J F JACKSON

sewerage, sewage treatment and refuse disposal for the city of sana'a

1. INTRODUCTION

The Yemen Arab Republic lays at the South West corner of the Arabian Peninsula, and comprises two well defined areas, namely the highlands in land, and the coastal strip along the Red Sea.

Sana'a, the capital city of the Yemen Arab Republic, is the administrative, political and judicial centre of the country. It is situated centrally on a mountain plain at an altitude of some 2 250 metres, with mountains on three sides rising well above this level.

The Old City, which lies to the East of the modern city centre, is most ancient and contains many buildings of historic and architectural importance, in particular the Great Mosque which is said to be one of the most ancient mosques in the Islamic World. The Old City is characterised by narrow streets, mostly unpaved, running between tall buildings, enclosed gardens and the local market places.

The city has expanded greatly over recent years and is still growing rapidly. It is predicted that due to the natural increase of population, and immigration from the rural areas, the annual rate of increase in the population will probably exceed 5% until the end of the century.

The rapid rate of expansion, which in the three years prior to 1976 incurred the building of nearly 3 000 dwellings, has overstretched existing sanitary facilities of the City and precipitated the need for modern sewerage and refuse collection services.

The paper now being presented is concerned with the study, and the development of the designs for Sewage Treatment and Refuse Disposal.

1.1 Consultants Terms of Reference

The appointment of Howard Humphreys & Sons, as Consultants to the National Water and Sewerage Authority for the Sana'a Sewerage Project, was made in

May 1976 following selection from proposals submitted in competition with other Consulting Engineers.

Funding for the study and design stage of the project was provided partly from a credit from the International Development Association.

The duties of the Consultant under the Terms of Reference of the Consultancy Agreement may be summarised:

Sewerage Project

The preparation of a Project Report incorporating the following main features:

(i) A review of the Sana'a Water Supply and Sewerage Master Plan which was drawn up by the Italian company Italconsult under the sponsorship of the World Health Organisation.

(ii) Projected water demands and determination of the expected per capita sewage flows, peak flows and pollution loads.

(iii) Definition of drainage areas, location of area pumping stations and the sewage treatment works.

(iv) Selection of sewage treatment method and disposal of the final effluent and sludge.

(v) Preparation of outline designs, and cost estimates.

(vi) Investigation of local storm water flooding, and proposals for remedial action.

(vii) Investigation of intermediate arrangements for the improvement of sanitary facilities in the areas of Sana'a not served by the initial stage of the sewerage project.

The preparation of detail designs and contract documents in accordance with the scope of works agreed by the Authority from the recommendations made in the Project Report.

Refuse Disposal Project

The preparation of a Project Report on the present and future requirements for refuse collection and disposal for the City of Sana'a, incorporating the following main items.

(i) Investigation of existing methods of collection and disposal.

(ii) Study of the quantity and composition of the refuse currently generated, and prediction of future quantity and composition.

(iii) Outline design and specifications with cost estimates of alternative methods of collection and disposal suitable for various stages of development of the City.

(iv) Recommendations for the implementation of an effective refuse collection and disposal system.

Howard Humphreys and Sons were not involved with the economic viability aspects of the project, as this work together with institutional and tariff studies, had already been carried out by other Consultants.

1.2 Organisation of the Project

Though Howard Humphreys and Sons had carried out many similar assignments in the Middle East, and elsewhere in the developing world, the Sana'a Sewerage Project with the Refuse Project were the first projects to be entrusted to the company in the Yemen Arab Republic. In accordance with the company's policy of maximum involvement and liaison with the client during the report and outline design stage of the project, a local establishment was set up in Sana'a to provide domestic and office accommodation for up to eight persons, and three vehicles were purchased to cover transportation requirements.

The study team resident in Sana'a for the six months duration of the study, consisted of the Deputy Project Manager of Principal Engineer status, with a Senior Engineer and two Assistant Project Engineers, all members of the Consultant's permanent staff. Three Yemeni Engineers on secondment from the staff of the National Water and Sewerage Authority completed the resident study team, which was backed-up by visits from the Consultant's Head Office of the Project Manager, and staff with specialist inputs.

The establishment set up in Sana'a by the Consultant for the purpose of the study has been retained to the present day to provide continuity of presence in liaising with the client, and to service other projects which have emerged subsequent to the appointment for the sewerage and refuse projects.

2. THE SEWAGE TREATMENT PROJECT

2.1 Existing Water Supply

The traditional source of water for the people of Sana'a is from hand dug wells situated locally within the curtilage of properties, and all inside the City limits. The wells are usually about 1.0 metre in diameter, masonry lined in the upper part and sometimes 40 metres or more in depth.

In more recent times, from about 1965 onwards, some wells were constructed using cable tool rigs to serve localised communities, and these go down to a depth of 150 metres.

The supply from the deep wells is distributed either by a limited pipework system, or by tankers.

Analysis of samples taken from various parts of the City indicated a high level of pollution, and there was also a serious problem of over abstraction due to increased domestic and irrigation demands which has caused a significant decline in the level of the water table. The average domestic consumption in 1976 was estimated at approximately 22 litres per head per day.

The inauguration of the first stage of the Sana'a Water Supply Project in October 1978 has done a great deal to improve the supply, particularly in the priority area of the Old City, but a large proportion of the population will remain dependant on local sources of supply for some time to come.

2.2 Existing Waste Disposal Facilities

At the present time, the City of Sana'a has no municipal or public sewerage system in the generally accepted meaning of the term. Within the confines of the Old City, where in the past water consumption per head of population has been relatively low, the multi-storey buildings which mostly prevail are served by rudimentary toilets consisting of a hole in the floor through which faecal matter is discharged, dropping through a shaft into a chamber within the confines of the building at street level. The contents of the chamber are removed periodically and transported to public bath houses where they are used as fuel for heating water. Alternatively the contents are used as fertilizer. Urine, and other liquid wastes, are separated from faecal matter and channelled to the outside walls of the building, where they are then discharged to the street.

In other areas of the City, particularly the modern properties served by tankers or local piped water supply, cesspits and septic tanks are in general use.

2.3 Health Conditions

In the absence of statistical documentation the only evaluation available is of a qualitative kind without numerical reference. Quoting from a report by Dr Lantini, who was a member of the Italian Medical Mission to Sana'a, the most commonly occurring diseases in Sana'a are:-

"1) Parasitic, including amoebic dysentery, ascariasis etc.

2) Dysentery, In all its forms and in all seasons is extremely frequent, and the consumption of antibiotics to combat it is enormous.

3) Viral Hepatitus. Seems most frequently to attack the expatriate community. Milder forms, which affect the local population, probably not brought to the attention of a doctor.

4) Trachoma. 60 - 70% of the school population in Sana'a suffer from this disease."

The report concluded that the high incidence of disease was attributable to the insanitary conditions prevailing.

2.4 Design Data

General

The purpose of the Project Report was to review and update the Master Plan and Preliminary Engineering Feasibility Studies for the Sewerage of Sana'a, under the sponsorship of the World Health Organisation, and to provide recommendations to form the basis of the final design.

Under the Consultancy Agreement, the area covered by the Project Report was contained within the boundary designated in the Master Plan as the city limits in the year 1985.

The implementation of the project was identified in two stages, according to priority of sanitary improvement and funding available. Stage 1 covers the older parts of the City, and the central area, where the density of population is highest and where sanitary conditions are generally least satisfactory. Stage 2 covers the balance of the area to the 1985 city limits, and generally represents an area of lower population density and more satisfactory sanitary arrangements.

The demarcation of the city limits in 1985, and the boundaries of Stages 1 and 2, are shown on Drawing No. 1.

Population

The task of predicting population growth in developing countries can be a notoriously difficult task.

In the case of the Sana'a Sewerage Project, population projections were made based upon data available from the first official census, made in January 1975, and the demographic studies carried out by Italconsult in the same year. Certain adjustments were made by Howard Humphreys and Sons because we found that certain areas formerly designated as green areas were being developed as residential areas. Our task was made easier by the fact that within the project area, most of the land was developed and hence the trends in land usage were quite clearly defined.

Project population estimates may be summarized:-

Stage 1 Construction Area population in 1985	108 217
Stage 2 Construction Area population in 1985	83 680
TOTAL	191 897

Sewage Flows

From the preliminary investigations carried out by Italconsult in 1972, it was estimated that the average water supply consumption for domestic purposes was 22.3 litres per capita per day. In formulating our designs, we have predicted that with the inauguration of the first stage of the Water Supply Project the per capita consumption would increase to 50 litres per day, and then continue to increase progressively to 200 litres per day until the year 2000.

Our estimated sewage flow per capita daily has been taken as 80% of the water consumption. These per capita projections are shown in Figure No. 1.

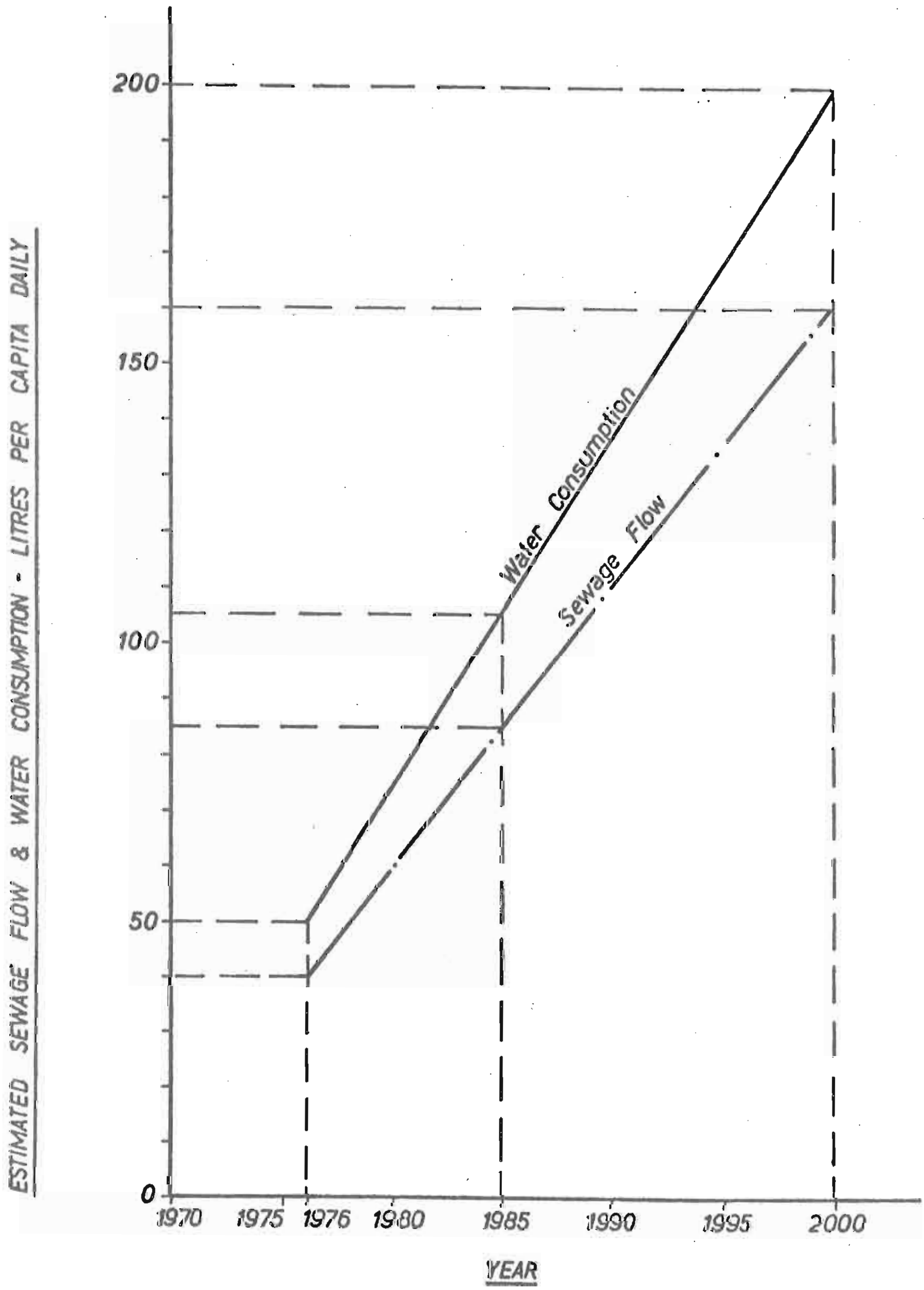
The daily sewage flows are expected to be 85 litres per person by 1985, and are deemed to include for commercial, institutional and industrial flows.

With the exception of the discharge from a textile factory, dealt with as a separate entity since it has its own water supply, the industrial flows are minor.

The design flows at the sewage treatment works may be shown as follows:-

Expected Dry Weather Flow in 1985

	Domestic, Commercial, Institutional, & Industrial Flows m^3/day	Discharge from Textile Factory m^3/day	Total Dry Weather Flow in 1985 m^3/day
Stage 1	9 198	1 860	11 058
Stage 2	16 310	1 860	18 170



PROJECTED PER CAPITA WATER CONSUMPTION & SEWAGE FLOW

FIGURE 1

Sewage Strengths

In the absence of a sewerage system in Sana'a, or indeed elsewhere in the Yemen Arab Republic, it was not possible to use the analysis of existing flows as a basis for estimating active design loads, and this work has been done by using data available from comparable projects elsewhere in the developing countries.

The figures adopted for the two basic parameters of Biochemical Oxygen Demand, and Suspended Solids were:-

Biochemical Oxygen Demand	54 gm/person/day
Suspended Solids	60 gm/person/day

With population equivalent allownaces for industrial, commercial and institutional contribution, the biological load used in the design of the treatment works are tabulated as follows:-

Estimated BOD Load

Stage 1

Industry etc.	1985 Population Served	1985 Equivalent Population	1985 BOD Load at 85 grm per head per day (KG)
	108 217		5 843
Textile Factory		8 600	464
Tanneries		300	16
Miscellaneous		750	41
Total Stage 1 BOD			6 364

Stage 2

	83 680		4 519
Slaughterhouse		9 000	486
Industrial Estate		1 200	65
Total Stage 2 BOD			5 070
Total 1985 BOD Load			11 434

2.5 Effluent Quality and Disposal

General

The method of final disposal of the treated effluent was considered to be an integral part of the Sewerage Project. In a region such as North Yemen, effluent was regarded as a resource which could be used to improve the environment and to benefit the community.

Effluent Re-Use and Disposal Methods

A number of disposal methods were considered:-

i) Disposal to the Wadi.

ii) Recharge of underground aquifer.

iii) Industrial use.

iv) Potable water

v) Irrigation

i) Disposal to the Wadi

Disposal to the Wadi was regarded as a method which achieved little benefit from the valuable water resource. It was recognised as being available in the immediate term, and as a means of disposing of the effluent in emergency circumstances.

ii) Recharge of Underground Aquifer

Recharging of the aquifer either by surface ponding or by deep well injection was not considered desirable or necessary at the present time because the underground resources, remote from Sana'a which are now being developed, appear to be sufficient to ensure supplies for the immediate and medium term requirements.

iii) Industrial use

Sana'a is not an industrial centre and due to its remoteness from the coast, it was considered unlikely of ever becoming a major manufacturing city.

The most important existing factory, the textile factory, has its own water supply and was not interested in utilizing treated effluent.

iv) Potable Water

Our report gave consideration to the possibilities of reclaiming potable water from sewage effluent and concluded that due to the high cost and level of technology involved, the process could not be justified at this time or in the foreseeable future.

v) Irrigation

The method of disposal considered most suited to local requirements was the re-use for irrigation of certain crops of areas of forestry.

It was proposed that treatment works effluent would be passed initially to an area on the site of the treatment works reserved for future extensions. The area would be planted with trees and grass requiring little maintenance, and securely fenced off to ensure that no unofficial and uncontrolled use is made of the area or of the effluent. Treated effluent not required for irrigation would be disposed of into the nearby Wadi.

The development of the irrigation potential is subject to further study as the works are completed.

Effluent Quality

The quality of effluent recommended in conjunction with disposal on to an area planted with trees and grass was 75 mg/l BOD and 75 mg/l SS.

2.6 Sewage Treatment Methods

General

In the selection of the sewage treatment process for Sana'a, consideration was given to the following factors.

a) The climatic conditions.

b) The volume of waste water to be treated.

c) The degree of operational and maintenance skills required.

d) The availability, cost and location of land.

e) The availability and nature of operatives.

f) The relative off-shore and on-shore costs.

g) The effluent disposal method.

From an assessment of the local conditions we concluded that three methods warranted detailed investigation:

i) Stabilisation ponds

ii) Biological filtration

iii) Oxidation ditches

In the absence of any definite data on the strength of sewage to be treated the various treatment methods were designed using conservative parameters to ensure that the effluent quality would comply with the disposal requirements.

The elements in common to the three treatment processes considered were:

Peak flow to treatment	3 x Dry Weather Flow
Effluent standard	75mg/l BOD 75mg/l SS
Inlet Works	
Emergency Stormwater Overflow	3 x DWF
Coarse Screens (Before Screw Pumps)	Bar Spacing 75mm
Mechanically raked fine screens and disintegrator (After Pumps)	Bar Spacing 15mm
Constant Velocity grit channels	Velocity 0.3m/sec.
Standing wave flumes for flow measurement	
Dual Screw Pumps	

Waste Stabilisation Ponds

Waste stabilisation ponds were selected as a possible method of treatment because they are relatively simple and very effective particularly in climatic regions similar to Sana'a which has a high incidence of sunshine. Though the land available for the treatment works was not expensive, most of it was already owned by the Government of the Yemen Arab Republic, our preliminary calcuations showed that the area required for treatment could be reduced by about 20% if mechanical aerators were introduced into the first stage of treatment. Another reason for the introduction of mechanical aeration was to obviate the potential problem from smell nuisance.

By comparison of the other treatment processes, the advantages of waste stabilisation ponds were seen to be:

a) Relatively low power consumption by the aerators.

b) No complex machinery.

c) Desludging required only at 5 to 10 year intervals, and the sludge fully stabilised.

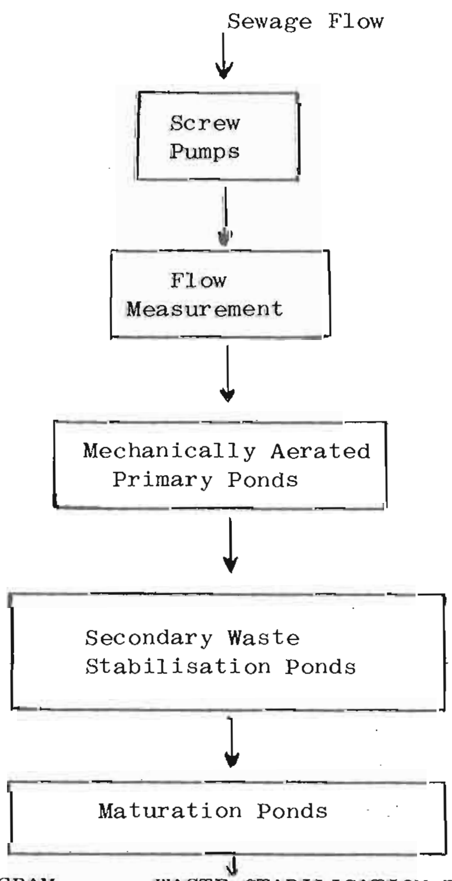
d) The maturation ponds would ensure a high bacterial die-off and would be available for fish culture at a later date.

e) The ability to absorb shock loadings.

f) The favourable ratio of on-shore to off-shore construction costs.

The flow diagram for the waste stabilisation pond method considered is shown in Figure No. 2, and the parameters for the designs, which followed the Thirumurthi method, are reproduced below:-

FIGURE 3



FLOW DIAGRAM - WASTE STABILISATION PONDS

Local Controlling Termperature	$11^{o}C$
Dispersion Factors	
a) Mechanical aeration	2.5
b) Facultative Stage	1.0
Pond Depths	
a) Mechanical aeration stage	3.5m
b) Facultative stage	1.75m
c) Maturation stage	1.0m
BOD Reduction	
a) Mechanical aeration stage	60%
b) Facultative stage	75%
BOD entering maturation pond	60 mg/l
Maturation pond detention period	9 days

The general arrangement of the waste stabilisation ponds is shown on Drawing No.3.

Biological Filtration

The biological filtration process was considered because it is a well proven sewage treatment method which has been used successfully in many parts of the world.

The merits of the process were seen to be:-

a) Reliable and well proven form of treatment.

b) Relatively simple to operate, and with low maintenance requirement.

c) Low running costs.

d) The ability to absorb shock loadings.

The disadvantages of the process were seen as:-

a) High hydraulic head loss.

b) Potential fly and odour nuisance.

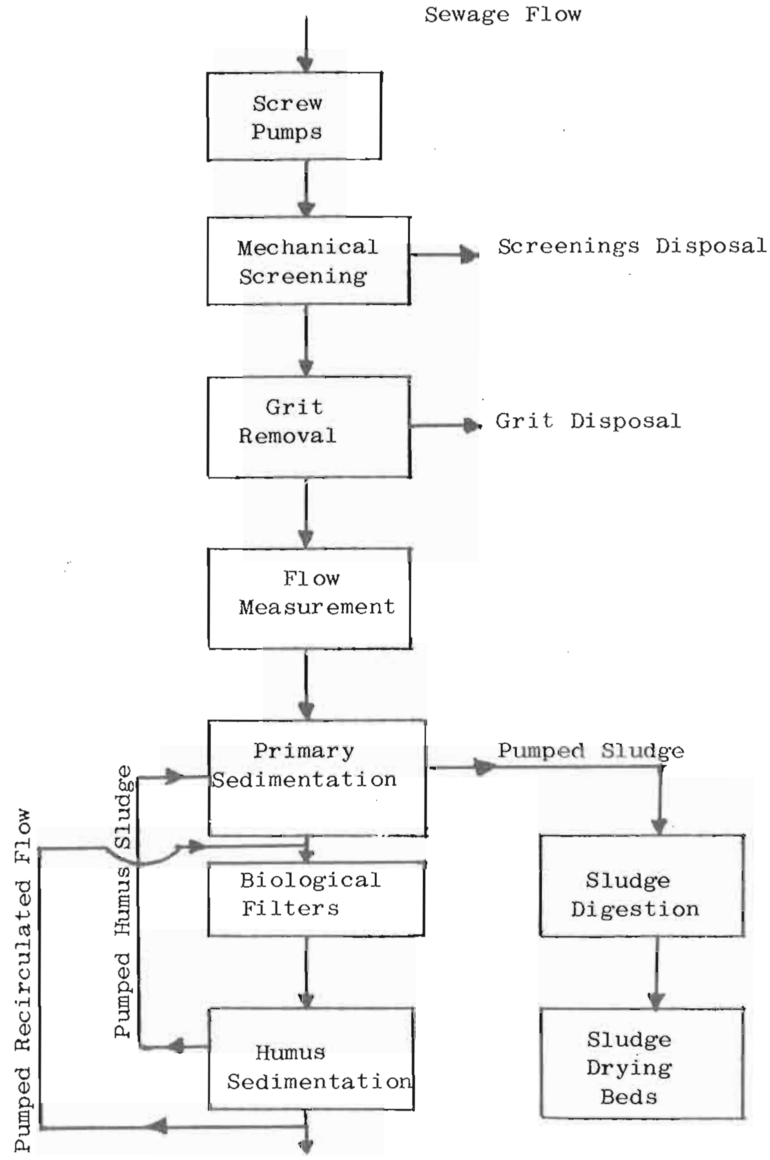
c) Relatively high construction costs with an undesirable element of off-shore cost incurred by the associated machinery.

The essential stages of the biological treatment process are shown diagrammatically in Figure No. 3, and the parameters adopted for the designs are shown below:

Primary Sedimentation Tanks

Radial flow type, 10^{o} floor slope	
Max. Surface Loading at peak flow	= $33m^3/m^2/d$
Retention Period at dry weather flow	= 6h
Minimum Weir Overflow Rate	= $100m^3/m/d$
Maximum Weir Overflow Rate	= $250m^3/m/d$
Estimated BOD removal	= 35%
Estimated SS removal	= 60%

FIGURE 4



FLOW DIAGRAM - BIOLOGICAL FILTRATION & RECIRCULATION

Biological Filters (rectangular) with recirculation of humus tank effluent

Single filtration, settled sewage	=	o.2 kg BOD/m^3/d
Average depth of media	=	2.00m
Estimated reduction in BOD	=	90%
Rate of Recirculation	=	1 - 2 times d.w.f

Humus Tanks

Radial flow type, 15^o floor slope

Max. Surface Loading at peak flow	=	60 $m^3/m^2/d$
Retention Time at dry weather flow	=	6h
Minimum Weir Overflow Rate	=	100 m^3/m/d
Maximum Weir Overflow Rate	=	250 m^3/m/d

Sludge Drying Beds

Undigested sludge	=	8 persons/m^2

The general arrangement of the biological filtration plant is shown on Drawing No. 4.

Oxidation Ditch

The oxidation ditch was considered as a possible method of treatment because:

a) The machinery is not complex, and the operation and maintenance of the works would be within the scope of the skills available.

b) The relatively small sludge produced is stabilised and would require no further treatment except air drying.

c) The process has the ability to absorb shock loadings.

d) The land requirement is minimal.

e) Construction costs are low.

The stages in the oxidation ditch process indicated diagrammatically in Figure No. 4, and the parameters adopted in the designs are shown below:-

Oxidation Ditch

Capacity	=	210mg BOD/l of ditch
Oxygen Supplied/BOD removed ratio	=	2 to 1

Final Settlement Tanks

Radial Flow type 15° floor slope

Max. Surface Loading at peak flow	=	22 $m^3/m^2/d$
Minimum Retention Period at dry weather flow	=	4.5h
Minimum Weir Overflow Rate	=	$100m^3/m/d$
Maximum Weir Overflow Rate	=	$250m^3/m/d$

Return Sludge Pumps

Capacity equal to the dry weather flow

Sludge Drying Beds

Undigested sludge	=	10 persons/m^2

The general arrangement of the oxidation ditch plant is shown on Drawing No. 5.

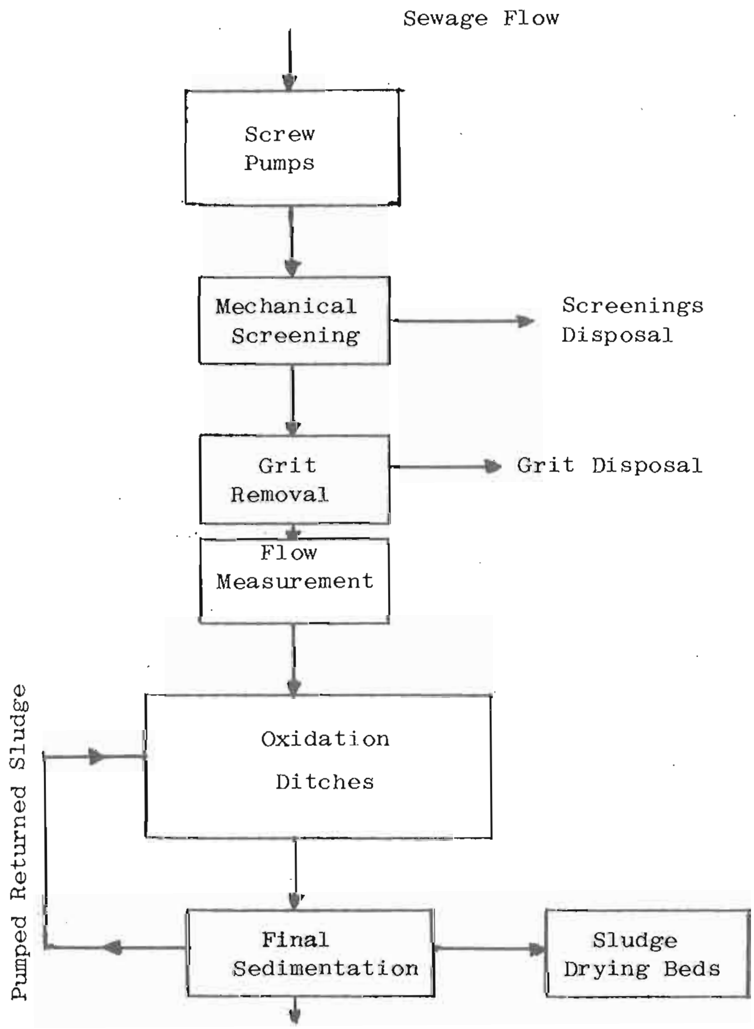
2.7 Cost Estimates for Sewage Treatment Works

General

The cost estimates were prepared using data obtained from Contractors working locally, from the Ministry of Public Works, and from the National Water and Sewerage Authority. The estimates for machinery were prepared from manufacturers' budget quotations.

The estimates are given in the local currency, Yemen Rials, which are converted to sterling at the rate of YR 8.5 = £(sterling) 1.0.

Capital costs for the three methods of treatment considered, together with running costs are given in the accompanying tables.



FLOW DIAGRAM - OXIDATION DITCHES

FIGURE 5

Capital Costs: Waste Stabilisation Ponds

Item	Unit	Rate (Y.R.)	STAGE 1 Quantity	STAGE 1 Cost (Y.R.)	STAGE 2 Quantity	STAGE 2 Cost (Y.R.)
Civil Costs						
Bulk excavation	m^3	20	210,000	4,200,000	147,000	2,940,000
Bulk fill in embankments	m^3	10	240,000	2,400,000	168,000	1,680,000
Pumping station and inlet works		lump sum		300,000		300,000
Administration building and watchman's house		lump sum		360,000		
Connections of ponds and site pipelines	m	785	6,000	4,710,000	3,800	2,983,000
Valves and penstocks		lump sum		450,000		250,000
Garage and workshop		lump sum		480,000		
Waterline protection to ponds (Rip-rap)	m^2	50	36,000	1,800,000	25,200	1,260,000
Fencing		lump sum		100,000		50,000
Land acquisition	ha	22,750	40	910,000		
Civil construction Costs				15,710,000		9,463,000
Electrical and Mechanical Plant Costs						
Sewage pumps		lump sum		280,000		280,000
Bar screen		lump sum		100,000		100,000
Flumes and flow recording		lump sum		80,000		80,000
Surface aerator		lump sum		1,600,000		1,080,000
Generator and transformers		lump sum		560,000		
Cabling and distribution board		lump sum		500,000		350,000
External electric supply		lump sum		70,000		
Laboratory equipment		lump sum		200,000		
Recirculation effluent pumps		lump sum		80,000		
Spares		lump sum		200,000		100,000
Electrical and Mechanical Plant Costs				3,670,000		1,990,000
Total Cost				19,380,000		11,453,000

Capital Costs: Biological Filters

Item	Unit	Rate (Y.R.)	STAGE 1 Quantity	STAGE 1 Cost (Y.R.)	STAGE 2 Quantity	STAGE 2 Cost (Y.R.)
Civil Costs						
Bulk excavation	m^3	30	31,400	942,000	23,500	705,000
Reinforced concrete	m^3	1,350	10,720	14,472,000	8,030	10,840,500
Pumping station and inlet works		lump sum		400,000		
Administration building and watchman's house		lump sum		360,000		
Site pipelines		lump sum		4,000,000		1,770,000
Valves and penstocks		lump sum		450,000		200,000
Garage and workshops		lump sum		480,000		
Site roads	m^2	220	13,100	2,882,000		
Sludge storage compound		lump sum		360,000		
Filter media	m^3	110	13,300	1,463,000	10,000	1,100,000
Fencing		lump sum		100,000		
Land acquisition	ha	22,750	25	568,750		
Civil construction Costs				26,477,750		14,615,500
Electrical and Mechanical Plant Costs						
Sewage pumps		lump sum		280,000		160,000
Bar screen		lump sum		100,000		80,000
Flumes and flow recording		lump sum		80,000		80,000
Settling tanks (primary)		lump sum		320,000		240,000
Filter beds		lump sum		2,400,000		2,400,000
Humus tanks		lump sum		256,000		192,000
Generator and transformers		lump sum		640,000		
Cabling and distribution board		lump sum		500,000		240,000
External electric supply		lump sum		70,000		
Laboratory equipment		lump sum		200,000		
Recirculation effluent pumps		lump sum		200,000		
Spares		lump		500,000		300,000
Electrical and Mechanical Plant Costs				5,546,000		3,692,000
Total Cost				32,023,750		18,307,500

Capital Costs: Oxidation Ditches

Item	Unit	Rate (Y.R.)	STAGE 1 Quantity	STAGE 1 Cost (Y.R.)	STAGE 2 Quantity	STAGE 2 Cost (Y.R.)
Civil Costs						
Bulk excavation	m^3	30	36,000	1,080,000	27,000	810,000
Reinforced concrete in:— ditches, settling tanks and drying beds	m^3	1,350	4,630	6,250,500	3,470	4,684,500
Lining of ditches	m^2	70	11,500	805,000	8,500	595,000
Pumping station and inlet works		lump sum		300,000		
Administration building and watchman's house		lump sum		360,000		
Site pipelines		lump sum		2,000,000		1,000,000
Valves and penstocks		lump sum		450,000		150,000
Garage and workshops		lump sum		480,000		
Site roads	m^2	220	11,700	2,574,000		
Sludge storage compound		lump sum		360,000		
Fencing		lump sum		100,000		
Land acquisition	ha	22,750	20	455,000		
Civil construction Costs				15,214,500		7,239,500
Electrical and Mechanical Plant Costs						
Sewage pumps		lump sum		280,000		96,000
Bar screen		lump sum		100,000		80,000
Flumes and flow recording		lump sum		80,000		80,000
Rotors and weirs		lump sum		1,440,000		1,080,000
Final settling tanks		lump sum		560,000		406,000
Generator and transformers		lump sum		480,000		
Cabling and distribution board		lump sum		400,000		150,000
External electric supply		lump sum		70,000		
Laboratory equipment		lump sum		200,000		
Recirculation sludge pumps		lump sum		80,000		40,000
Spares		lump		350,000		200,000
Electrical and Mechanical Plant Costs				4,040,000		2,132,000
Total Cost				19,254,500		9,371,500

Estimated Power Consumption and Costs

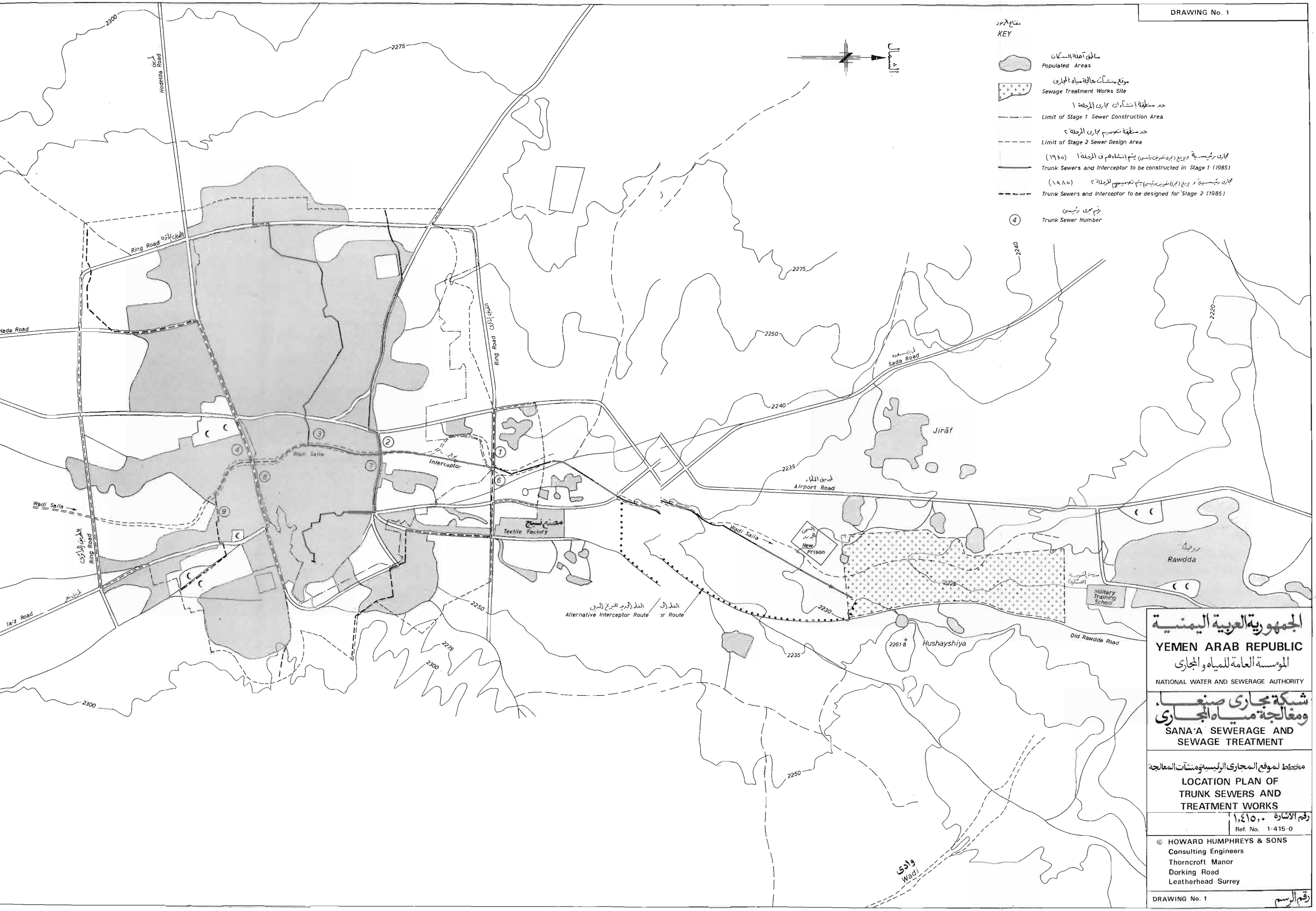
Biological Filtration Plant	Power Consumption (kWh/day) Stage 1	Stage 2
Inlet works: Screw pumps	272	444
Bar screen	8	16
Grit remover	–	80
Primary Tank sludge scrapers	80	140
Filter bed machinery	960	1,680
Humus tank sludge scrapers	96	168
Recirculation pumps	444	444
Sludge pumps	12	18
Washout pumps	8	12
Total	1,880	3,002
Power consumption cost per day at 0.6 Y.R./kWh	1,128 Y.R.	1,801 Y.R.
Oxidation Ditches		
Inlet works: Screw pumps	92	149
Aeration rotors	3,360	5,880
Final tank sludge scrapers	192	336
Recirculation sludge pumps	130	212
Total	3,774	6,577
Power consumption cost per day at 0.6 Y.R./kWh	2,264 Y.R.	3,946 Y.R.
Waste Stabilization Ponds		
Inlet works: Screw pumps	182	296
Pond aerators	3,226	5,376
Recirculation effluent pumps	256	256
Total	3,664	5,928
Power consumption cost per day at 0.6 Y.R./kWh	2,198 Y.R.	3,557 Y.R.

Summary of Estimated Capital Costs for Sewage Treatment Works

Biological Filter Plant	Cost – Yemeni Rials Stage 1	Stage 2
Civil	26,477,750	14,615,500
Electrical and Mechanical	5,546,000	3,692,000
Total	32,023,750	18,307,500
Oxidation Ditches		
Civil	15,214,500	7,239,500
Electrical and Mechanical	4,040,000	2,132,000
Total	19,254,500	9,371,500
Waste Stabilization Ponds		
Civil	15,710,000	9,463,000
Electrical and Mechanical	3,670,000	1,990,000
Total	19,380,000	11,453,000

Summary of Estimated Annual Operating Costs for Sewage Treatment Works

Biological Filtration Plant	Cost – Yemeni Rials Stage 1	Stage 2
Staff	228,000	250,000
Electrical Power	411,720	657,365
Consumables	60,000	80,000
Total	700,520	987,365
Oxidation Ditches		
Staff	211,600	230,000
Electrical Power	826,360	1,440,290
Consumables	40,000	50,000
Total	1,077,960	1,720,290
Waste Stabilization Ponds		
Staff	197,200	210,000
Electrical Power	802,270	1,298,305
Consumables	30,000	40,000
Total	1,029,470	1,548,305


DRAWING No. 1
مفتاح الرموز
KEY
مناطق آهلة بالسكان
Populated Areas
موقع منشآت معالجة مياه المجارى
Sewage Treatment Works Site
Limit of Stage 1 Sewer Construction Area
Limit of Stage 2 Sewer Design Area
Trunk Sewers and Interceptor to be constructed in Stage 1 (1985)
Trunk Sewers and Interceptor to be designed for Stage 2 (1985)
Trunk Sewer Number
الشمال
Hodeida Road
Ring Road
Hada Road
Taiz Road
Sada Road
Airport Road
Old Rawdda Road
Wadi Saila
Interceptor
Textile Factory
New Prison
Military Training School
Alternative Interceptor Route
Jirāf
Rawdda
Hushayshiya
Wadi
وادى
2300
2275
2250
2240
2235
2230
2225
2220
2261·8
الجمهورية العربية اليمنية
YEMEN ARAB REPUBLIC
المؤسسة العامة للمياه والمجارى
NATIONAL WATER AND SEWERAGE AUTHORITY
شبكة مجارى صنعاء ومعالجة مياه المجارى
SANA'A SEWERAGE AND SEWAGE TREATMENT
مخطط لموقع المجارى الرئيسية ومنشآت المعالجة
LOCATION PLAN OF TRUNK SEWERS AND TREATMENT WORKS
رقم الاشارة ١،٤١٥،٠
Ref. No. 1·415·0
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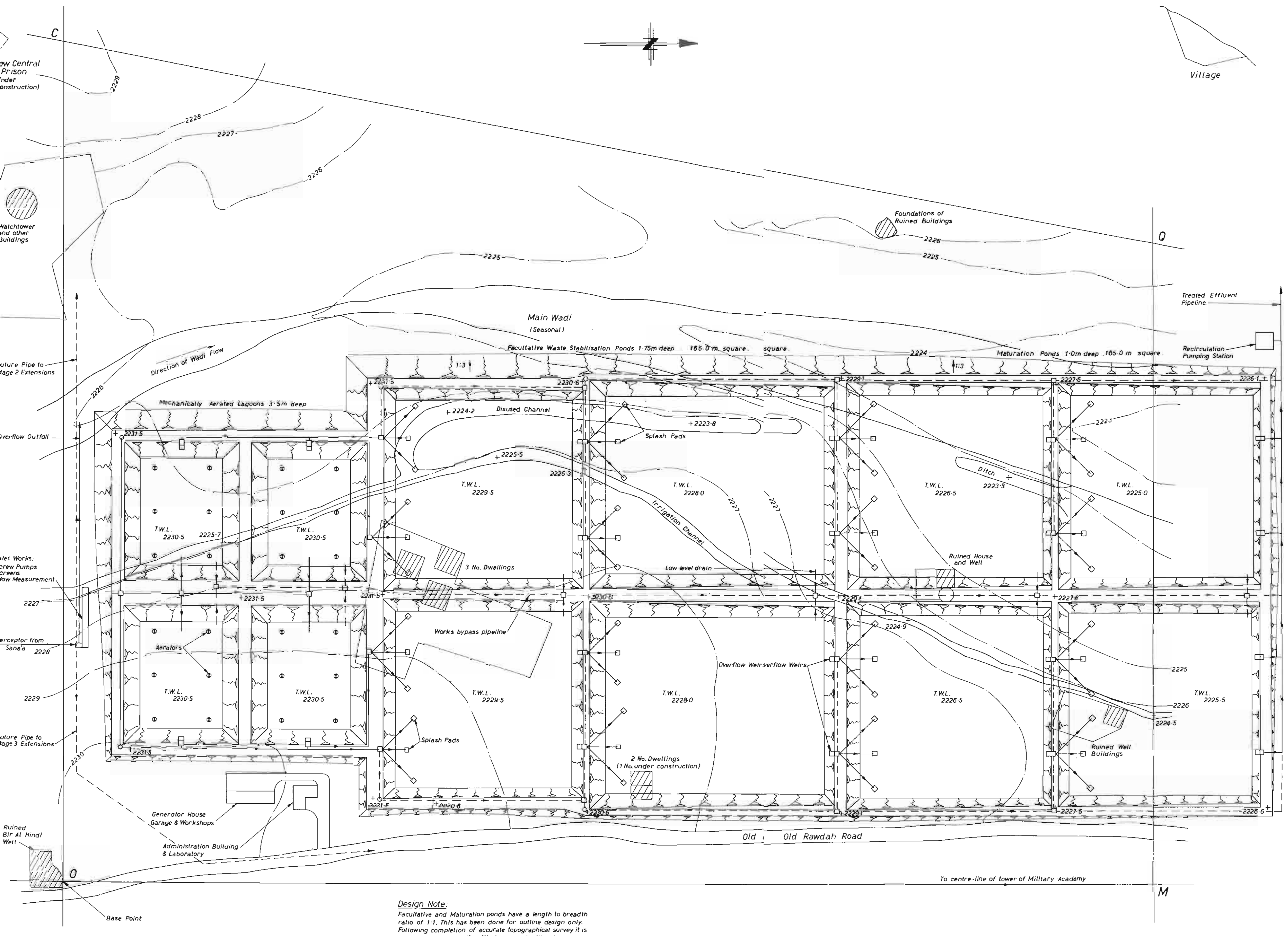
Consulting Engineers
Thorncroft Manor
Dorking Road
Leatherhead Surrey
DRAWING No. 1
رقم الرسم



NOTES

1. This drawing is based on a preliminary survey only. It should not therefore be used for purposes other than outline design.
2. The positions and dimensions of buildings and enclosed areas have been surveyed approximately only.
3. Roads and tracks, other than the old Rawdah road to the East of the site, have been omitted for clarity.
4. All levels are based on the Czech Bench Mark at Rawdah Military Academy, level 2223·700
5. Contours crossing man-made channels and ditches indicate the approximate original ground levels, the inverts of the channels being shown by spot-heights at intervals.

Key to Topographical Features

2226 — Contours at 1-metre intervals
+ 2225·7 — Spot height in metres
Building and compound
Physical feature (road, wadi etc.)
Direction of seasonal flow
O — Survey control point and control lines

Design Note:
Facultative and Maturation ponds have a length to breadth ratio of 1:1. This has been done for outline design only. Following completion of accurate topographical survey it is expected that this ratio will change, but will not exceed 2:1, in order that the available site will better accommodate the stage 2 works units.

Stage 1 units only shown.

Note:- All embankments to be at 1:3

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شبكة مجاري صنعاء ومعالجة مياه المجاري
SANA'A SEWERAGE AND SEWAGE TREATMENT

GENERAL ARRANGEMENT
WASTE STABILISATION PONDS

رقم الأشارة ١،٤١٥،٠ مقياس
Ref. No. 1·415·0

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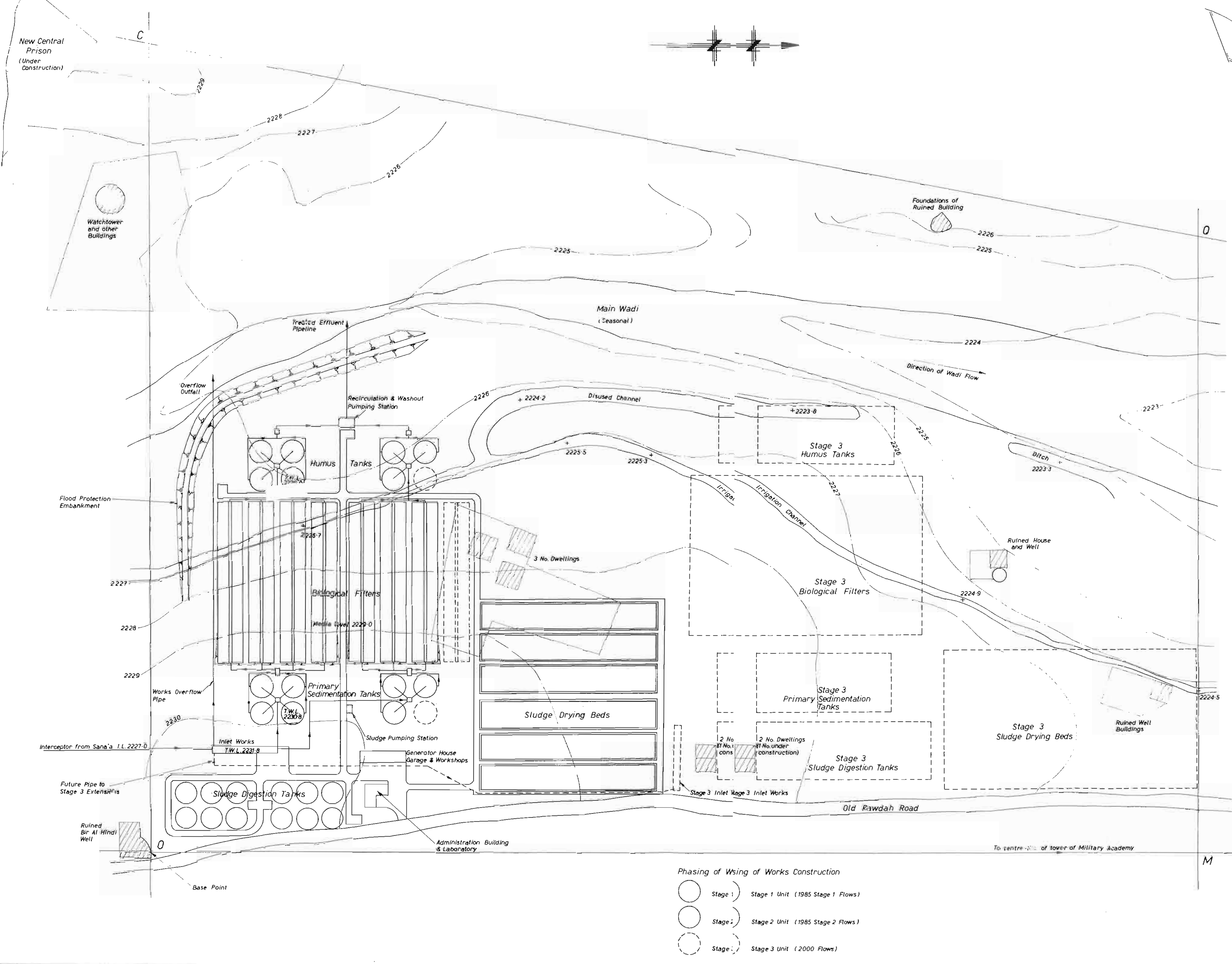
DRAWING No. 3 رقم الرسم

DRAWING No 4



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Key to Topographical Features

- 2226 — Contours at 1-metre intervals
- + 2225·7 — Spot height in metres
- Building and compound
- Physical feature (road, wadi etc.)
- Direction of seasonal flow
- O — Survey control point and control lines

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SANA'A SEWERAGE AND SEWAGE TREATMENT

GENERAL ARRANGEMENT

BIOLOGICAL FILTRATION PLANT

رقم الاشارة ١،٤١٥،٠ مقياس

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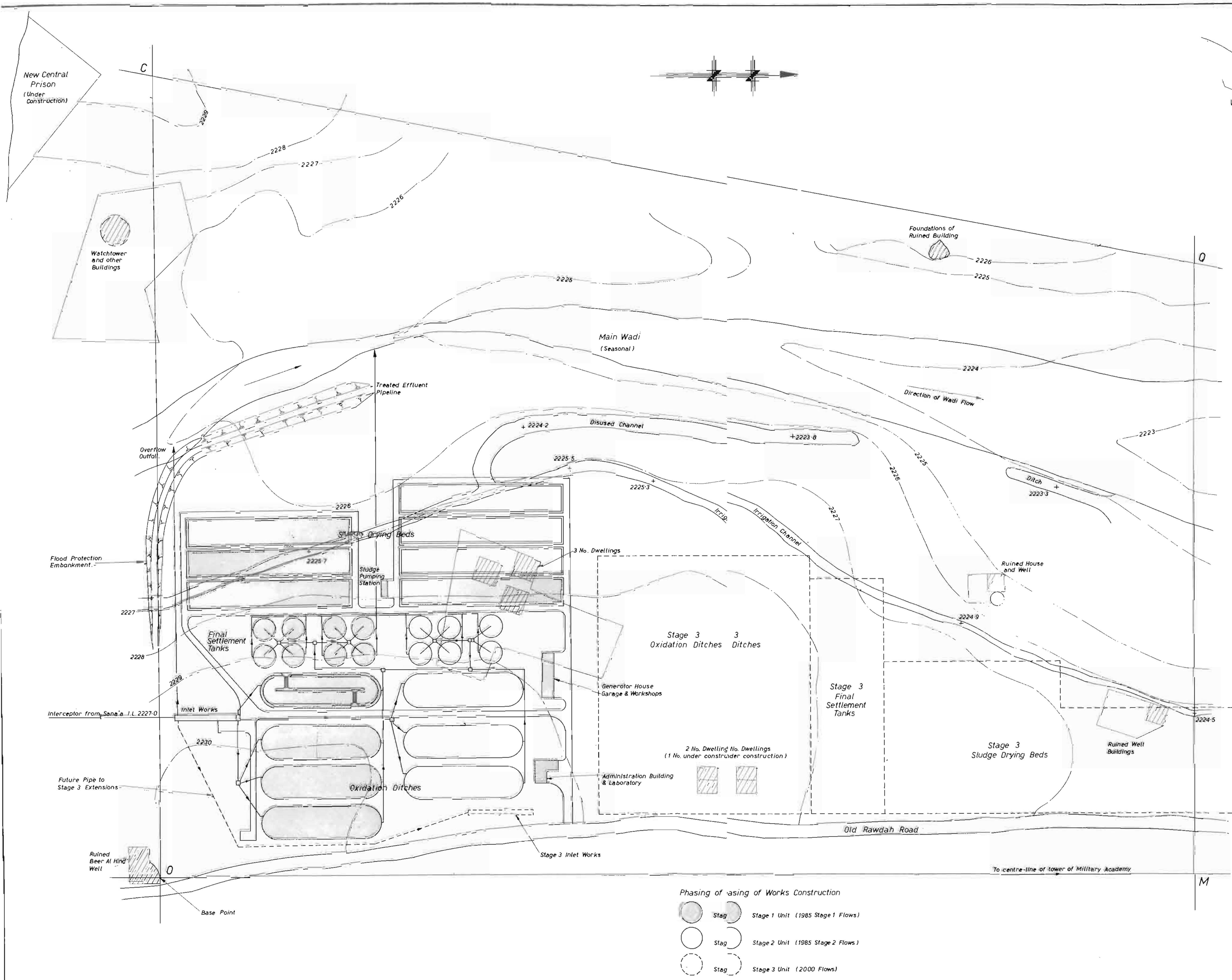
DRAWING No. 4 رقم الرسم



NOTES

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Key to Topographical Features

2226	Contours at 1-metre intervals
+ 2225·7	Spot height in metres
	Building and compound
	Physical feature (road, wadi etc.)
	Direction of seasonal flow
O	Survey control point and control lines

Phasing of asing of Works Construction

Stag	Stage 1 Unit (1985 Stage 1 Flows)
Stag	Stage 2 Unit (1985 Stage 2 Flows)
Stag	Stage 3 Unit (2000 Flows)

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SANA'A SEWERAGE AND SEWAGE TREATMENT

GENERAL ARRANGEMENT
OXIDATION DITCH PLANT

مقياس ١:٤١٥٠٠ رقم الاشارة
Ref. No. 1·415·0

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DRAWING No. 5 رقم الرسم

2.8 Recommended Treatment Process

Following the comparison of construction, operational and maintenance costs for the three methods of treatment considered, it was concluded that the waste stabilisation process was the most suitable method of treatment under the prevailing circumstances at Sana'a.

Referring to the outline design of works shown in Drawing No. 3 the design features of the works are now described further.

Sewage flow reaches the works through a single 1,400mm diameter sewer. At the inlet works, the sewage is raised through a height of 5 metres by two screw pumps, working on duty and standby basis, to allow gravity flow through the treatment process. The flow is measured using critical velocity flumes. Coarse screening is provided before the pumps, and this is followed by mechanically raked fine screens. Screenings will be disposed of by burial or by incineration.

The layout of the primary and secondary facultative ponds, and the maturation ponds together with the associated pipework, has been arranged in two parallel streams to give flexibility in operation, and individual ponds can be by-passed as required for maintenance purposes.

The primary facultative ponds have been designed with mechanical aeration to assist with the transfer of oxygen into the sewage. It is not intended that complete mixing of the pond contents will take place, and the ponds will therefore remain facultative. The use of aerators in the primary ponds reduces the area that would otherwise be required, by about 60%

The aeration plant will take the form of vertical spindle floating aerators either secured to the banks of the ponds by cables, or fixed to towers standing on the bed of the pond. The depth of the primary ponds is 3.5 metres.

A pond depth of 1.75 metres has been adopted for the secondary ponds with a length to breadth ratio of 1 : 1. The length to breadth ratio is subject to modification at the final design stage when more detailed ground level information will be available. The pond depth of 1.75 metres was adopted to ensure adequate sludge storage, to balance temperature variations, and to inhibit weed growth on the bottom of the ponds.

The maturation ponds, with a depth of 1.0 metres, have been provided to ensure a high bacterial die-away, and to produce further reductions in BOD.

The ponds will be constructed by using excavated material to raise the surrounding embankments which will be lined with rip-rap to give protection from wave action, and to discourage the growth of vegatation which could provide a breeding ground for mosquitoes. The site conditions are such that it will be necessary to seal the bottom of the ponds to make them watertight.

A pumping installation has been provided adjacent to the maturation ponds to enable treated effluent to be recirculated to the head of the works to give dilution, and to maintain the water levels, particularly during commissioning and the flow build-up stage. The pumping station also serves to dispose of treated effluent to the irrigation area. Final effluent from the pumping station is used for general washing down purposes, with a high pressure facility to break up floating mats of algae should they occur.

The following tables give the predicted BOD reductions between the various stages in the treatment process, together with pond data.

B.O.D. Reduction by Pond Stages

B.O.D. reduction	1985	
	Stage 1	Stage 2
Total flow (D.W.F.) m^3/day	6364	11434
Total B.O.D. load kg/day	11058	18170
B.O.D. load on Works mg/l	575	629
B.O.D. reduction in primary ponds (mechanically aerated)	60%	60%
Effluent B.O.D. from primary ponds mg/l	230	252
B.O.D. reduction in secondary ponds	75%	75%
Effluent B.O.D. from secondary ponds mg/l	58	63
B.O.D. reduction in maturation ponds	65%	65%
Final effluent B.O.D. mg/l	20	22

Pond Data	1985	
	Stage 1	Stage 2
Primary Ponds (mechanically aerated)		
Depth m	3.5	3.5
Surface area ha	4.0	6.5
Detention days	10.0	10.0
B.O.D. reduction	60%	60%
Number of aerators	24	48
Power required kW	130	235
Secondary Ponds		
Depth m	1.75	1.75
Surface area ha	10.0	17.0
Detention days	15.0	16.0
B.O.D. reduction	75%	75%
Maturation Ponds		
Depth m	1.0	1.0
Surface area ha	10.0	17.0
Detention days	9	9
B.O.D. reduction	65%	65%
Total pond surface area ha	24	40.5

2.9 Sewerage System

General

The area around Sana'a forms one of the many plains that exist at altitudes in the mountains. The Sana'a plain is generally flat and oriented in a north-south direction. Ground slopes are very gradual and, in the area around Sana'a, the slopes fall towards the Wadi Saila which forms the natural water course for surface water run-off from the area.

The Old City of Sana'a was built on the east bank of the Wadi, on the lower slopes of the Jebel Nuqum. The development and expansion of the City in recent times has resulted in the city expanding westwards so that the City now straddles the Wadi.

The plain of Sana'a has a downward slope towards the North, and with the availability of land in this direction, it followed that the sewage treatment works would be located to the North of the City. It is a feature of the sewerage system that, with the exception of the screw pumps at the inlet works, all the flows are by gravity.

Drawing No. 1 shows the location of the treatment works site, and the routes of the trunk sewers and interceptor.

Design of Sewers

The design of the sewerage system was carried out according to the following parameters:

i) To allow for illicit rain water connections, and to accommodate variations in the population density above those predicted, we recommended that sewers up to and including 500 mm diameter should be designed on a peak flow factor of 6, and sewers in excess of 500 mm diameter should be designed with a peak factor of 3.

ii) To minimise the possibility of blockages, and to facilitate maintenance, it was recommended that the minimum diameter of sewer should be 200 mm.

iii) The sewers were designed on the Colebrook-White formula, with the roughness factor (K) taken as 0.6mm.

iv) A velocity of 1.0 m/sec. at peak flow was adopted as the minimum desirable.

Sewer Construction

The strength requirements of the sewers were designed generally in accordance with the recommendations of National Building Studies, Special Report No. 37.

The strength of the pipes was selected such that the sewers would be constructed on granular bedding, with concrete bedding in more extreme loading conditions. A high proportion of the smaller diameter sewers will be laid within the confines of the narrow streets in the Old City where it will be necessary to use concrete in backfill to the trenches of the sewers to safeguard the foundations of the existing buildings.

Pipe Materials

With the exception of a factory in Taiz manufacutring unplasticised poly vinyl chloride pipes up to 250mm diameter there is no pipe manufacturing industry in the Yemen Arab Republic. To obviate shipping delays at the Red Sea port of Hodeida, and to take advantage of the credit available, it was decided that the basic construction materials, including the pipes, would be procured under a separate supply contract to be implemented in advance of letting the main construction contracts.

The pipes to be supplied under the supply contract, which do not include materials for the house connections, range in size from 200mm to 1400mm in diameter. The pipe materials specified are unplasticised polyvinyl chloride, asbestos cement with sulphate resisting cement, vitrified clay and glass fibre reinforced plastic.

The award of the materials supply contract will be made on the basis of delivery times and the cost of the materials delivered to the stockyards of the National Water and Sewerage Authority in Sana'a.

Cost Estimates for the Sewerage System

The summary of estimated capital costs for the sewerage system is given as follows:-

	Cost in Yemen Rials	
	Stage 1	Stage 2
Sewer Network	68 501 000	77 614 200
Interceptor	17 670 000	2 460 000
Local Flood Relief	320 000	-
Public Conveniences	1 258 300	-
	87 749 300	80 074 200

Yemen Rials are converted to sterling at the rate of YR 8.5 = £(Sterling) 1.0

3. THE REFUSE DISPOSAL PROJECT

3.1 Introduction

As part of the main project study for the sewerage and sewage treatment for Sana'a, a study was also carried out to determine the immediate and future needs for Refuse Collection and Disposal.

This chapter, describing the background conditions to the refuse project and the recommendations formulated for dealing with the problem, is submitted as a supplement to the Sewerage and Sewage Treatment paper.

3.2 Background

The city of Sana'a is some three thousand years old and the old city walls and streets are still intact today. The Old City is situated to the east of the new modern city centre and consists of narrow streets and alleys, all highly congested with pedestrian and vehicular traffic, and bordered by the traditional Yemeni houses of five or six storeys, many with shops on the ground floors. A similar area, Gaal Ulufi, lies to the west of the town centre and consists of similar streets and houses.

The modern expansion of the city of Sana'a with typically Middle Eastern villa development and wide streets, has expanded the total area of the city many times, but the existence of the two distinct styles of building creates a total contrast, and presents also special problems for any refuse collection service in terms of vehicle selection to cater for the narrow congested streets of the Old City and Gaal Ulufi and to provide effective collection in the modern sprawling suburban areas.

The Project Report for the Sana'a Refuse Scheme was submitted in the Autumn of 1976. Whilst the recommendations were approved, implementation had to await the allocation of funds. However, in January 1978 further instructions were given to the consultants, and work commenced on the design of the various buildings, service facilities and tip facilities, and on the preparation of contract documents and specifications for the equipment. Delivery of equipment commenced in January 1979 and is expected to be completed in Summer 1979.

3.3 Existing Conditions

A rudimentary system exists in Sana'a whereby refuse is picked up periodically from collection points within the City, and then transported to the outskirts and deposited on to open ground.

Being undermanned, and with insufficient equipment, the system is totally inadequate, and the inhabitants of Sana'a have resorted to dumping their refuse in the streets, or on to vacant building plots. Sometimes the refuse is dumped into disused well shafts.

As the refuse collection service cannot keep up with this indiscriminate dumping, there is a backlog of refuse waiting to be cleared away.

The dumping grounds outside the City are not controlled in any way, and efforts to bury the wastes are ineffective. The tips frequently catch fire and are allowed to burn in an effort to reduce the fly nuisance, and scavenging by vermin.

3.4 Proposed Collection and Disposal Service

Concepts

It was considered that the most important immediate need was to provide effective facilities for legitimate disposal of refuse which was collected. Having established an effective means of disposal, efforts could be made to improve the efficiency of the collection service, to extend the service to provide collection to the rapidly expanding suburban development, and to provide facilities suitable for a collection service to serve the Old City areas.

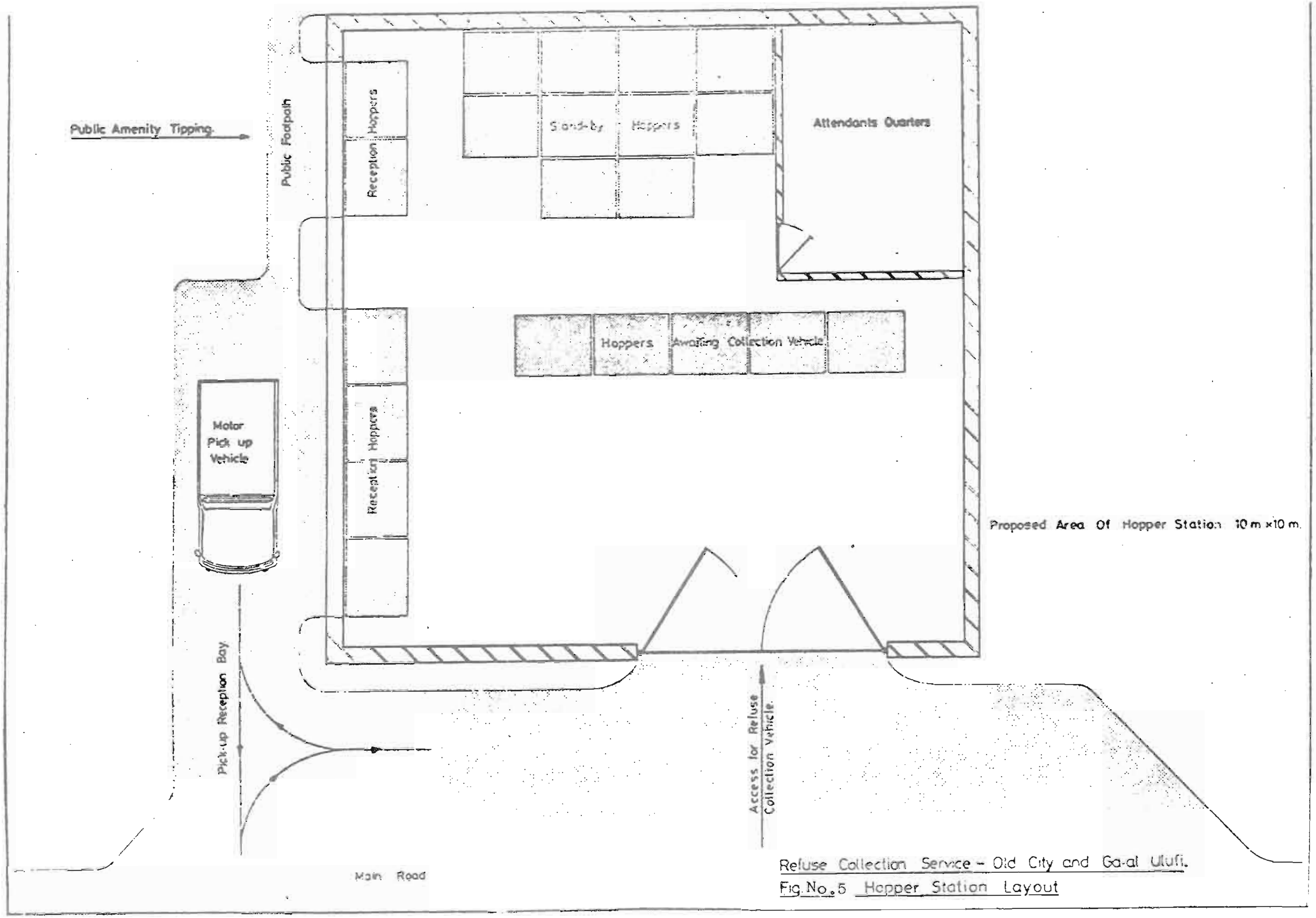
If a system could be implemented that would have real visible results in improvement of street cleanliness, removal of unsightly insanitary dumps within a short period, then public support for the project in the long term would be forthcoming.

Any system had to be simple to operate and relatively easy to administer. It was desirable to have a service which was labour intensive, but low in capital cost.

Collection Service

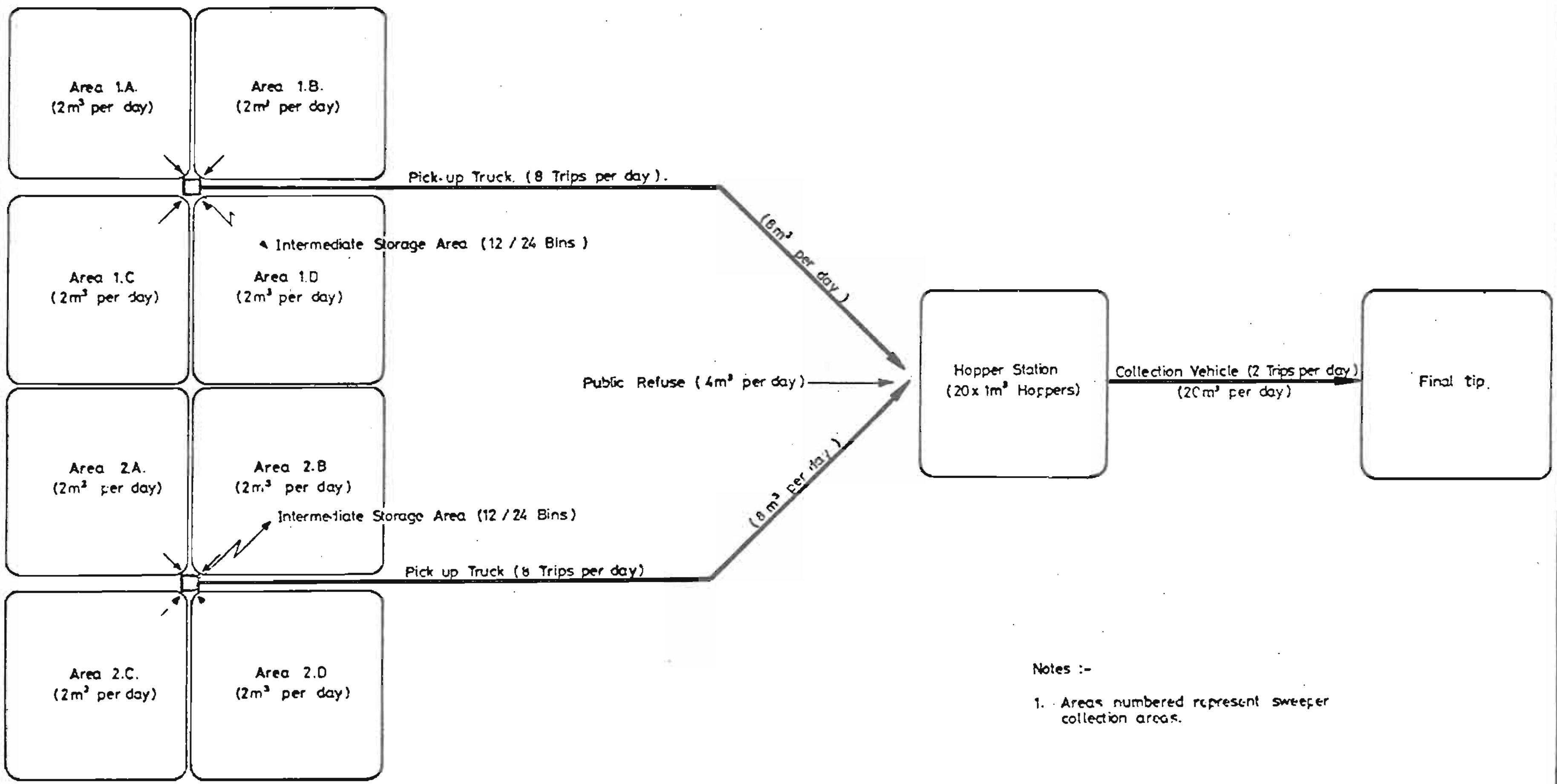
It was apparent that it would not be possible to service the entire city area with one style of domestic refuse collection. The difference in development density and street widths and access were too great to be suitable for service by one type of vehicle.

It was proposed that the Old City and Gaal Ulufi with their acute problems of vehicular access, should be served by a system employing a large number of manual collectors and little mechanisation. Street collectors equipped with hand orderlies carrying two eighty litre bins would carry out house to house collection. When the orderly bins were filled, the collector would leave them at determined collection points and replace them with empties and resume his collection. Small pick-up trucks, which were the largest vehicles which could be effectively



Refuse Collection Service – Old City and Ga-al Ulufi.

Fig. No. 5 Hopper Station Layout



Notes :-

1. Areas numbered represent sweeper collection areas.

Refuse Collection Service - Old City and Ga-al Ulufi.

Fig. No. 6 Operation Chart.

employed in these areas, would be used to transport the full bins to hopper stations situated on the periphery of the high density development areas. The hopper stations would also serve as civic amenity sites for local disposal. Refuse would be collected from the hopper station by standard compression fitted collection vehicles, and the refuse transported directly to the tip site.

The arrangement for the collection of refuse in the Old City and Gaal Ulufi areas is shown diagrammatically in Figure 5. Figure 6 shows the layout of a typical hopper station.

The more modern areas of the City, including the modern city centre and suburban areas, would be served by compression fitted collection vehicles. Refuse collection containers of one or two cubic metre capacity would be positioned at intervals along all streets, generally to provide a container within a maximum of one hundred metres and normally less than fifty metres of every home. It had been considered that house to house collection from villa style residences was impractical because of the time required, and also because of the problems of gaining access to private houses in Moslem communities. The collection vehicles were all to be fitted with container lifts to facilitate emptying of these streetside containers which were fitted with hinged lids to prevent refuse scatter or animal refuse nuisance.

Other collections from institutions, hospitals and trade premises were to be handled either by containers similar to those for the kerbside system or using bulk, eight cubic metre, containers serviced by a container transported vehicle.

The collection service for the high density areas will serve 104 hectares of the Old City and 16 hectares in Gaal Ulufi. The two areas will be serviced by a total of five hopper stations. The areas have been divided into forty-eight collection districts of approximately 130 households each, served by one collector carrying out a daily household collection. Ten small pick-up trucks will be continuously employed in transporting refuse to the hopper stations from the collecting areas. In addition one hundred street sweepers will assist in maintaining street cleanliness. Two fifteen cubic metre compression fitted collection vehicles will be employed fulltime on transporting refuse from the five hopper stations to the disposal site.

Other parts of the city have been divided into eleven collection districts for which a twice weekly collection will be serviced by a total of fifteen collection vehicles, eleven $15m^3$ and four $10m^3$ capacity, including standby vehicles. Each vehicle will make two trips to the disposal site per day. The smaller districts serviced by $10m^3$ vehicles will contain approximately 1 870 households, while the larger districts serviced by $15m^3$ vehicles will contain approximately 2 800 households. The population served, and the total daily production of refuse, is shown in Tables 1 and 2.

Refuse Disposal

Sanitary landfill was the proposed method of disposal and various tip sites were investigated. Geological investigations in conjunction with the water resources studies were carried out.

Land ownership is highly complex in the Yemen and eventually, after long protracted negotiations, a suitable site was acquired which was just on the economic limit of distance from the city for transportation of refuse in collection vehicles.

The tip site was situated to the North West of the City on a slope adjacent to a main highway.

Site works which were necessary included the provision of a surface water cut-off ditch to divert run-off from the surrounding hillsides.

A system of sanitary landfilling was devised and special provisions were made for the disposal of large items such as scrap vehicles and other scrap by burial.

It was further proposed that the existing unsightly open dumps should be cleared and reinstated, the refuse being transported to the new disposal site.

Street Cleaning

A very important ancillary to the refuse collection and disposal was the provision of an effective system of street cleaning and sweeping to cater for the dust and general litter which is dropped in the streets.

As few streets in Sana'a are yet fully metalled and kerbed, mechanised road sweeping would be premature. Over the next few years, with the installation of sewers and water service pipes in the majority of streets, such methods which are high in initial capital cost, would be ineffective in producing the desired results.

Manual sweeping using sweepers equipped with hand orderlies and eighty litre bins similar to the collectors in the Old City were proposed. An initial intensive cleaning of an area, prior to implementation of the collection and sweeping service, would assist in gaining public support, and the sweepers would then maintain the clean state of the roads and alleys. In support, mechanised cleaning would be provided for the kerbside refuse containers. A container cleansing vehicle would service all the kerbside contained locations, washing the surroundings and the outside of the container. At necessary intervals, the containers would be removed to the central depot for steam cleaning, lubrication and maintenance checks.

Table 1

Total Population of the City of Sana'a	
Year	Population
1976	141 873
1980	176 404
1985	225 971
1990	283 258
2000	424 651

Total Projected Refuse Production - City of Sana'a	
Year	Total Daily Production m^3
1976	288
1980	451
1985	756
1990	1 321

Organisation and Maintenance

As part of the consultants' continued work on the project, organisational reports and recommendations have been prepared, including a staff structure, job descriptions, wage levels and levels of responsibility. Maintenance schedules for all vehicles and equipment, including steam cleaning, lubrication and safety checks for all vehicles and equipment, have been worked out. An equipment replacement programme was devised to enable the client to plan the Solid Waste Management Department's future budget.

A central service depot is to be constructed to provide all the necessary maintenance and service facilities for the Solid Waste Management Department. The depot will contain administration offices, a vehicle workshop with ancillary workrooms and stores, vehicle washing and steam cleaning facilities, fuelling provisions and vehicle parking areas. In addition, stores and reporting facilities for all manual labourers and sweepers have been included.

Operation of the Service

The consultants work includes the provision of an Advisor to assist with the initial running of the service, including training of operators and development of new procedures to implement the overall plan for the Department. Recruitment of top personnel is a difficult problem in the Yemen, where all people with technical or managerial abilities are in great demand in all the expanding Government services.

It is proposed that the collection service be implemented in stages; one collection district at a time, with service in other districts being initiated only when adequate trained personnel and supervision is available. Such a start will also give time for adjustment, as necessary, to cope with problems such as significant local increase in refuse or difficulties with collection rounds due to traffic congestion, which is an increasing problem in Sana'a.

It is anticipated that the initial phase of the project will be accomplished within the six months and that, by Autumn 1979, a comprehensive and efficient refuse collection and disposal service will be operating in Sana'a.

3.5 Cost Estimates

The project is being implemented under two main contracts.

Contract R1 covers the Supply of Vehicles and Equipment, and Contract R2 covers the Civil Engineering Works which includes for the construction of the Hopper Stations, the Central Depot and the Tip Site Works.

The estimated capital costs for the project, expressed in Yemen Rials, are given as follows:-

	Yemen Rials
Contract R1	12 300 000
Contract R2	9 000 000
	21 500 000

The conversion rate for Yemen Rials to Pounds Sterling is YR. 8.5 = £(Sterling) 1.00.