL										8542.55	
	DEDUCTION AGINST SUPERVISION									-	3000.00	
	**** FINAL TOTAL AMOUNT										590065.77	

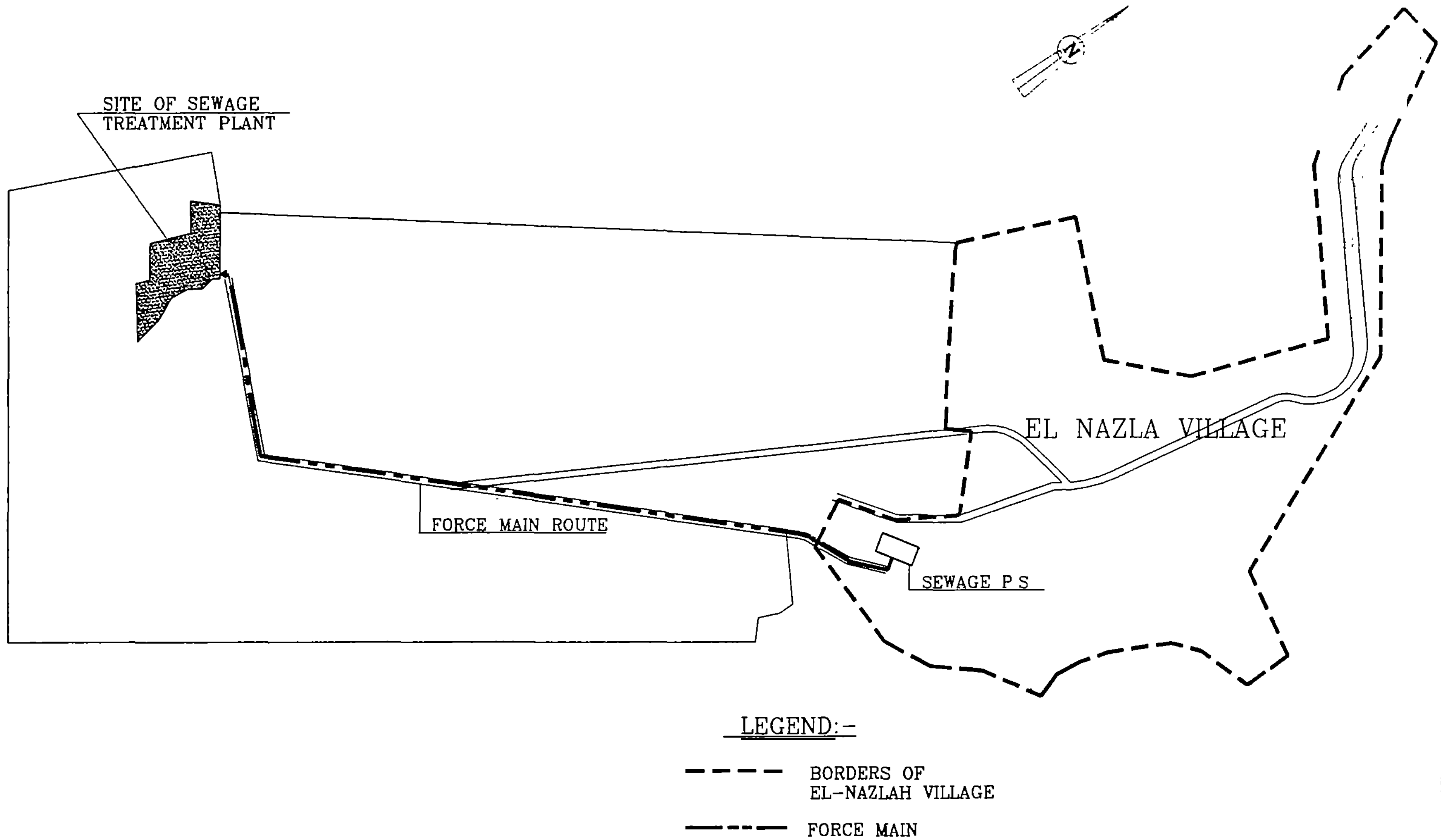
CHANGE ORDERS
CO1 : CHANGE IN DESIGN DUE TO CHANGE IN SITE AREA
excution of inside linning & outside
linning according to TENDER DOCUMENTS
CO2 : CHANGE POLYETHYLENE 300 MIC. TO
1000 MIC. IN ANAEROPIC PONDS
OMISSION POLYETHYLENE 300 MIC.IN OTHER PONDS
EXCUTION OF PC LAYER 15 CM TH. UNDER PIPES
CO3 :UNIT PRICES WERE REQUIRED FOR EXISTING TENDER WORKS
% OF INCREASING AGAINST CONTRACT VALUE = 4%

APPENDIX C

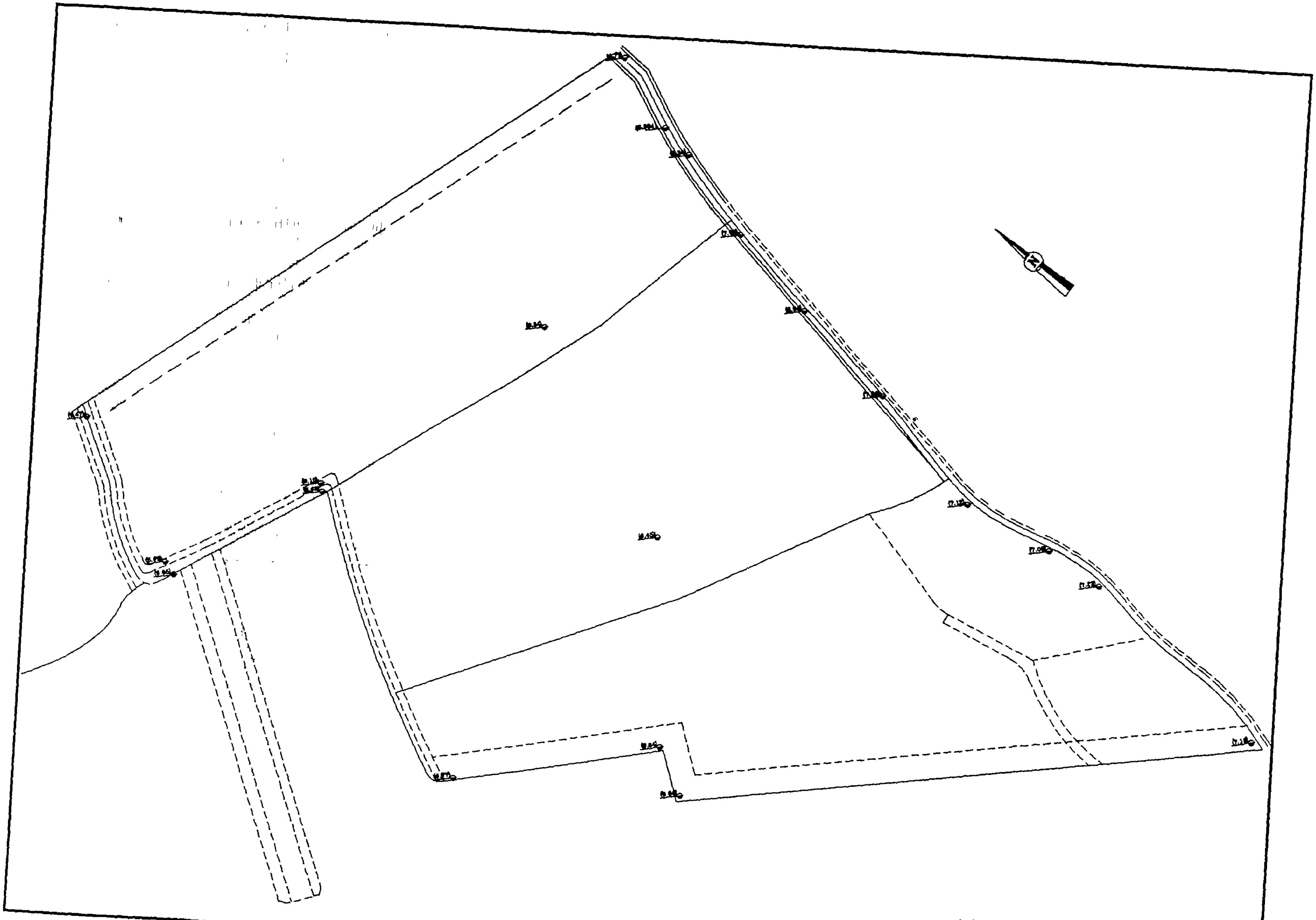
CONSTRUCTION DRAWINGS

El Nazla Ponds

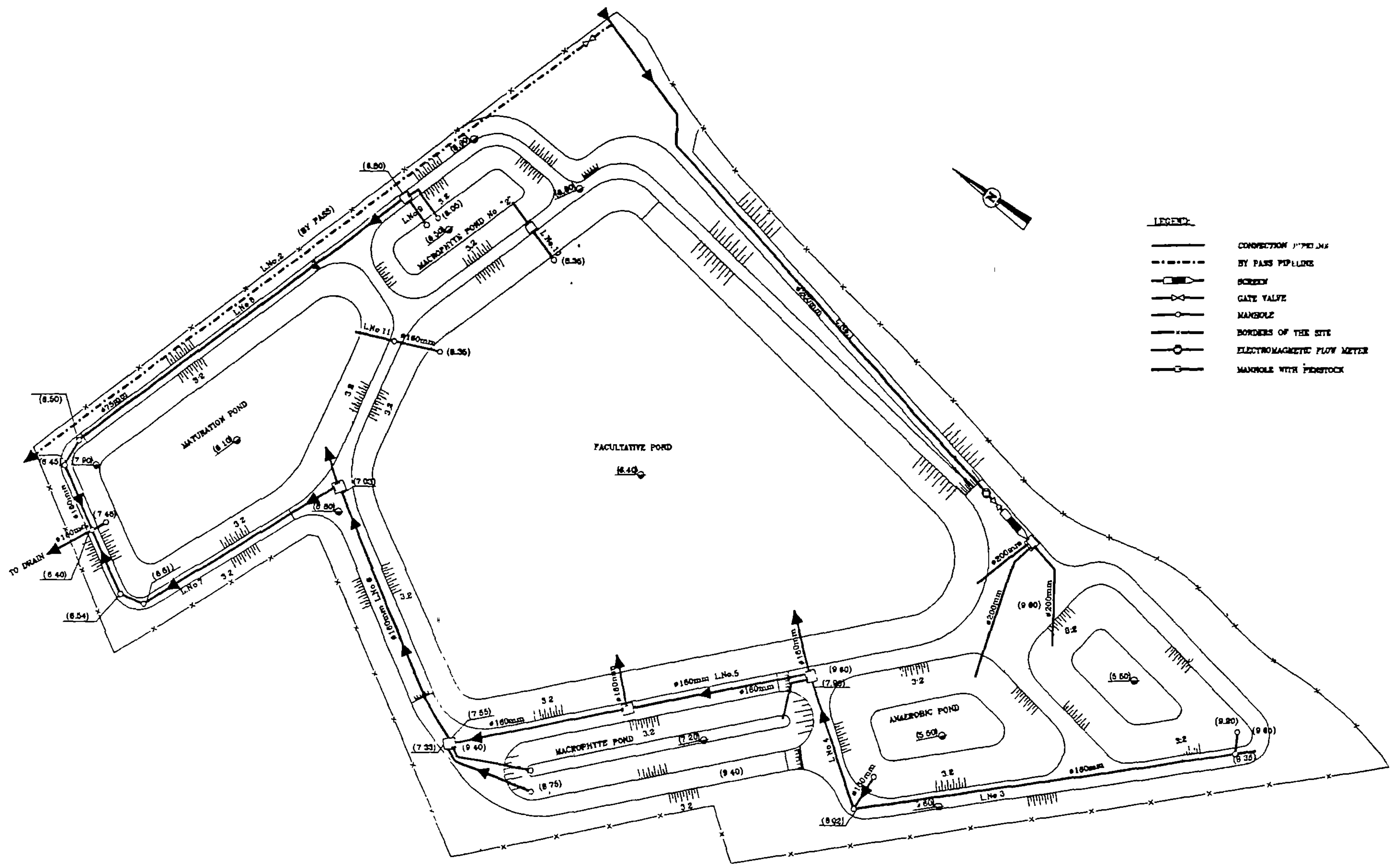
List of Drawings



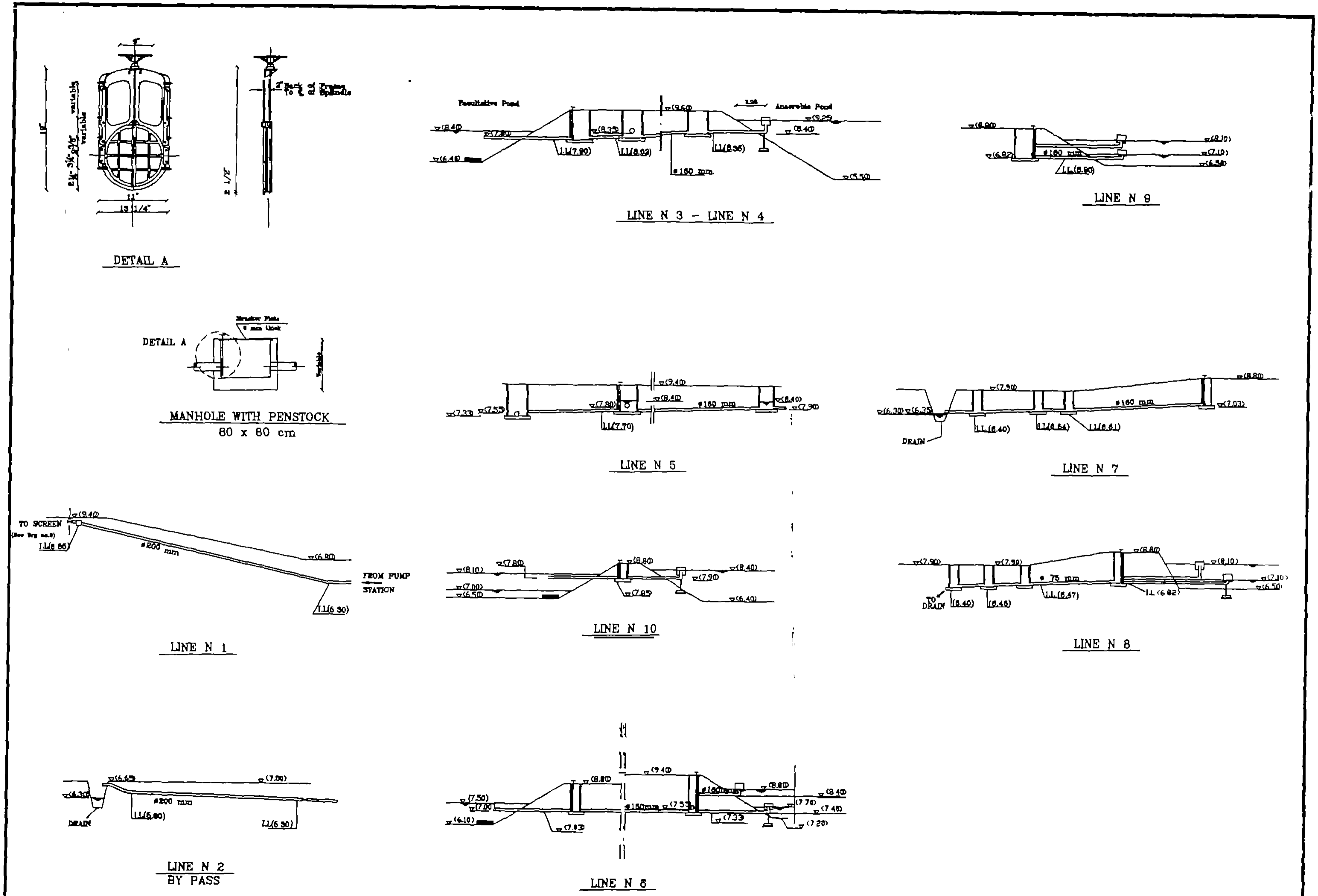
(1) GENERAL LOCATION OF EL-NAZLAH VILLAGE & SITE OF S.T P



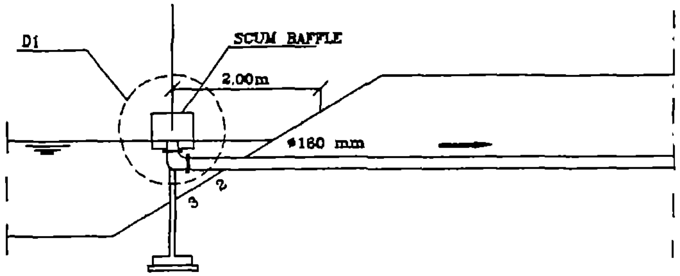
(2) GROUND LEVELS FOR SITE OF SEWAGE TREATMENT PLANT



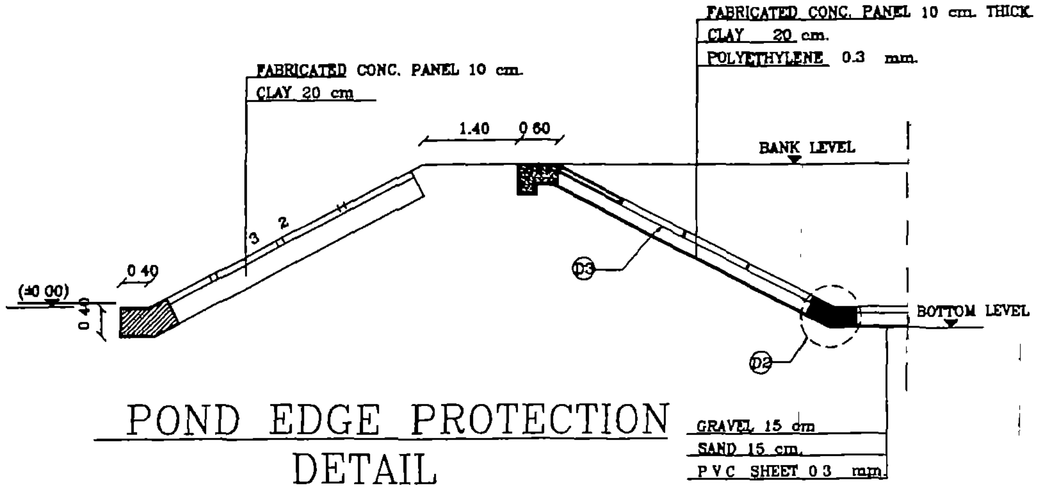
(3) GENERAL LAYOUT FOR SEWAGE TREATMENT PLANT



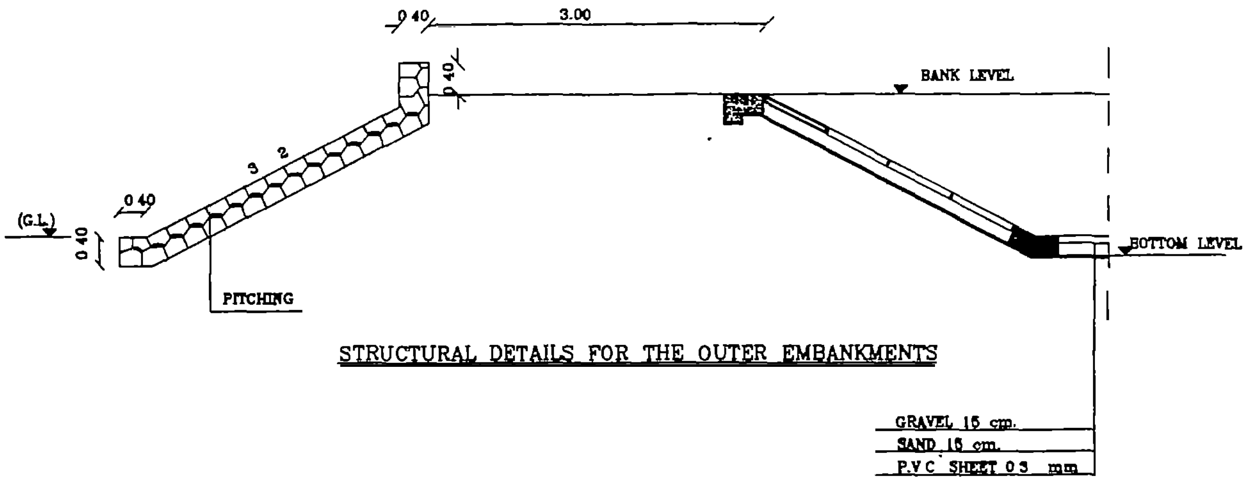
(4) LEVEL OF PIPING SYSTEM & DETAILS OF PENSTOCK



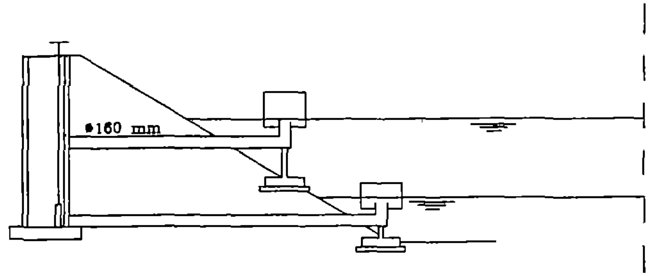
OUTLET PIPE



POND EDGE PROTECTION DETAIL



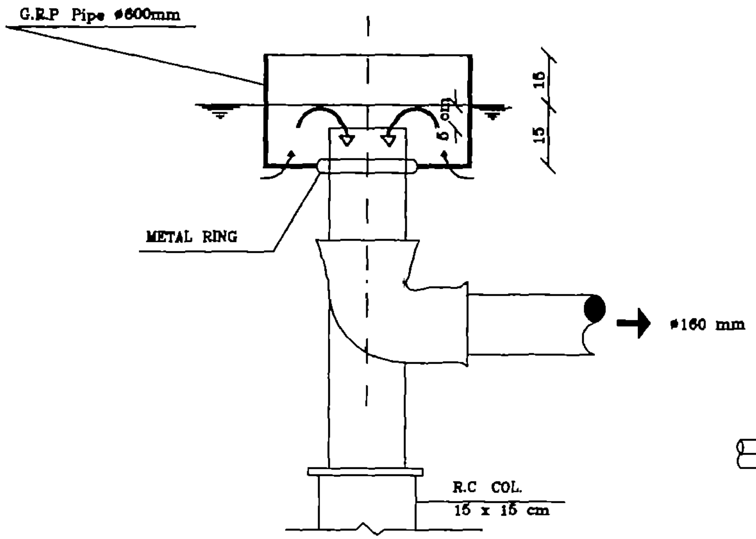
STRUCTURAL DETAILS FOR THE OUTER EMBANKMENTS



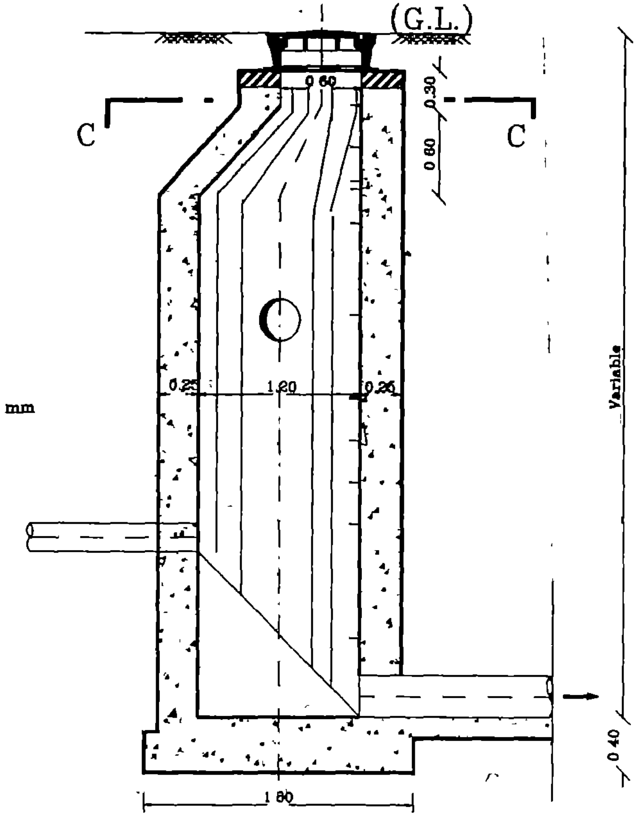
OUTLET PIPE

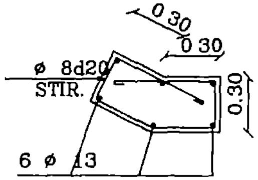
FOR MACROPHYTE POND

(5) DETAILS OF EMBANKMENT & OUTLETS

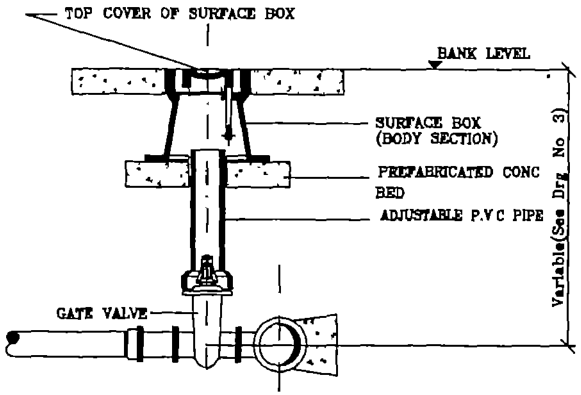


DETAIL (1)

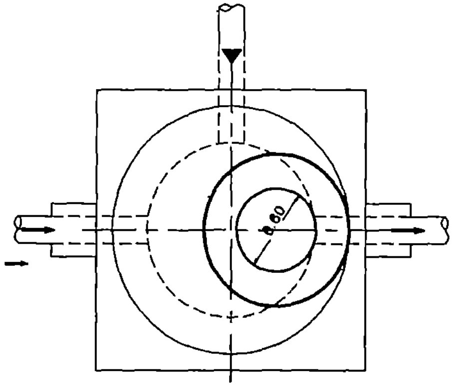




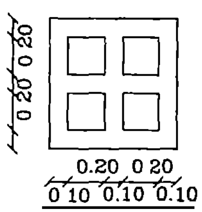
DETAIL (2)
REINFT.



SURFACE BOX FOR GATE VALVE

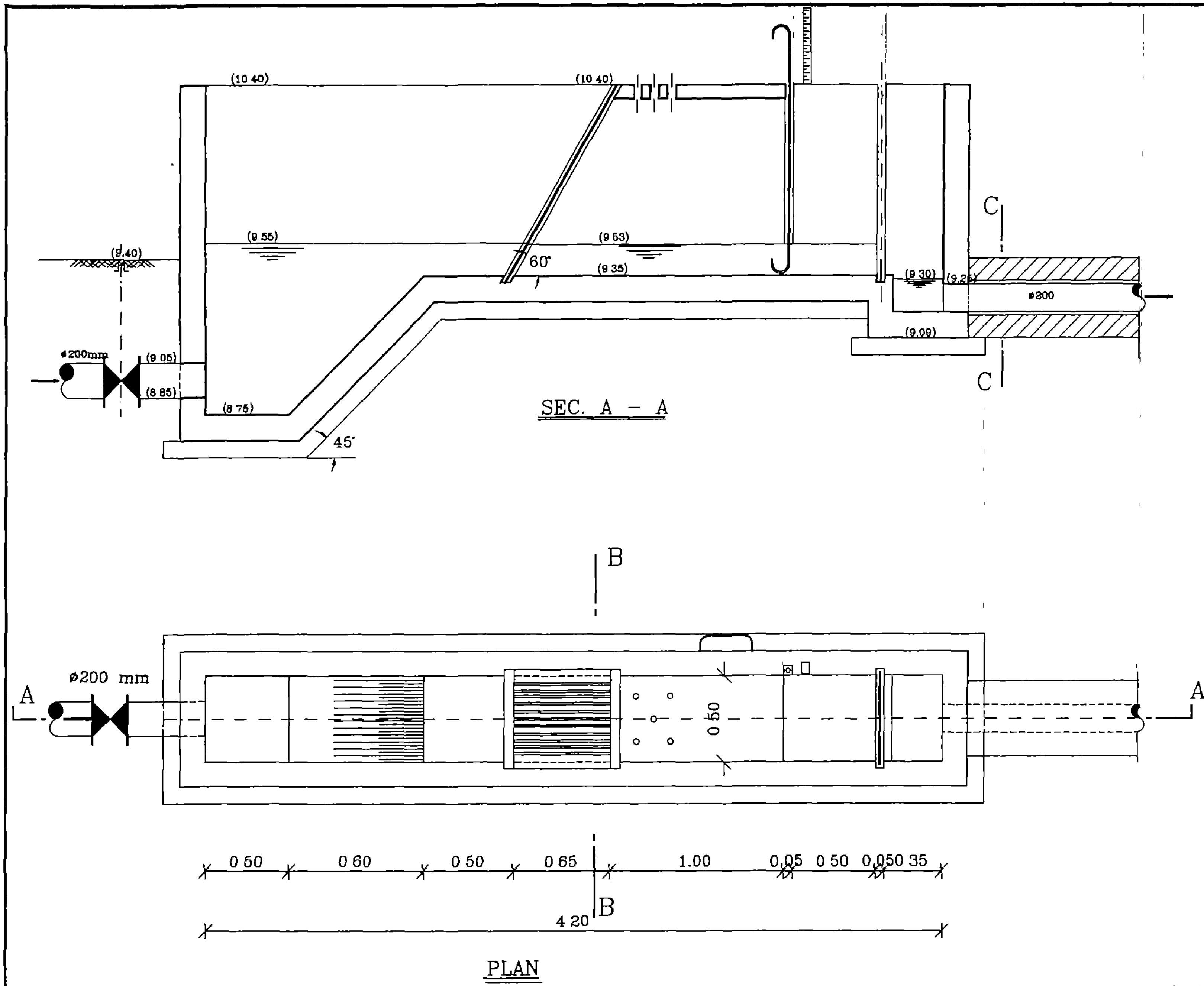


SEC. C–C
DETAIL OF MANHOLE

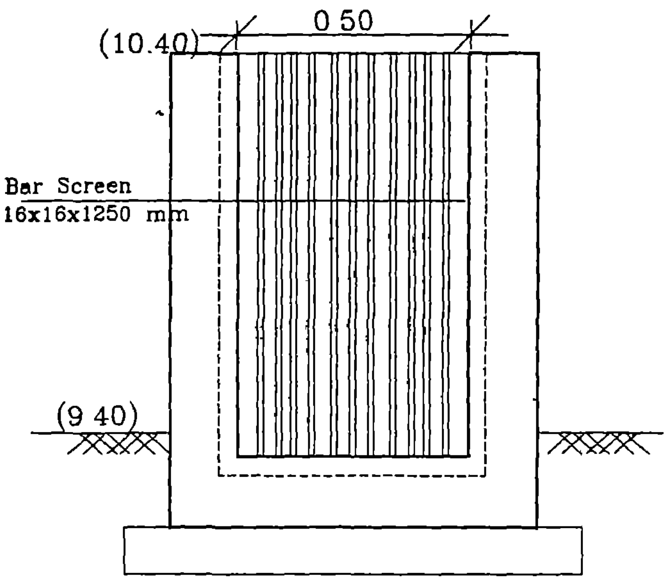


DETAIL (3)

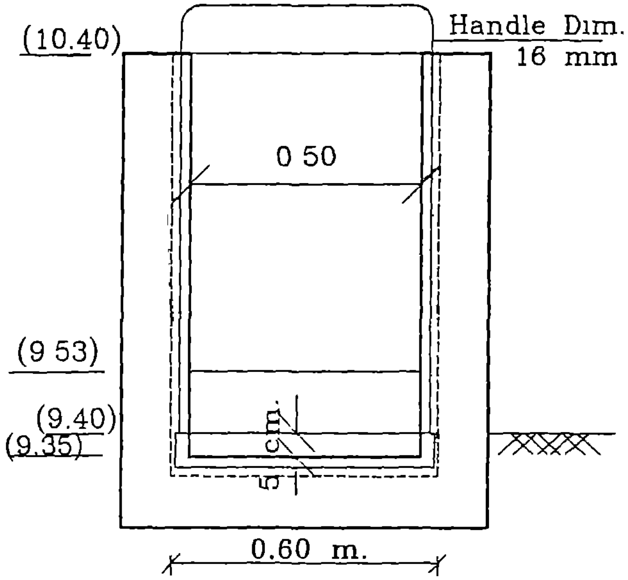
(6) DETAILS OF MANHOLES,SURFACE BOX



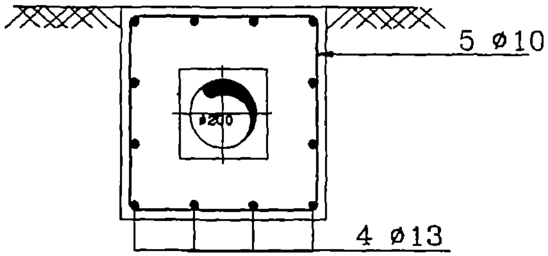
(7A) DETAILS OF SCREEN & MEASURING WEIR



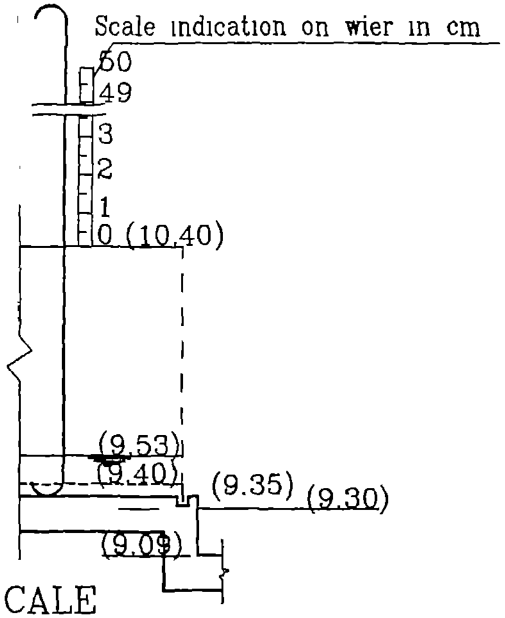
SEC. B- B



DETAIL OF WEIR

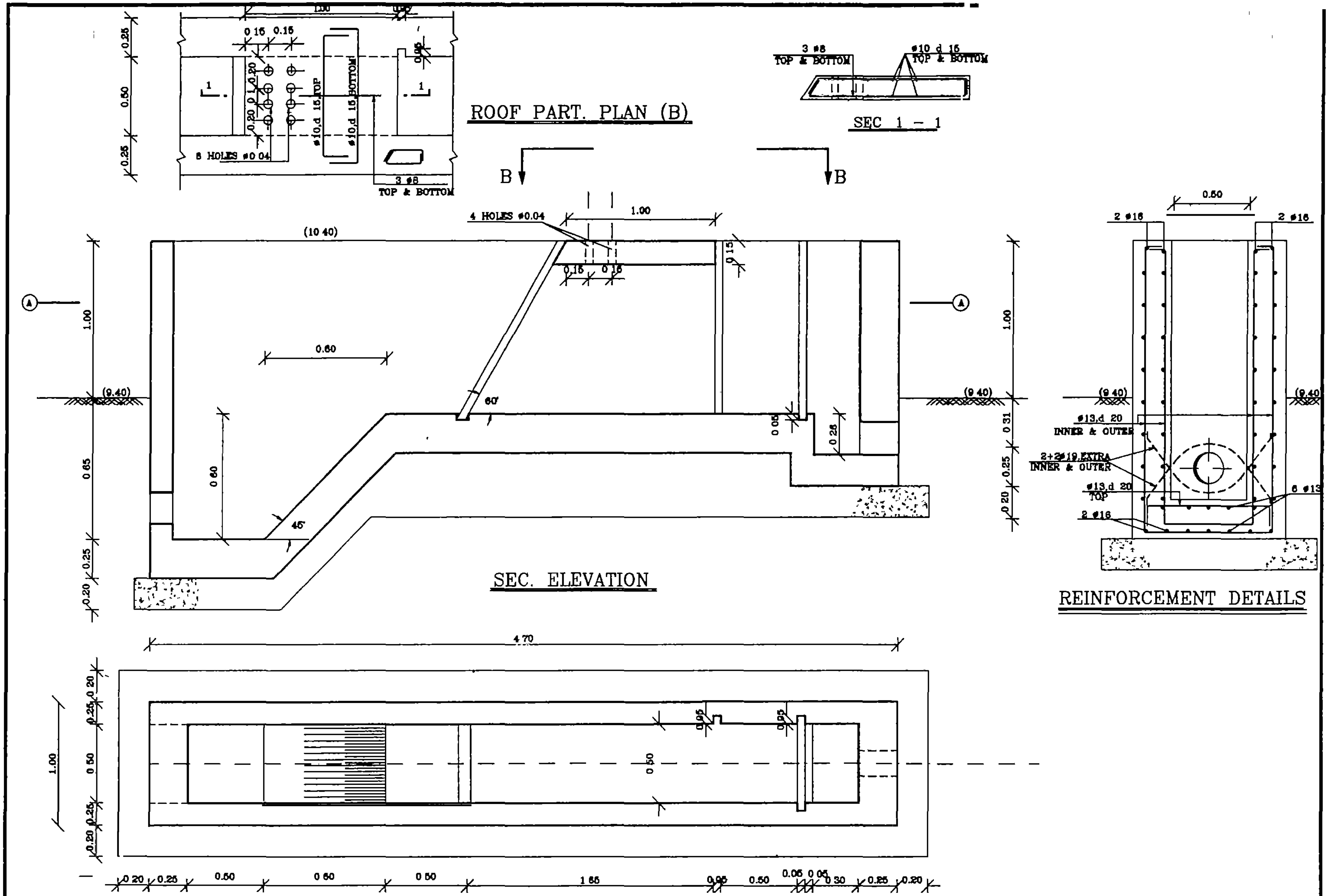


SEC. C - C

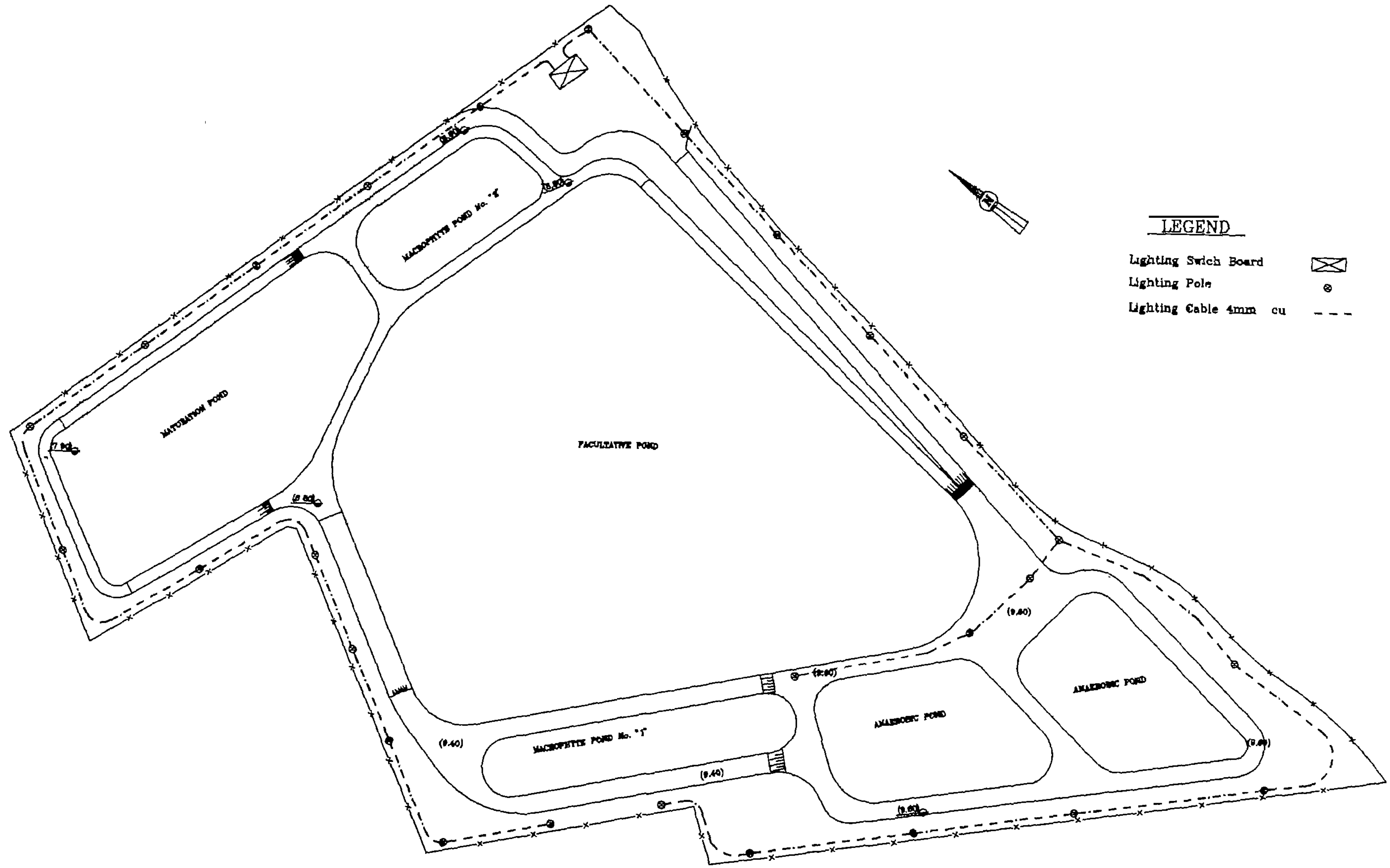


MEASURING SCALE

(7B) DETAILS OF SCREEN & MEASURING WEIR



(8) STRUCTURAL DETAILS OF SCREEN



(9) SITE LIGHTING

APPENDIX D

LIST OF EQUIPMENT AND SUPPLIES FOR MONITORING PROGRAMME

1. EQUIPMENT

1.1 General Purpose

	Approx. Current Price £
Water still	850
Analytical balance	1,800
Top pan (dual range) balance	1,000
Drying/sterilising (40-220°C) oven	900
Refridgerator/freezer	400
Magnetic stirrers (2)	320

1.2 Specific Equipment

pH meter + spare pH and temperature probes	(pH)	750
Max/Min thermometer + 3m probe	(Temp. monitoring	40
Vacuum pump	(Solids & coliforms)	400
Filter holders (3)	(Solids)	70
Filter holders, membrane (2)	(Coliforms)	160
Incubator 20°C	(BOD)	1,400
Air pump	(BOD)	70
Kjeldahl equipment + 6 spare flasks	(Nitrogens)	3,400
Incubator 37°C & 44°C	(Coliforms)	1,400
Autoclave	(Coliforms)	1,750
Conductivity meter	(Conductivity)	300

2. CONSUMABLES

2.1 General Items

Beakers 50-1000 ml Glass	105
" 50-20000 ml Plastic	65
Pipettes Volumetric 1-100 ml	190
" Graduated 1-10 ml	65
Bottles, Storage 60-1000 ml Clear Glass	160
" " " " Amber Glass	120
" " 125-1000 ml Plastic	80
" Sample 125-1000 ml "	70
" Wash 500 ml "	10
" Aspirator 50 l (Dist H_2O) Plastic	40

Flasks, Volumetric 50-2000 ml Glass		580
" Erlenmeyer 100-2000 ml "		155
Burettes, Standard 50 ml		60
" Micro 10 ml		60
" Stands (2)		30
Thermometers, range of		40
Dessicators (2)		120
Measuring cylinders 25 ml - 1000 ml Glass		220
" " 50 ml - 1000 ml Plastic		75
Spatulas and Forceps		20
Magnets		10

2.2 Specific Items

Filter flasks, 1 litre (3)	(Solids & Coliforms)	40
GFC Filters (6000)	(S. Solids)	840
Membrane filters & pads (12000)	(Coliforms)	2,750
Evaporating basins (20)	(T.D. Solids)	80
Tubing, bungs, taps for filtration equipment		30
Autoclavable sample bottles	(Coliforms)	90
Petri dishes Alternative 1) Reusable glass		90
2) Disposable plastic		560
BOD bottles, 250 ml (250)	(BOD, DO)	875
Aspirators, plastic	(BOD)	35
Tubing, 'T' pieces, diffusers	(BOD)	20
Pipettes, seriological (100 x 1 ml & 50 x 10 ml (Coliforms)		190
Sterilising cans		200
Medical flats		50

2.3 General Chemicals

Buffer powders pH4 100 sachets		50
7"		88
9.2"		50
Sodium borate 10 H_2O	3 Kg	10
Methyl red	25 g	8
Methylene blue	100 g	9
ISO propyl alcohol	5 litres	13
Boric acid	1 Kg	8
Sodium hydroxide	100 Kg	500
Sulphuric acid conc.	50 litres	102
Potassium sulphate	30 Kg	142
Mercuric oxide (Red)	500 g	41
Sodium thiosulphate 5 H_2O	3 Kg	9
NI CVS N_aOH 1 litre ampoules	2 boxes	31
NI CVS H_2SO_4 1 " "	1 box	14
Potassium Dihydrogen orthophosphate	500 g	6
Dipotassium hydrogen orthophosphate	500 g	11
Disodium hydrogen orthophosphate	500 g	9

Ammonium chloride	1 Kg	7
Magnesium sulphate 7 H_2O	1 Kg	4
Calcium chloride 6 H_2O	2 x 500 g	14
Ferric choride	500 g	4
Phenolphthalein	100 g	5
Methyl orange	25 g	4
Oxoid ringers tablets	20 bottles	52
Oxoid membrane media	1 Kg	27
Silica gel (Self indicating)	2 Kg	21

3. SPECIAL ANALYSES

3.1 DO and BOD_5

The recommended methods are given on pp. 413-426 and pp. 525-532 of 'Standard Methods for the Examination of Water and Wastewater', 16th Edition, 1985.

In addition to the general items of equipment required for these tests, the following specific chemicals are required:

30 Kg	Manganous sulphate 4 H_2O	565
30 Kg	Sodium hydroxide pellets	110
10 Kg	Potassium iodide	275
500 g	Sodium azide	44
55 l	Sulphuric acid concentrated	112
5 Kg	Starch (soluble)	78
500 g	Salicylic acid	7
7 Boxes	CVS sodium thiosulphate 1 litre ampoules	100

3.2 COD

The method recommended is given on pp. 532-538 of 'Standard Methods for the Examination of Water and Wastewater', 16th Edition, 1985. This method produces only 10 per cent of the waste products containing mercury salts of alternative methods. The method requires the following items from Hach Chemical Co., USA:

1	Hach digestion block	550
20 Boxes	Hach digestion vials high range	500

In addition, the following chemicals are required:

500g	Ferrous ammonium sulphate	8
5 g	1:10 Phenanthroline hydrate	13
1 Kg	Ferrous sulphate 7 H_2O	7

3.3 Nitrate

The simplest semi-quantitative method for nitrate analysis is marketed by E. Merck and Co., W. Germany and requires:

Merck Nitrachec Meter + strips	400

3.4 Phosphate

The method recommended is given on pp. 437-452 of 'Standard Methods for the Examination of Water and Wastewater', 16th Edition, 1985, except a colour comparator is used in place of a spectrophotometer to determine the resultant colour. The following items are required:

1	Colour comparator, disc, cells and stand	126
500 g	Ammonium molybdate	34
25 g	Ammonium metavanadate	5
7.5 l	Hydrochloric acid concentrated	20
250 g	Potassium dihydrogen orthophosphate	5