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water pollution control works in libya

1. INTRODUCTION

This paper sets out to describe some aspects of the major water pollution control works which have been and are being provided in various towns in the Socialist People's Libyan Arab Jumahereya (formerly known as the Libyan Arab Republic and subsequently in this paper referred to as Libya).

It is not intended to describe every detail of the work done at each town, but certain aspects have been selected for discussion and reference made to specific cases where appropriate. The paper is based on projects undertaken at the six largest towns of Tripoli (Capital), Benghazi (Second City), Derna, Misurata, Tobruk and Sebha. All these places are situated on the coast except Sebha which lies in the Sahara Desert some 600 kilometres south of Tripoli. Projects are also proceeding in other centres, but the Author's knowledge principally covers those mentioned above. In the case of Sebha, Misurata and Derna this knowledge is limited to Phase 1 only.

The works concerned cover the era 1961 to the present and in some instances include projected future works which are anticipated to be carried out over the next fifteen to twenty years.

It is hoped that the paper, in addition to being informative, will form a basis for discussion and also elicit from delegates comparative information and data related to similar projects in other countries or, indeed in Libya itself.

2. LIBYA

General

Libya (figure 1) covers an area of approximately 210 million hectares along the north coast of Africa. It borders Egypt and the Sudan on the east, Chad and Niger on the south and Algeria and Tunisia on the west. It consists of the three former provinces Tripolitania, Cyrenaica and the Fezzan, and the main commercial cities are Tripoli and Benghazi. Libya

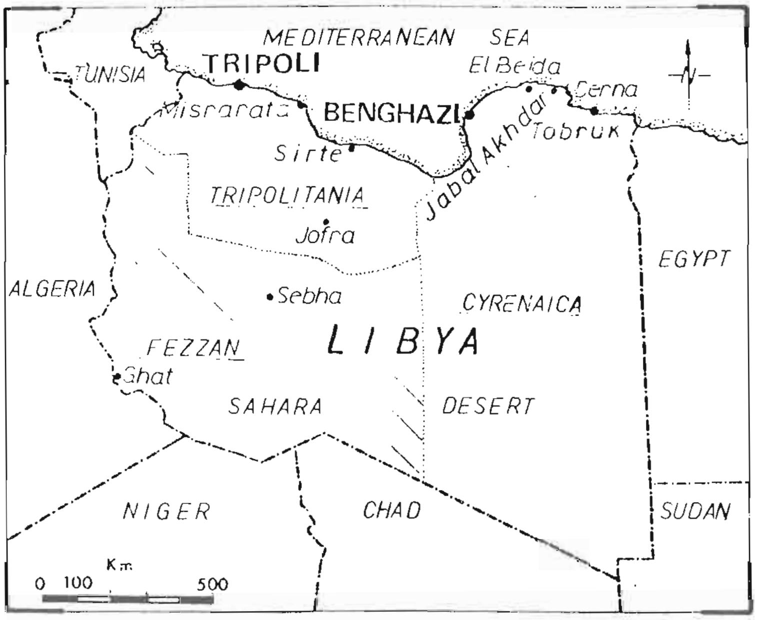


Fig.1 — LIBYA

became a Republic on the 1st September 1969 but is now the Socialist People's Arab Jumahereya.

Vast sand and rock deserts are the predominating features of much of the country, the southern part of which lies within the Sahara Desert. The coastal region of much of Tripolitania and part of Cyrenaica is comparatively fertile, the wide and desolate expanse of the Sirte Desert separating the two provinces. The eastern part of Cyrenaica between Barce and Derna is mountainous and the Jebel Akhdar or Green Mountain rises to a height of 800 metres. The Fezzan is mostly desert with a few scattered oases, the most important being those at Jofra, Sebha and Ghat.

There are few rivers and rainfall is sporadic. The greater part of the country has a hot and arid desert climate. Along the Mediterranean coast, however, where all the main towns are located, the climate is more temperate. Rain occurs mostly between October and March and no rain falls in June, July and August. The maximum temperature in summer is about 44°C and in winter the temperature may change from near freezing at night to quite warm in the afternoon. Humidity is often 80% or above. Temperatures soar when the wind (known locally as the ghibli) blows from the south.

Population

The present population of Libya is about 2.6 million, Tripolitania being the most heavily populated area. 85% of the population live in the more temperate coastal regions. Libya is an almost exclusively Muslim country and its people observe most of the traditional customs of Islam.

Economy and finance

Oil accounts for about 99.5% of the total value of Libyan exports, the main oil producing region being in Cyrenaica. Oil revenue in 1976 was of the order of LD 2000 million equivalent to £4000 million.

In common with many other Arab countries, revenue from oil sales has enabled the Libyan Government to embark on large development programmes which require infrastructure engineering, including drainage facilities which had previously hardly existed. Funds are provided from central Government sources to local municipalities on a direct grant basis to the full amounts required, there being no borrowing and repayment arrangements and no system of revenue collection. In spite of the high level of oil revenue the flow of funds is often slower than required to match the necessary rate of progress on projects.

3. THE PROJECTS

General

In 1961 when the Government decided to proceed with drainage schemes in certain towns, the only sewerage system of any significance was that in Tripoli, an old combined system. Benghazi boasted an old inadequate network of overloaded sewers in part of the central area whilst Tobruk had only a limited foul system serving an army barracks. Derna, Misurata and Sebha had no system of main sewers and drainage was to cesspits and septic tanks.

The systems of Tripoli and Benghazi, such as they were, discharged to the sea or partly enclosed bodies of water through various short outfalls, most of which were situated close to built-up areas. The Tobruk system discharged to a small treatment plant.

Although not considered in this paper, a basic system of sewers and a sewage treatment plant had been installed at Beida in 1959. The treatment plant was of the traditional biological filter type.

Apart from a desire to deal urgently with the amenity aspect, the Government concluded that the discharge to the sea of such large volumes of water in a country where its conservation is so important was wrong. Their terms of reference, therefore, provided for the treatment of sewage to a standard which would permit the use of the effluent for irrigation purposes.

Work on the initial phases of sewerage projects for each town commenced in the year 1961 to 1973, each project having its own chequered history and reaching completion during the period 1963 to 1977. The second phase of each project commenced with Benghazi in 1973 followed by Tripoli and Tobruk. Work on Phase 2 of Sebha, Derna and Misurata has also started but, as previously stated, the Author is not in a position to know details of progress on these schemes.

Phase 1 projects

The basic details of the Phase 1 projects are given in Table 1. The Phase 1 projects were all affected to a greater or lesser degree by labour problems, unsettled political conditions in the Middle East, financial failure of some contractors, and general administrative difficulties, resulting in delays; in the case of Benghazi some seven years beyond the original contract completion time of four years.

TABLE 1: Details of Phase 1 projects

	Benghazi	Tripoli	Tobruk	Misurata	Sebha	Derna	Total
Total length of sewer (kilometres)	162	267	15	41	15	49	549
Number of foul sewage pumping stations	10	4	3	18	5	3	43
Number of S.W. pumping stations	4	-	-	1	1	-	6
Capacity sewage treatment works (m^3/day). (All to tertiary standard, biological filter plant with sludge digestion and drying beds)	27 300	27 300	1360	1360	1360	4550	-

Phase 2 projects

Benghazi

In 1973 the Municipality of Benghazi commissioned the Author's firm to prepare a comprehensive Master Plan to cover sewerage and sewage treatment requirements for the town to the year 2014, to be followed by project reports and a vast programme of design and construction. The Master Plan and all project reports have been accepted, a large amount of design work executed, certain contract work under construction and contracts out to tender. Tables 2 and 3 have been prepared to indicate progress to date on design and letting to contract and the programme for the future.

TABLE 2: Benghazi - details of Phase 2 projects (sewerage)

Contract	Total length main sewers ($) (km)	No. of P.S's	Contract start date	Contract time (months)
101S	60	-	Sept. 1974	30
102A	12 *	-	Aug. 1974	39
102B	11 *	-	Aug. 1974	39
101N	60	2(F)	Dec. 1975	30
104	25	1(F)1(S)	Nov. 1975	30
105	31	-	Mar. 1977	24
108A	36	2(F)	Out to tender	36
106A	61		Out to tender	30
111	Replacement & modifications to P stations		Out to tender	30
106C	20 (pumping main)	1(F)	After 1977	36
108B	30	1(F)	After 1977	30

....Table 2 (Cont)

Contract	Total length main sewers($) (km)		No. of P.S's	Contract start date	Contract time (months)
108C	30		1(F)	After 1977	30
102C	5	*	2(S)	After 1977	36
106B	50		2(F)	After 1977	36
109A	35			After 1977	30
113A	50		1(F)	After 1977	36
110A	40			After 1977	30
102D	5	*		After 1977	30
102E & F	13	*	1(S)	After 1977	36
109B	45			After 1977	36
115A	70			After 1977	36
115B	72			After 1977	36
102G & H	9	*	2(S)	After 1977	36
Total:	770				

(F) = Foul sewage
(S) = Stormwater
* = R.C. Box culverts
$ = Excluding laterals

TABLE 3: Benghazi - details of Phase 2 project (sewage treatment)

Contract	Dry weather flow (m^3/day)	Extension (E) or New (N)	Contract start date	Contract time (months)
103A	54 500 (stage 2&3)	E	June 1977	
107A	65 000 (1 & 2)	N	Out to tender	
Further extensions to be carried out as required in the future.				

As will be seen from Table 2 the second phase commenced on site in late 1974 when three contracts were let for the construction of sewers and stormwater culverts. Two more contracts were signed in 1975 for sewer and pumping station construction followed very recently by a further sewer contract and one for the extension of the existing sewage treatment works on the south side of the town (Guarchia). Further sewer contracts will be let soon together with a contract for a new sewage treatment works to the north of the town.

The total value of current contracts is some £340 million, peak monthly value of work executed having been £5 million with a new peak of £8 million likely in 1978.

A notable feature has been the operation for two years of the sewage treatment works by a contractor. Further details are given in Section 10 in this paper.

Tripoli

Progress on the development of the sewerage system at Tripoli has proceeded at a slower rate than that at Benghazi, one reason being that the original system is more extensive at Tripoli. Some work has preceeded piecemeal, part of which has been undertaken by the Author's firm. There has so far been no townwide concerted action, apart from the recent preparation of a Master Plan for the year 2000, to provide for the rapidly expanding city.

In respect of the treatment works the Author's firm were engaged in 1974 to prepare designs for an extension by 110 000 m^3 per day to the existing 27 500 m^3 per day works and tenders received in June 1976 are still being considered.

Tobruk

The Author's firm was engaged in 1974 to prepare a sewerage Master Plan for the town followed by project reports, detailed design and supervision of construction. The position to date is that the Master Plan has been accepted. Project Reports have been prepared for Contract Areas 1 and 2 and for Contract 11. A draft report has been submitted for Contract 3 - extensions to the sewage treatment works. The drainage work to connect a Government housing project, Contract 11, is at present under construction. Tenders have recently been received for Contract 1. Instructions to prepare contract documents for Contract 2 have also been received. A site investigation contract to cover the proposed development area was let in December 1976 and completed in March 1977.

TABLE 4: Tobruk projects

Contract	Total length+ Main foul sewer (km)	Number of P stations	Capacity of works m^3/day	Type of works
1	30 ϕ	4 *	-	-
2	10	-	-	-
3	-	-	30 000	Filters
Future sewer contracts	60	2	-	-
Future works extensions	-	-	10 000	Filters
11	30	1	-	-

* 1 No. new pumping station and refurbishing 3 No. existing stations.

\+ Does not include lateral connections

ϕ Foul and stormwater sewers

4. FOUL SEWERAGE

Type of system

The practice of providing separate foul and stormwater systems, now widely accepted in countries where total annual rainfall is low and confined to relatively short periods during the year, has been adopted, except in the case of Tripoli West where instructions by the employing authority required a combined system. The existing system at Tripoli, apart from a satellite development to the West, has been designed on the combined system with overflows of storm sewage to the sea.

Design criteria

One of the most difficult aspects of the engineer's work is in deciding basic design criteria and achieving confident acceptance of them by the authorities because of some or all of the following reasons:

a) The absence of established sewerage systems and therefore of experience of practice resulting therefrom.

b) Feedback of experience from established systems for which he or others have been responsible.

c) The absence of the professional bodies in the country concerned which, for example in Great Britain, provide a forum for the exchange of experience and opinions.

d) The uncertainty of planning policy both at national and regional levels.

e) The confusion in the minds of officials arising from the differences in approach and criteria proposed by different consultants.

f) The difficulty of employing authorities in realising that, at least in some cases, exact science cannot be applied.

In the case of current schemes for Tripoli, Benghazi and Tobruk, the design criteria and parameters adopted are as shown in Table 5.

TABLE 5: Design criteria and parameters for foul sewers

Minimum diameter of sewer	200 mm
Pipe size for properties connections	150 mm
Minimum velocity normal	1.00 m/sec
absolute	0.75 m/sec
Friction formula	Colebrook-White
K value	0.6 mm
Pipe capacity	6 x dwf
Flow/capita (future)	
Benghazi	270 litres/day
Tripoli	270 litres/day
Tobruk	150 litres/day
Population densities	
Benghazi	100 - 600 persons/ha
Tripoli	100 - 600 persons/ha
Tobruk	100 - 600 persons/ha
Pumping mains	
Maximum velocity	2.0 m/s
Minimum velocity	0.75 m/s
Pumping rate (generally where overflow possible)	3 dwf

The need to reduce the possibility of septic conditions in the sewage and the resulting corrosive effects was taken seriously and one of the precautions enlisted was to adopt a minimum normal design velocity in the sewers of 1.00 metres per second to ensure self-cleansing. It was necessary in places to relax this criterion to reduce for instance depth of excavation, but in all cases sewers have an absolute minimum self-cleansing velocity of 0.75 m/s at full bore.

The value of K selected in the Colebrook-White formula seems to vary among consultants and this variation causes employing authorities some concern since with such large schemes overall costs will be affected as well as anticipated velocities. A value of 0.6 mm appropriate to matured sewers was accepted and used in the design of the foul sewers in the present cases.

The dry weather flows (dwf) were calculated from the projected ultimate per capita water consumption figures. Sewers were sized by multiplying the dwf by a factor of 6 to be sufficient to provide a margin for possible groundwater infiltration and incidental surface water ingress. With rubber ring joint pipes infiltration is not expected to be large. The minimum size of main sewer adopted was 200 mm in the light of the following factors:

a) The need to minimise sewer blockages and to facilitate maintenance

b) To allow some margin against possible higher population densities than foreseen by the planning authorities, this factor being influenced by the many changes taking place between planned and actual development.

Property connections

Experience has shown that the sewerage system is considered by the users to be available for the reception of not only normal human waste but for the disposal of all kinds of objects of varying sizes and shapes. This has resulted in frequent blockages and generally heavy maintenance problems and at the request of the authorities special precautions have been taken in the designs. The two main steps taken were to limit the distance between manholes to 50 metres and to arrange where possible for property connections to enter the main system only by way of manholes and not through pipe junctions. A chamber is provided outside each property for the connection of the internal system and the chambers are linked through a lateral system which in turn is connected to a main sewer manhole. This arrangement is not always possible, such as in narrow streets or where existing services prevent it, but is the rule rather than the exception.

MATERIALS

Gravity sewers

For the original Phase 1 works design the choice of pipe material lay between concrete, glazed vitrified clay and asbestos cement. The concrete pipe manufacturers at that time showed considerable problems in transporting their product economically and the locally manufactured material was inferior and very sub-specification. The GVC pipes, of course, unquestionably provided a material with good anti-corrosive properties, but this advantage was offset by the high transportation costs, the limit on diameter and the short lengths entailing higher laying costs. In addition, early experience produced very high breakage costs. The problems associated with sewer fabric attack by sulphuric acid are each day more manifest and the current expansion in works in the Middle East have accentuated these problems. The prevention of this corrosion is uppermost now in the design engineer's mind.

The general experience from early examination of the existing sewer fabrics, mainly concrete pipes and culverts, showed no visible sign of fabric attack by sulphuric acid. At the Phase 1 stage this situation was acknowledged, but the lack of firm evidence demonstrated that conditions were obviously not conducive to the formation of sulphuric acid. It is felt that the very high per capita water consumption provides a weak sewage well below the strength of an average U.K. sewage. This, coupled with the low average temperatures (18 - 25°C) and the high velocities achieved and designed for in the sewer network, reduce the likelihood of the formation of sulphuric acid.

The asbestos cement pipes, the material eventually chosen, were readily available from local Mediterranean sources. The AC pipe suffers a small breakage loss owing to the ability to remove the fractured element and to provide a pipe of reduced length by turning the end. Similar argument was put forward for the choice of gravity sewer material for the second phase of the works for Tripoli, Benghazi and Tobruk.

The operating experience of the AC pipes constructed under the Phase 1 works showed no attack; similarly the manholes appeared sound. During recent construction of Phase 2 work it was necessary to 'exhume' a length of 900 mm diameter AC pipe after six years of service. It was in 'mint' condition and was relaid and put back into use. Consideration was given to the introduction of lining materials, especially in regions known to provide ideal conditions for generation of sulphuric acid, but the previous and current operating experience coupled with the continued practice of minimum velocity criteria excluded any revision to the original choices.

Due to the rapid programme of sewer construction it was necessary to ensure that there would be adequate pipe supplies to permit the speedy construction. For this reason it was decided that stormwater networks could be of concrete. The tendering procedures permitted the use of GVC pipes in the lower diameters and also the use of glass reinforced plastic pipe. However, the use of the latter was excluded from those areas where adequate protection to external damage by construction and development works was the overriding factor.

Pumping mains

A similar approach was undertaken in the choice of pumping main material. This lay in Phase 1 between steel and asbestos cement. The steep pumping mains were designed with an internal bituminous lining and externally sheathed and provided with cathodic protection. Mains of both these materials were used in the Phase 1 works. For Phase 2 the choice was extended to include GRP and ductile iron, the choice being left generally to the tenderer on pricing grounds. An exception to this was where development was likely to take place and GRP were excluded as having insufficient external structural strength against accidental damage caused by adjacent construction works.

Manholes

The original designs were similar to the standard practice in U.K., a precast ring with concrete surround. This proposal involved the contractors in providing fabrication facilities for the precast element and recent designs have included circular or rectangular in-situ castings, following a preference by the contractors for this construction system. The covers were specified to exclude sand ingress as far as possible. This was best achieved by correct seating arrangements and most suppliers of this item have achieved this requirement.

There is a tendency by the local authorities to use for their own work a very sub-standard form of circular cover which frequently seats inadequately and provides a traffic hazard.

Pipe protection

The pipe bedding and protection details were designed for rigid pipes using the method set out in Special Report No. 37 published by the Building Research Station. The design for flexible pipes varies but principally adopts the approach set out by Mr N W B Clarke in his paper "Buried pipelines".

Bedding materials are usually sand gravel or concrete depending on the design conditions, but sand is specifically excluded for lengths where formation level is below groundwater table. The design has generally been carried out for varying trench conditions. Generally sand and gravel bedding with medium strength pipes have been used in preference to a lower strength pipe on a higher bedding factor support.

Testing

Small diameter gravity sewers are tested using water with a permitted loss under a minimum head of 1.0 m at the upstream end. Larger sewers are tested using air against a permitted loss on a pressure equivalent to 100 mm of water. The test requirements for pumping mains using a water test is the greatest of 2 x working or 1½ x closed valve, or 3.5 kg/cm^2 whichever is the greater.

Ventilation

Originally all house connections lateral chambers were provided with ventilation pipes, but subsequently the local authority have enacted legislation to ensure that house drainage is vented similar to normal U.K. practice, and thus lateral chambers are not now provided with separate ventilation pipes. Ventilation pipes on the sewerage network are provided on all branch sewers greater than 100m in length and at the head runs of all main lines.

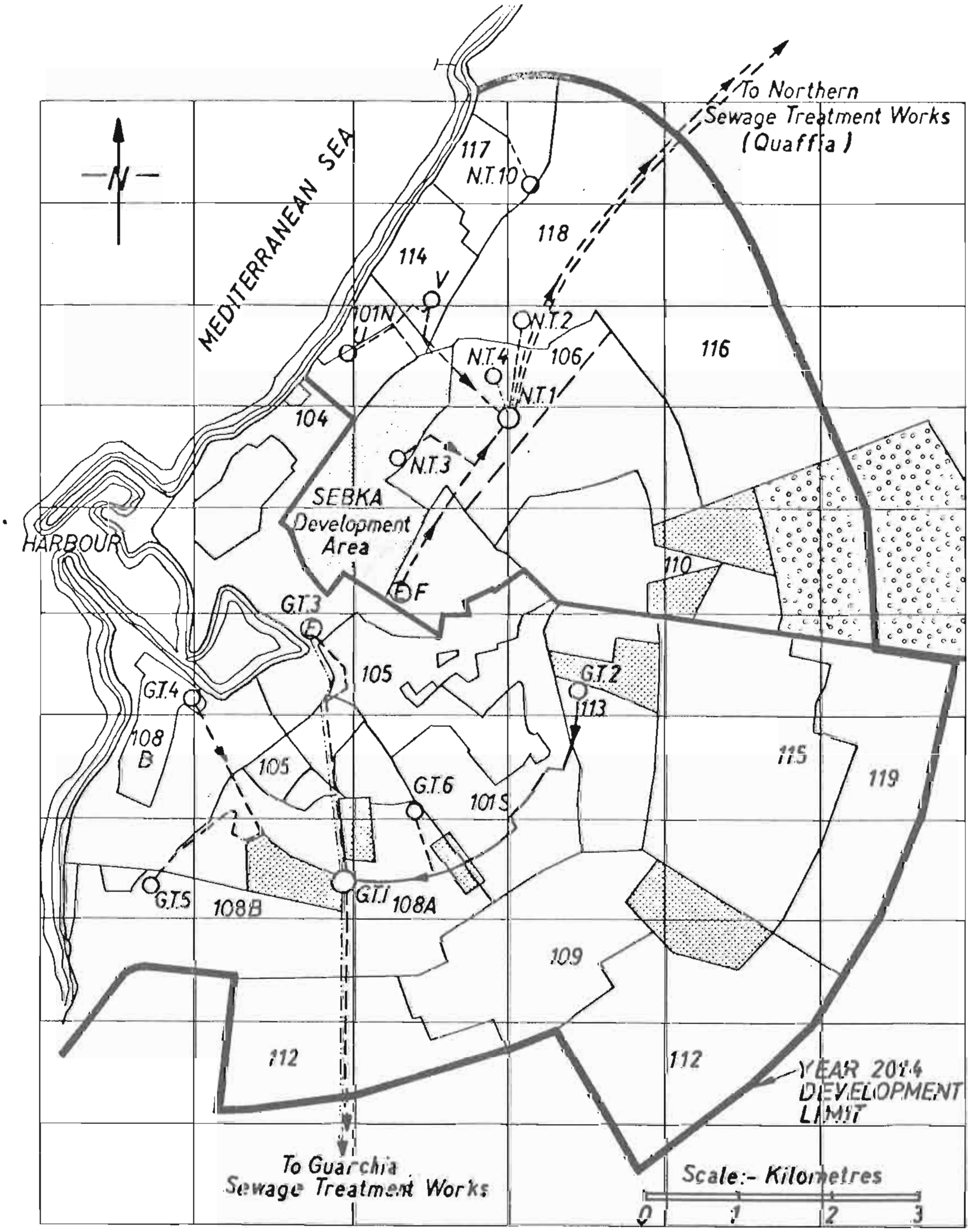
Benghazi sewerage system

Benghazi is generally flat, being a sebka area. The land generally falls seaward from the East, but the central and northern areas require pumping stations to lift the sewage from the low lying areas. The overall plan provides for development up to the year 2014 (see figure 2).

An extensive study resulted in the decision to provide two separate treatment works, one on the North side and one on the South side, their location being if possible close to the agricultural areas that will be using the treated effluent. The existing sewage treatment works at Guarchia, located South of the city, at present drains the central zone of Benghazi. This arrangement conveniently divided the city into a North and South drainage zone.

Pumping stations

The major sewage pumping stations have flow measurement equipment and overflow facilities. At certain of the smaller pumping stations where it is not convenient to separate flows greater than 3 dwf because of overflow problems, outlet pumps have been installed for rates of up to 6 dwf.



LEGEND:-

—— Boundary between areas served by GUARCHIA and NORTHERN Treatment Works

Housing Sites

Industrial Housing Site

—— Sewers

- - - - Pumping Mains

—·—·— Existing

○ Foul Pumping Station

(E) Existing Foul Pumping Station

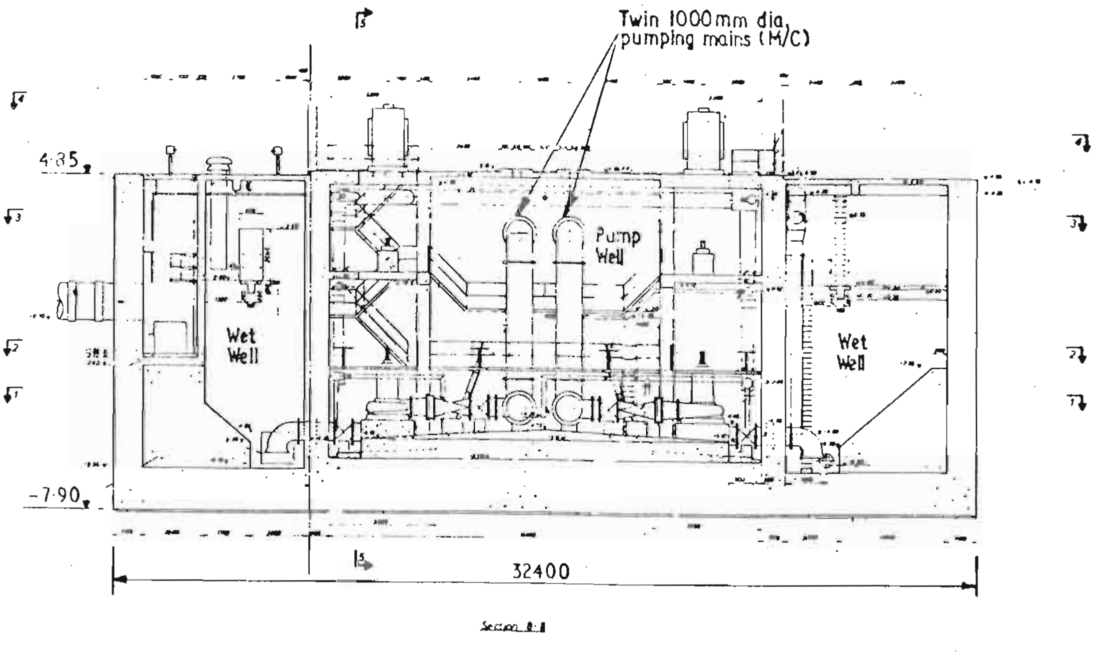
FIG. 2 BENGHAZI FOUL SEWERAGE SYSTEM

The pump arrangements are conventional using centrifugal sewage pumps. In the main pumping stations in addition to the duty pumps, one standby and one maintenance pump have been provided.

The majority of pumping stations are provided with coarse screens which are hand raked. The main town pumping stations are provided with semi-rotary mechanically raked screens, flow measurement and overflow facilities. Flow measurement readings are used to transmit signals to control motorised penstocks which restrict the flow to the wet wells to 3 dwf capacity of the treatment works. Overflowed quantities are allowed to pass to the stormwater culverts after passing through vertical raked fine screens.

One of the larger pumping stations pumps to the Northern Treatment Works. A plan and section (figures 3 and 4) show the general layout of the station.

FIGURE 3: Typical foul sewage pumping station (section) (all diameters in millimetres)



The station is arranged with a central pumping hall with two wet wells on either side. The pump casings have been sized as to be suitable for the initial, intermediate and ultimate stages of the design. Each of the last two stages will be achieved by a change of impeller and change of speed achieved by the use of two speed double wound motors. Table 6 summarises the initial foul pumping station capacities. The pumping mains to the new sewage treatment works will be twin 1200 mm with cross-over connections at suitable distances.

Experience so far

Clearly the mere provision of physical structures and systems is not the end of the story and much needs to be done in educating the public in the proper use of them and in providing efficient maintenance facilities. The sewerage system is often looked upon as the repository for all manner and size of objects.

FIGURE 4: Typical foul sewage pumping station (plan) (all dimensions in millimetres)

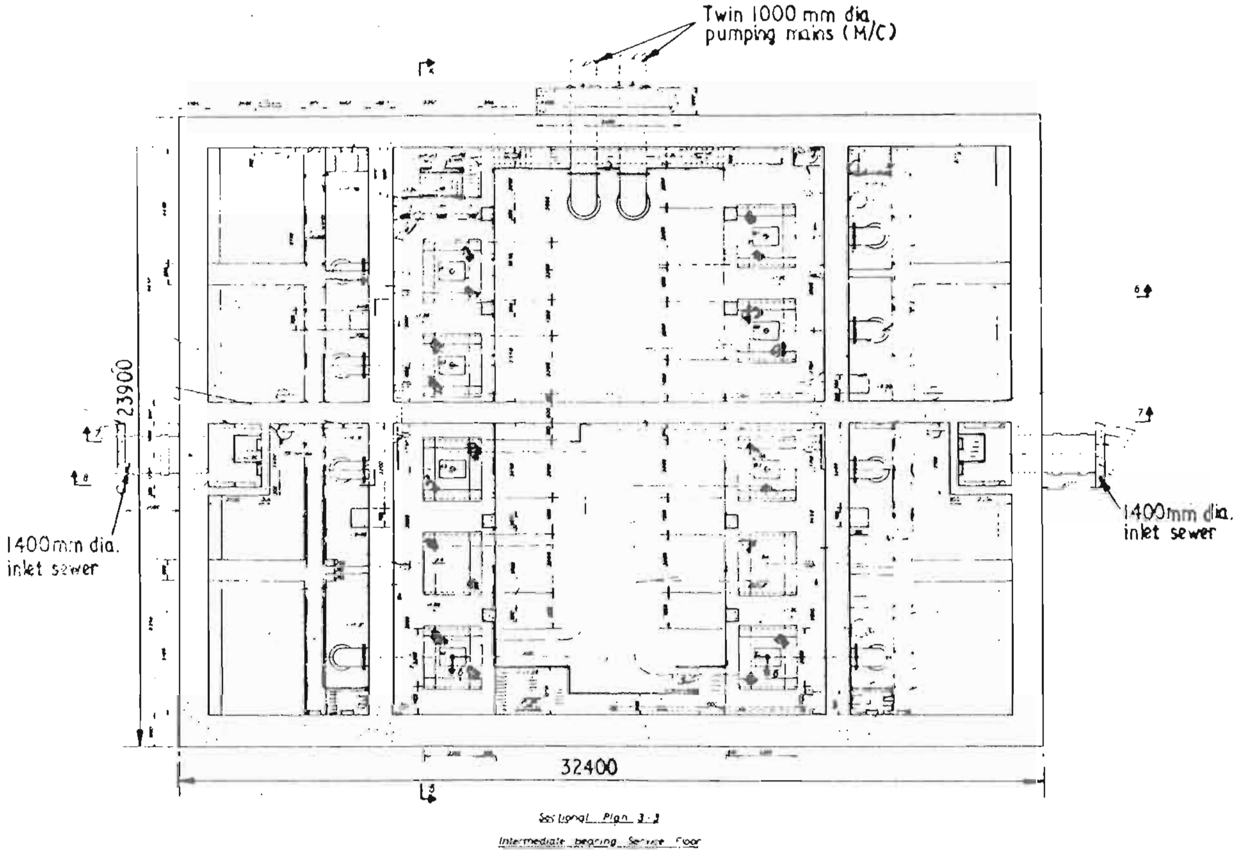


TABLE 6: Benghazi - Phase 2 sewage pumping stations (initial) summary of pumping rates

Pumping station	No of pumps	Maximum capacity m^3/hr	Pumps		Max. total head m
			Type	Size (mm)	
U	2 + 1	670 (ultimate)	Sewage	250	11.0
V	2 + 1	2024 (ultimate)	Sewage	350	10.12
	2 + 1	2024 (storm)	Sewage	350	10.00
F	2 + 1	1644 (ultimate)	Sewage	350	26.00
GT1 'A' pumps	2 + 2	5800	Sewage	600	40.00
'B' pumps	5 + 2	17 680 (ultimate)	Sewage	600	37.00
GT6	3 + 2	3125 (ultimate)	Sewage	300	9.00
NT1	3 + 2 and 3 + 2	16 250 (ultimate)	Sewage	600	21.00

In some countries the rate of property connection can be very slow, resulting in low rates of flow in the sewers and ensuing problems of solids settlement and septicity. In Libya there is generally a keenness to connect and indeed many difficulties have been suffered by contractors who have found sewage flowing in systems still being constructed by them due to illegal connections being made.

On the whole sewers laid so far have worked well and there has been no reason to drastically change the design approach other than the spacing of manholes and providing rider lateral systems. The corrosion problem with asbestos cement pipes has not arisen as has been the unfortunate experience elsewhere.

The old sewer network in Tripoli constructed before the Author's firm's involvement with the sanitation of the city, was principally constructed of minimally reinforced concrete. These sewers, having a variety of shapes and in places very flat gradients, have so far shown no deterioration from sulphuric acid attack.

Manhole covers have generally worked satisfactorily, especially considering the extreme traffic loadings that are more than occasionally encountered and incorrect reseating and repositioning resulting in unbalanced loadings and thereby fracture of cover frame or both. This latter problem being a direct cause of inadequate understanding and of inexperience in proper maintenance of the sewerage network.

5. STORMWATER DRAINAGE

General

The approach to the provision of stormwater systems in the various towns in Libya is basically the same. The broad differences between the projects stem from differences in topography, i.e. essentially the need to pump as opposed to disposal by gravity. In the cases of Tobruk and Derna the topography and available falls are such that little pumping is necessary and long trunk sewers are rare. Misurata is generally "dish shaped" and run-off has to be collected and pumped away from the town centre. The Phase 1 arrangements here were to pump to the sewage treatment works for partial treatment before either ground soakage disposal or pumping to the irrigation areas. Sebha is flat and similar to those at Misurata were provided. The Tripoli Phase 1 provision did not involve pumping but will probably be necessary in future developments. The extent of systems to be provided vary depending on the topography of the particular town. It is proposed to discuss the Benghazi system since it is the largest and most advanced and includes most of the features of the other projects.

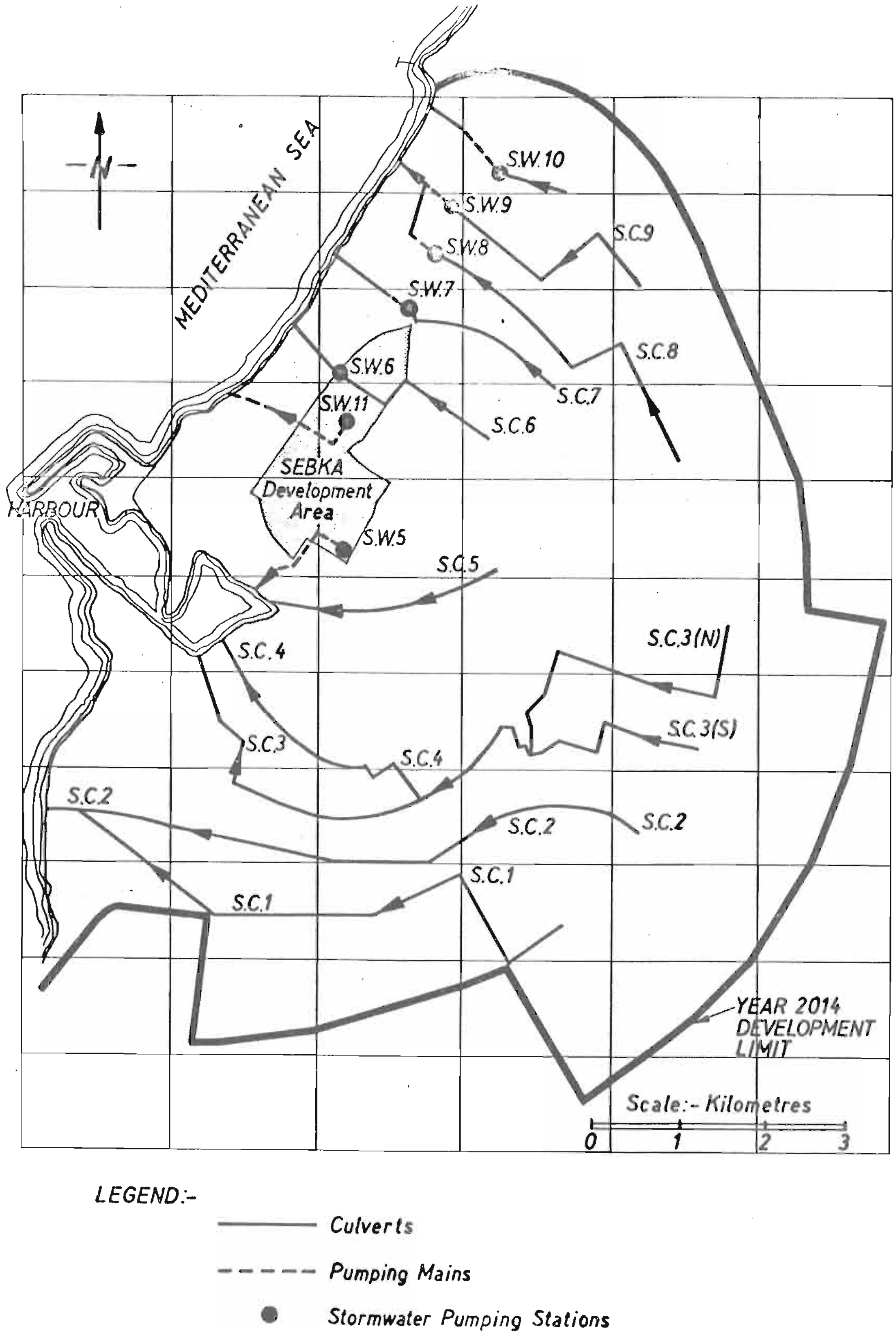
BENGHAZI STORMWATER SYSTEM

General

Benghazi is probably the most difficult of all the six towns for which to provide stormwater disposal facilities since surface water from itself and the hinterland flows across it and there are no defined natural watercourses or wadis available for the orderly collection and transport of run-off to the sea. Also the fall of the ground is generally very slack and the way to the sea is inhibited by fast-growing development which is already extensive and which has already sterilised the few natural routes which did exist at one time. The situation is further aggravated by the fact that the ground surface in some cases rises before finally sloping down to sea level. Again, the Selmani Sebka, a large inland lagoon near the town centre, which at one time served to receive run-off from certain areas, has been filled in and is now itself a flat area which is rapidly developing.

It is thus necessary to provide long artificial waterways across the town and at some points to finally pump to the sea. The type of waterway chosen is the box culvert which at their low reaches becomes considerable in size. The pumping stations are also substantial. Figure 5 illustrates the main culvert collectors and pumping stations.

FIGURE 5: Benghazi stormwater drainage system



Rainfall

Benghazi is situated in a semi-arid climatic zone and rainfall is concentrated into the winter months and is practically non-existent in the summer months. The following are monthly average precipitations in millimetres.

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual total
67	40	19	5	2	-	-	-	3	17	46	66	265 mm

From records available from 1921 to 1972 the average highest rainfall in one day is:

In 1 year - 29.6 mm
In 2 years - 34.5 mm
In 5 years - 41.0 mm

At the time of the design of the Phase 1 project in 1962/63 the only available information on rainfall intensity for Libya was that compiled by the United States Weather Bureau in a paper published in 1975 entitled 'Rainfall intensities for local drainage design in coastal regions of North Africa'(1). The data therein covered the region in the vicinity of Tripoli only. A storm curve was selected for Benghazi with the aid of this data based on a two-year return, one-hour intensity storm.

For the Phase 2 designs, rainfall data from the Meteorological Office at Benghazi was used in conjunction with data compiled by the British Meteorological Office to formulate rainfall statistics used for design purposes. These were for a two-year, two-hour storm intensity curve and a one-year, two-hour storm hydrograph respectively. The former was used in the Lloyd-Davies method for some stormwater sewers and the latter modified for use as a two-year, two-hour storm used in a computer program for the design of majority of stormwater sewers and the stormwater culverts. For hydrograph purposes the storm profile was assessed as being similar to a fifty percentile British summer storm and for Lloyd-Davies purposes the maximum intensity was limited to 37 mm/hr at a minimum of five minutes time of concentration.

Impermeability factors

Unpaved areas of Benghazi act in many cases as though they are paved due to the hard impermeable rock at the ground surface. Also where soil is present it is often of a fine cohesive nature when wet. These conditions produce high overall impermeability factors and actual experience during storms does indicate a high percentage run-off. The overall impermeability factors adopted after site investigation and due consideration are as follows:

Residential	0.6 to 0.8
Industrial	0.9
Open areas	0.2
Agricultural	Nil
Community facilities	0.9
Military	0.9
Educational	0.9

In general properties are not connected directly to stormwater drains but entry is by way of the road gullies.

Culverts

The pipe reticulation system is conventional and reasonably straightforward, the maximum size of pipe being 2000 mm diameter. The hydraulic and structural design of the culverts was also relatively straightforward, but due to their size a great deal of thought had to be put into the choice of route. In the case of one culvert it was necessary to split the culvert to take two routes since there was no route wide enough for a single structure large enough to take the total flow. The sizes, total lengths and capacities of the culvert system are given in Table 7.

TABLE 7: Culvert details

Culvert	Maximum size (metres)	Total length (km)
SC1	4.0 x 2.5*	7.50
SC2	4.0 x 2.0*	7.80
SC3	4.0 x 2.0*	12.8
SC4	4.0 x 2.5*	3.5
SC5	2.5 x 2.0	2.8
SC6	4.0 x 2.5	3.5
SC7	4.0 x 2.5	3.5
SC8	3.5 x 2.0	5.5
SC9	4.5 x 2.5	3.5
SC10	4.0 x 2.5	2.5

*Twin culverts

In order to try to reduce the size of culverts, consideration was given to the provision of balancing reservoirs, perhaps by using old disused quarries, but the proposal was rejected by the authorities as a possible health and environmental hazard as well as presenting a maintenance problem.

All culverts for some part of their length are either partly or totally below sea level and during the dry season when no stormwater is entering the system, there will be static water remaining. In order to allow for cleaning and to reduce the possibility of odours issuing from road gullies arrangements have been provided so that the sea may be excluded and the culverts pumped out. Each culvert is provided with a specially designed outfall chamber structure containing penstocks in addition to the normal tide flaps. At the end of the rainy season the penstocks can be closed and mobile pumps used to empty the culverts.

Each culvert is provided with a low flow channel to reduce deposition of solids so far as possible. However in such a sandy area there is expected to be deposition of heavy particles and access for cleaning gangs with skips and other tackle has been provided by large multiple-cover shafts.

Stormwater pumping stations

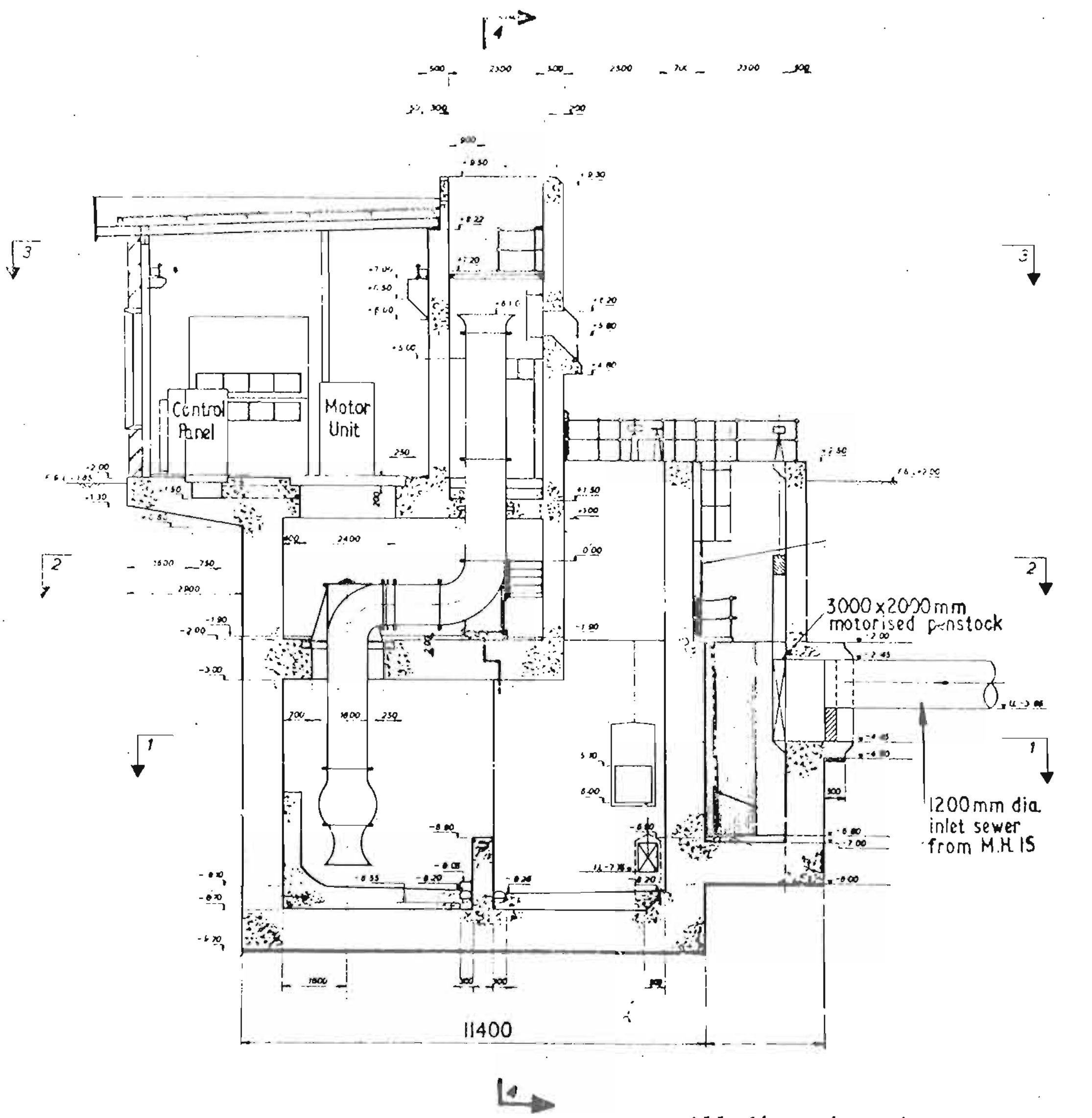
Included in the Phase 1 project were two pumping stations, SW1 and SW2 consisting of suspended mixed flow pumps, SW1 lifting into a header chamber built on to the upper end of an R.C. pressure box culvert and SW2 pumping into an asbestos cement pumping main. SW1 pumps to the inner harbour and SW2 to the sea.

The earlier stations in the Phase 2 works contained conventional mixed flow suspended pumps. A typical example of this type is pumping station SW5 where four duty and one standby unit have been provided. All pumping stations have model tests before approval is given and considerable changes were required in the baffle arrangements of Station SW5 to improve flow pattern to the pump sections.

When four pumps are operating the total discharge is 36 000 m^3/hr. Each 1000 mm pump discharge is fitted with a single door non-return valve and sluice valve. The general configuration of the station dictated the rather oblique angle of entry of the sewer to the wet well.

All future stormwater pumping stations will be of a different design. They will pump direct to a header chamber and discharge above the maximum TWL, therefore making the use of valves unnecessary. This arrangement reduces the size of the pumping station and also incorporates the header chamber as part of the pumping station structure. The cost of the mechanical equipment is also reduced with the omission of the reflux and sluice valves (see figure 6).

FIGURE 6: Typical stormwater pumping station



All dimensions in millimetres

The new stormwater pumping stations will be provided with grit-retaining walls in the wet wells designed such that the major quantity of grit is contained in an area remote from the pump suctions. At the end of the rainy season the remaining water in the wells will be pumped into the nearest foul sewers by submersible pumps located in their own suction chambers isolated from the main wet wells. Weir penstocks have been provided so that top water only from the main wells is allowed to enter the drainage pump sump leaving the grit to be removed by use of skips lowered into the wet wells by mobile cranes. Table 8 shows the basic data for stormwater pump stations, either designed or to be designed.

TABLE 8: Stormwater pumping stations

Pumping station	Maximum capacity m^3/hour	No of pumps	Pumps		Maximum total head (m)
			Type	Size (mm)	
SW1	19 500	3 + 1	Mixed flow	600	7.50
SW2	10 220	4 + 1	"	600	11.00
SW5	36 000	4 + 1	Mixed flow	1000	14.00
SW6	55 900	5 + 1	"	1000	12.50
SW7	55 300	5 + 1	"	1000	14.00
SW8	43 388	5 + 1	"	1000	7.00
SW9	64 580	6 + 1	"	1000	6.80
SW10	66 960	6 + 1	"	1000	7.00
SW11	37 800	5 + 1	"	1000	11.20

Standby generation

Standby generation has been provided at all pumping stations to ensure operation of the pumping equipment in the event of a failure of the main electrical supply. The large stations have separate structures housing the generator sets and high voltage switching systems to control the load to the pump motor demand.

In the interests of economy and to maintain a standby electrical supply in some of the smaller stations in Phase 1 a 200 amp 5 pin connecting socket and plug system has been introduced. To this plug a mobile generator can be connected to reinstate the power supply until the network mains is restored.

The type of generator installed is diesel engine driven. Each generator has its own day tank for oil and the generator station has a bulk oil tank for supplying the day tanks. Thus once called for during a power failure the standby generator can keep the station supplied with electricity for as long as is necessary.

6. SEWAGE TREATMENT

Phase 1

The six Phase 1 towns, Tripoli, Benghazi, Tobruk, Sebha, Misurata and Derna, are all provided with central sewage treatment facilities to which the town's sewage is pumped from one main pumping station in each case through pumping mains from three to eight kilometres long. Conventional biological filter plants are provided in each case with sludge digestion (heated at Tripoli and Benghazi and cold at the other towns) and drying on beds. Treatment is to the tertiary stage in each case. The biological filter process was chosen on grounds of simplicity and reliability, there being ample land available at the time.

The conventional stages of treatment adopted were:

Preliminary treatment	- comminution - detritus tanks
Primary treatment	- sedimentation tanks
Secondary treatment	- biological filters - recirculation - humus tanks
Tertiary treatment	- rapid gravity sand filters - prior chemical dosing - chlorination of filtrate (pre and post-chlorination at Benghazi)
Sludge digestion	- heated at Tripoli and Benghazi - cold at Derna, Tobruk, Misurata and Sebha
Sludge drying	- open with underdraining except at Sebha where underdrainage was omitted.

All plants have been successful in so far as design is concerned, but operational achievements are in proportion to the availability of sufficient and suitable staff, the larger works being the most successful. As with all progress, experience has suggested improvements for future designs, but mainly in terms of detail, except in the case of the tertiary plants where rapid gravity sand filters have proved too complex and sensitive to mal-operation. In the Phase 2 designs, microstrainers have been adopted for the two Benghazi Works.

Phase 2 - Benghazi

In the extensions to the existing Southern sewage works and the provision of new sewage treatment works to serve the northern half of the city, various sewage treatment processes were considered. The concept of stabilisation oxidation ponds was rejected on the grounds of environmental nuisance, land area required and the need to provide an impermeable lining to all agoons to prevent infiltration into the limestone aquifer was a major cost factor especially as the lining was required to be absolutely watertight to satisfy the stringent requirements of the Water Authority. This left the principal choice between percolating filters and an activated sludge plant for secondary processes. The other unit designs were based on conventional practice. It was felt that owing to the very limited operational experience on the existing works at Benghazi it would not be prudent to propose a change from the existing percolating filter system to the early stages of the extension.

The initial stages of the works include for percolating filters whilst for future stages it is proposed that the activated sludge process be adopted. In fact, due to the limited space available at the Southern Sewage Treatment Works, it will be essential in the future to adopt a less land-hungry process than percolating filters for the final extensions.

Southern treatment works - Guarchia

The proposed extensions to the treatment works at Guarchia are summarised in Table 9, together with the corresponding features of the proposed extensions of the works at Tripoli. It is not intended to expand on the description of the treatment units for each extension except where the units proposed provide a special interest.

TABLE 9: Units for proposed extensions to new and existing treatment works at Tripoli and Benghazi

	TRIPOLI Stage 2 (110 000 m^3/d) dwf	GUARCHIA, BENGHAZI (Southern works) Stages 2 and 3 (54 000 m^3/d) dwf	QUAFFIA, BENGHAZI (Northern works) Stages 1 and 2 (65 000 m^3/d) dwf
INITIAL TREATMENT			
Screening	6 no. 900 mm dia, comminutor 3 no. fine screens with disintegrator	3 no. fine screens (also serve Stage 1) with disintegrator	2 no. fine screens with disintegrator
Grit removal	2 no. 11.0 m dia. detritors	1 no. 10.0 m dia. detritor	1 no. 11.0 m dia. detritor
Grease removal	4 no. tanks 17.4m x 7.1m x 4.4m	-	-
PRIMARY TREATMENT			
Sedimentation tanks	8 no. tanks 42.7m dia x 2.0m deep	6 no. tanks 28.0m dia x 2.2m deep AND 4 no. tanks 18.3m dia x 2.4m deep (linked with Ph.1 sizing)	8 no. tanks 28.0m dia x 2.5m deep
SECONDARY TREATMENT			
Biological treatment	32 no. aeration pockets 17.0 x 17.0 x 5.0m deep with 50 hp motors	8 no. filter beds 205.0 x 34.0 x 2.0m with 3 no. distributor	12 no. filter beds 162.0 x 32.0 x 2.0m
Settling tanks	8 no. tanks 42.7m dia x 2.7m deep	6 no. tanks 28.0m dia x 2.2m deep AND 4 no. tanks 18.3m dia x 2.4m deep (linked to Ph.1 sizing)	8 no. tanks 28.0m dia x 2.5m deep
TERTIARY TREATMENT			
Microstrainers	-	11 no.5.0m x 3.0m dia	13 no.5.0m x 3.0m dia
Chlorination	Max. 12 mg/1	Max. 12 mg/1	Max. 12 mg/1
IRRIGATION			
Pumping	3 x dwf	3 x dwf	3 x dwf
Storage	3 days	3 days	3 days

/cont.....

Table 9 (cont...)

	TRIPOLI	GUARCHIA, BENGHAZI	QUAFFIA, BENGHAZI
SLUDGE TREATMENT			
Consolidation	2 no. tanks 15.8m dia x 4.5m deep	-	-
Storage	2 no. tanks 14.5m dia x 2.5m deep	-	-
Thickening	5 no.electroflotes 36m^2	-	-
Primary digestion	6 no. heated tanks 21.5m dia x 11.1m deep	4 no. heated tanks 18.0m dia x 10.8m deep	4 no. heated tanks 21.5m dia x 9.5m deep
Secondary digestion	3 no. unheated tanks 21.5m dia x 11.1m deep	2 no. unheated tanks 18.0m dia x 10.8m deep	2 no. unheated tanks 21.5m dia x 9.5m deep
Drying beds	54 bays each 20.0m x 40.0m	24 bays each 14.0m x 40.0m AND 20 bays each 17.5m x 40.0m	40 bays each 20.0m x 40.0m

The primary sedimentation tanks were of two sizes to permit the most economic use of available space left on the existing site following the Phase 1 works. Rectangular percolating filters were adopted to maximise the limited space available when all stages of the work were laid out. Experience with the Phase 1 rectangular filters was successful and encouraged their adoption again.

It has already been stated that the performance of the rapid gravity sand filters with the low level of operational/maintenance skills had resulted in continued mal-functioning of the tertiary treatment process. Micro-strainers will therefore be adopted for the polishing stage for these extensions.

Recirculation facilities are included to firstly ensure biological film activity during periods of low flow and further to overcome septic conditions in the primary sedimentation tank resulting from lengthy detention periods.

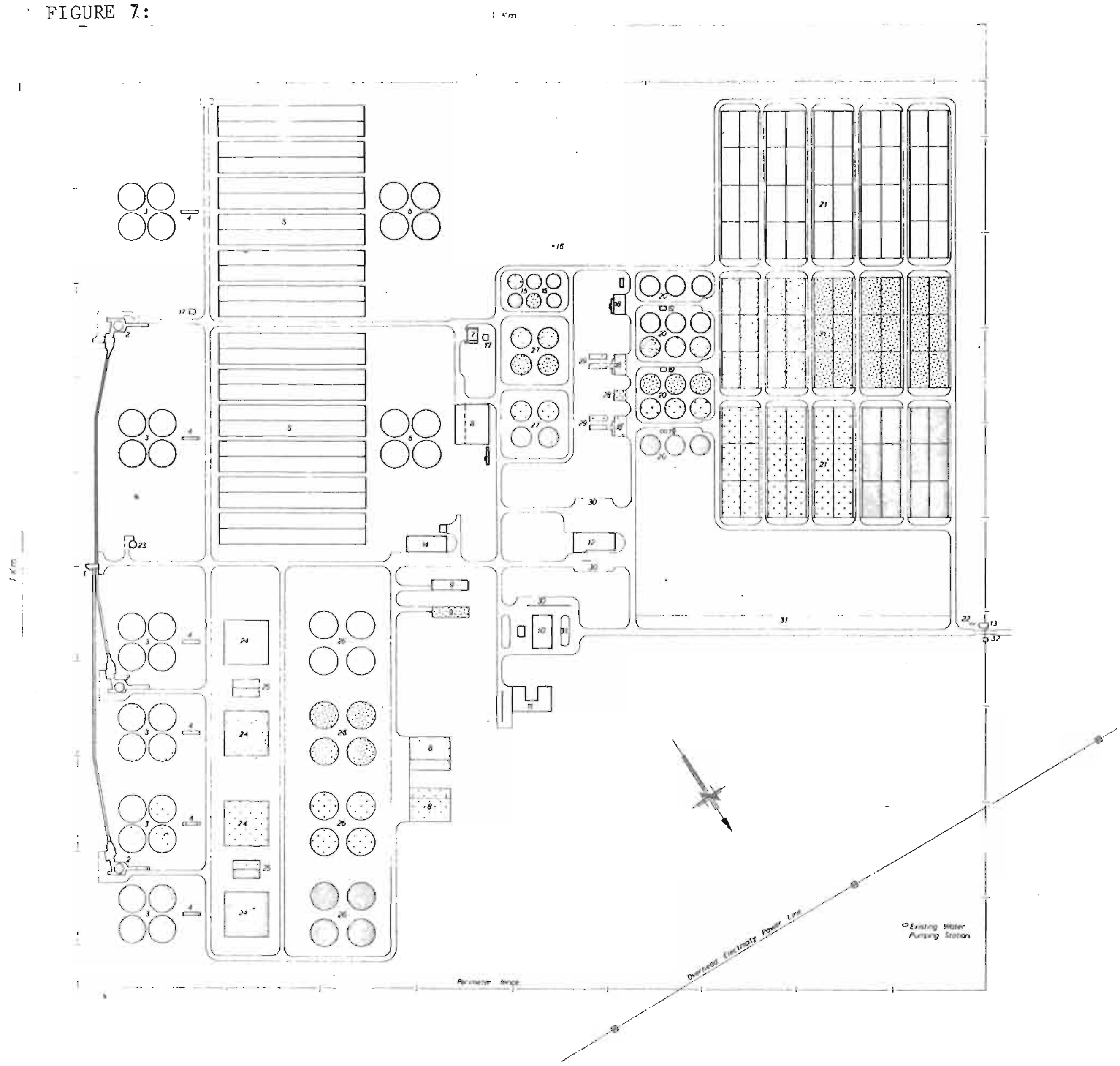
Northern sewage treatment works - Quaffia

Figure 7 shows the staged development of this sewage treatment works. The site chosen to the north east of the city is presently remote from development and on unused land.

The layout involves the distribution to each extreme of the works via long open channels where velocities are such as to ensure that grit is carried to the settlement basins. Future extensions to the works will employ the activated sludge process following the gaining of general works operation experience from the operation of the percolating filter plant. As for the Southern sewage treatment works, this works has a conventional heated sludge digestion system. For part of the summer months with high ambient temperatures, heating is not required.

Sludge for these early stages is dried on open sludge drying beds. The sludge drying beds design omits conventional media and underdrainage. The designed drying times for the Phase 1 works were considerably improved upon and following tests on paved areas it was found that evaporation drying was adequate with a minimum of floor run-off to achieve a spadeable sludge within a sludge drying cycle of 28 days. The absence of media and floor drainage permits mechanical lifting with a wheeled front loading bucket tractor.

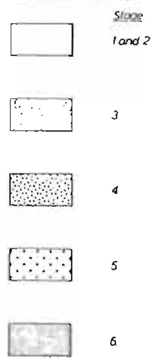
FIGURE 7:



WORKS UNITS & BUILDINGS

1 Flow Splitting Chamber
2 Inlet Works
3 Sedimentation Tanks
4 Filter Distribution Flumes
5 Filter Beds
6 Humus Tanks
7 Works Pumping Station
8 Microstrainer Building and Chlorine Store
9 Irrigation Pumping Station
10 Administration Building
11 Welfare Building
12 Workshop and Stores Building
13 Gatehouse
14 Generator Building
15 Gasholders
16 Waste Gas Burner
17 Electrical Switchgear Houses
18 Sludge Pump and Boiler House
19 Control House
20 Sludge Digestion Tanks
21 Sludge Drying Beds
22 Water Pumping Station
23 Water Tower
24 Aeration Tanks
25 Returned Activated Sludge Pumping Station
26 Final Settlement Tanks
27 Secondary Sludge Storage Tanks
28 Sludge Liquor and Washout Pumping Station
29 Secondary Sludge Thickeners
30 Parking Areas
31 Planted Areas
32 Shelter.

WORKS STAGE DETAILS



BLOCK PLAN
NORTHERN SEWAGE TREATMENT WORKS (QUAFFIA) BENGHAZI

Phase 2 - Tripoli

The operational experience of the Phase 1 works at Tripoli is more comprehensive although not available at the time of writing. However, at the design stage in 1973 of the Benghazi and Tripoli works, a senior member of the staff of the Water Research Centre was retained to take samples and analyse raw sewage, and for information the results of the investigation are given in Table 10. A typical effluent analysis is given in section 7 - Re-use of treated sewage (Table 11).

TABLE 10: Analysis of raw sewage at main inlet to sewage works (Tripoli)

Time	pH value	4-h PV	Temp (°C)	Flow (mgd) sewage	recirc.	SS	OrgC	COD	Amm N	KjN	BOD_3	BOD_5
10/7 Wednesday												
1715	7.0	48	27.6	11.5	3.1							
1815		No flow		5.7	3.0							
1915	6.9	39	26.6	12.0	3.0							
2015		No flow		3.3	3.9							
2115	6.8	42	25.4	12.4	1.7							
2215	6.8	38.5	25.6	13.2	2.0							
11/7 Thursday												
0715	6.8	40	25.2	8.5	3.5							
0815	6.7	43	26.2	14.5	3.7							
0915	6.6	31.5	27.2	13.0	2.5							
1015	7.0	41	27.6	12.5	4.0							
1115	6.8	41	27.6	16.7	2.2							
1215	6.8	36.5	28.0	14.8	3.5							
1315	6.8	32.5	28.0	8.0	2.4							
1415		No sample taken										
1515	6.8	40	28.6	16.3	0.4							
1615	7.1	25	28.0	14.0	0.8							
15/7 Monday												
0800}	7.1	53		12.4	3.7}	228	112	415	20	28		150
1000}				4.8	2.6}							
1200}	6.8	56		9.6	2.1}	228						
1400}				11.0	3.8}							
1600}	7.3	52		7.4	3.8}	184	117	385	23	35		170
1800}				7.0	4.0}							
2000	7.5	56		11.0	3.0	132						
2400		No flow			3.5							
0400		No sample taken										
17/7 Wednesday												
0800	7.1	57		9.5	3.9	192}						
1000	7.1	55		2.1	3.9	164}	127	385	23	28		140
1200	7.1	47		10.3	3.9	112}						
1400	7.1	32		10.1	4.0	196}						
1600	7.1	58		9.5	3.9	60}						
1800	7.2}	52		13.7	3.9	108}	141	385	30	37		129
2000	7.2}			10.2	3.2	240}						
2400	7.2	32		3.4	4.0	196}						
0400		No main flow		1.0	4.0							
19/7 Friday												
0800	7.2	60		9.6	4.1	390}					324	
1000	7.1	39		7.0	4.0	205}	160	505	23	33	254	90
1200	7.6	31		6.9	4.1	220}					234	
1400				1.9	3.9							
1600				0.9	4.0							
1800				2.8	4.0							
2000				1.2	4.0							
2400				0.8	4.0							
0400	7.0	54		3.1	4.0	180	68	285	24	33	215	143

Notes to table 10

All results are given in mg/l except where otherwise stated.
Flow from El Medina pumping station and pumping station B only.
Composites made according to sewage flow at works.

The crude sewage is much weaker than normal UK domestic sewage and is comparatively low in nitrogen. The strength of the sewage is probably due to a lower BOD/capita, a high water usage and in the old network groundwater infiltration.

The works have been designed on the basis of sewage strengths of 300 mg/l BOD with SS content of 350 mg/l which it is anticipated will eventually occur in Tripoli. Although Tripoli is a large works it will be served by numerous small pumping stations draining areas with low times of concentration. A figure of 3 dwf for peak flows was adopted for the hydraulic design of the sewage treatment works, together with an allowance of ½ dwf for returned operational flows.

The layout of the works is shown on figure 8 together with a flow diagram (figure 9). The proposals include grease removal tanks to overcome the grease/oil problems occuring on the existing Phase 1 works. The sedimentation tanks, eight in number with a diameter of 42.7 m, have triple arm scraper blades to ensure rapid evacuation of the sludge.

The secondary treatment uses the activated sludge process with air applied by electrically driven vertical axis surface rotors. Control and performance is automatic using dissolved oxygen probles actuating weir draw-offs. The final settling tanks are similar to the primary sedimentation tanks but are flat bottomed. The sludge evacuation is by vacuum lift. The surplus activated sludge is gravity thickened before flotation thickening to increase the d.s. content to 4%. The thickened sludge is then mixed with the primary sludge before conventional heated digestion.

As for the Benghazi works, Tripoli will have concrete bottomed sludge drying beds with no underdrainage system. Initially, design for the works included tertiary treatment using microstrainers, but following discussions with the Agricultural Project Authorities and their consultants, the Client instructed the omission of these units. The designed effluent standards from the final tank with chlorination, 15 mg/l BOD 20 mg/l SS was felt to be adequate for the irrigation requirements for the particular arrangements planned. Standby generation has been provided at this works and the two in Benghazi.

Comparison

From the very brief description of the sewage treatment works in the previous paragraphs it will be obvious that there are certain differences between the provisions made at the various works. Differences of approach depend on local circumstances as is well known, although there needs to be a common aim within one country where possible. It may be useful here to explain the reasons behind some of the major decisions and the reasons for variation in process design between the two major cities.

Screening

The contents of the sewage at Tripoli occasionally contain excess of particular screening matter and maceration of this excess has not always been complete. There has been a tendency for stringing of the screenings to build up downstream. It was felt that a second stage screening and disintegration would overcome this problem.

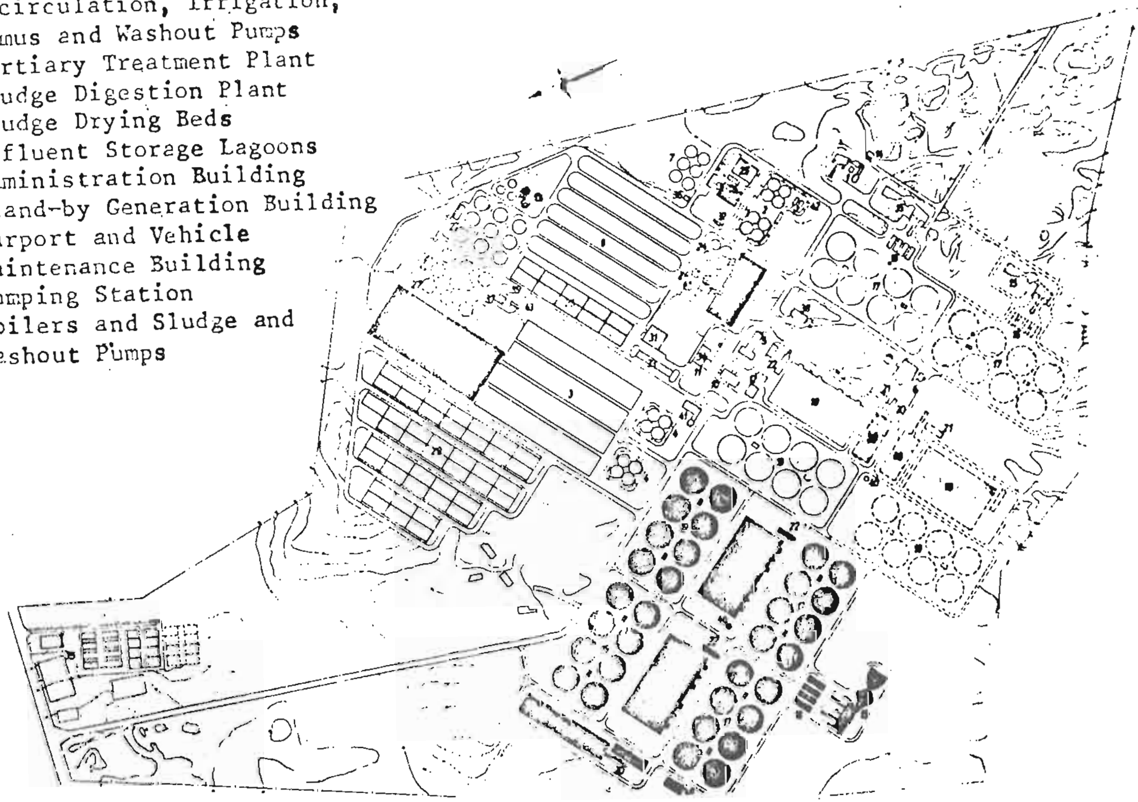
However, at Benghazi a single stage screening and maceration unit was proposed as being adequate. A further stage could be introduced if the same problem occurs here.

Existing Treatment Works

1 Inlet Works
2 Primary Sedimentation Tanks
3 Filter Beds
4 Humus Tanks
5 Pumping Station Recirculation, Irrigation, Humus and Washout Pumps
6 Tertiary Treatment Plant
7 Sludge Digestion Plant
8 Sludge Drying Beds
9 Effluent Storage Lagoons
10 Administration Building
11 Stand-by Generation Building
12 Carport and Vehicle Maintenance Building
13 Pumping Station Boilers and Sludge and Washout Pumps

Key

Existing Phase 1 Treatment Units
Proposed Phase 1 Treatment Units
Stage 1
Stage 2
Stage 3 & 4

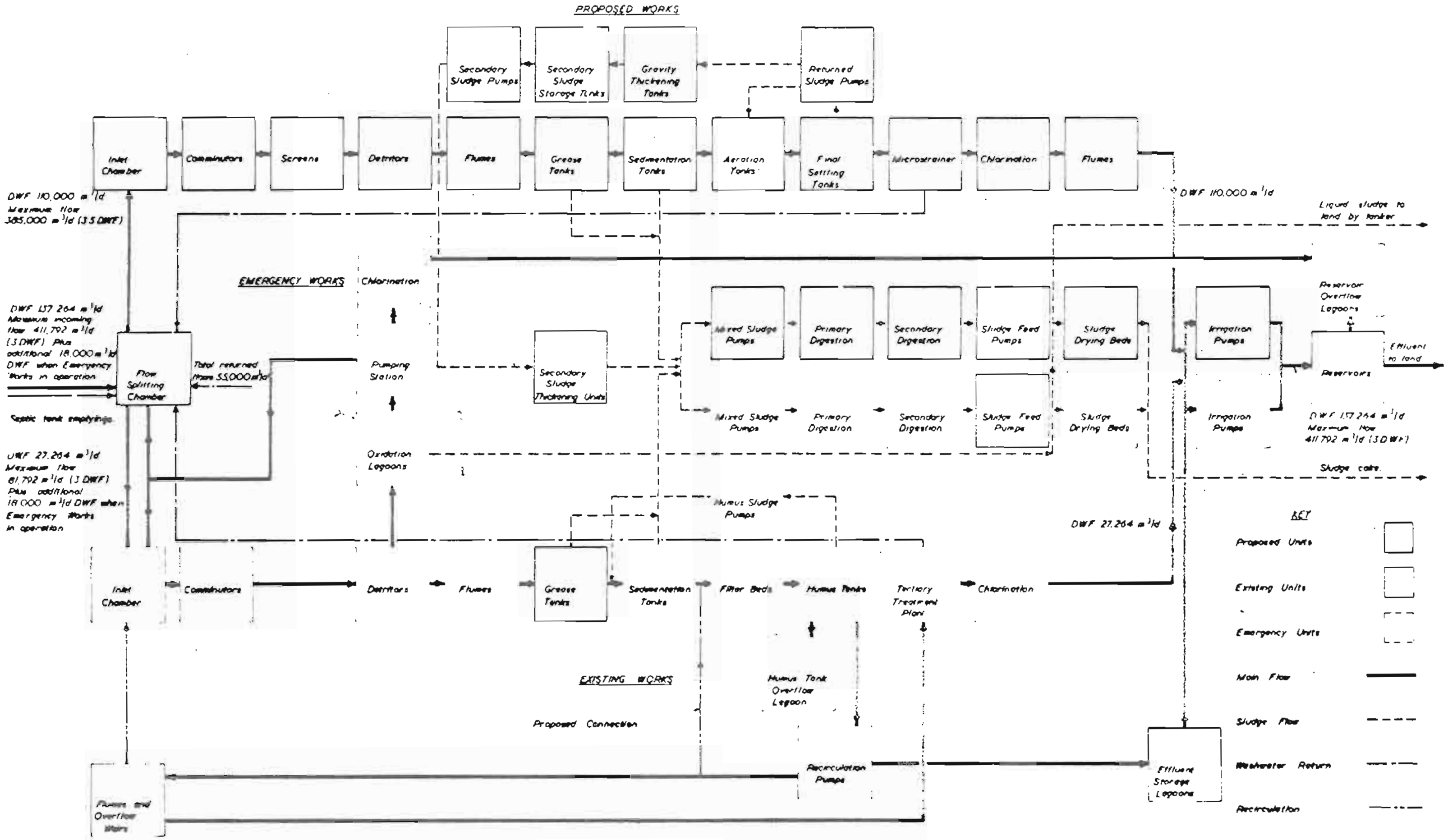


Proposed Treatment Units

14 Flow Splitting Chamber
15 Inlet Works
16 Grease Tanks
17 Primary Sedimentation Tanks
18 Aeration Tanks
19 Final Settling Tanks
20 Measuring Flumes
21 Chlorination House
22 Pumping Station Returned Activated Sludge Pumps
23 Secondary Sludge Gravity Thickening Tanks
24 Secondary Sludge Storage Tanks
25 Secondary Sludge Thickening Units
26 Pumping Station Mixed Sludge Pumps
27 Sludge Digestion Plant
28 Gasholders
29 Sludge Drying Beds
30 Microstrainer House
31 Main Workshop and Stores Building
32 Pumping Station Secondary Sludge Feed Liquor Pumps
33 Carport
34 Stand-by Generation Building
35 Site Houses
36 Pumping Station Digestion D
36 Pumping Station Digestion Sludge Pumps
37 Pumping Station Digestion Sludge Pumps
38 Pumping Station Irrigation Pumps
39 Pumping Station No.9 Digestion Plant Washout Pumps
40 Pumping Station Washout Pumps
41 Instrumentation Centre
42 Grease Tanks
43 Sludge Tanker Filling Bay
44 Area for Future Sludge Dewatering

Figure No. B

BLOCK PLAN
SEWAGE TREATMENT WORKS-TRIPOLI



FLOW DIAGRAM

SEWAGE TREATMENT WORKS - TRIPOLI

Figure No. 9

Grease removal tanks

Tripoli has experienced large build up of oils and grease at the sedimentation tank. To reduce this nuisance grease removal tanks have been incorporated in the design.

Secondary treatment

The comparison of advantages and disadvantages of percolating filter bed and activated sludge plants are well documented. The dominant factor that prompted the adoption of percolating filters for Benghazi works was the lack of specialist skills necessary for the successful operation of the A.S. treatment plant, especially in view of the need to maintain the necessary standards for irrigation water.

The reverse of this argument applied for Tripoli where it was felt that the operational expertise established over the year permitted the use of the activated sludge process. A process more suitable and economic for an extension of this size. Space problems were also pressing at Tripoli.

Effluent standards tertiary treatment

One could spend much time on arguing the virtues of providing various standards of water for irrigation. Many parts of the world use crude sewage for soil improvement and it is not many years since this was practised in the UK. However, the argument has always lain in making the effluent as safe as possible, especially if there is any likelihood of misuse and mistaken identity.

The reasons for the lower standard at Tripoli is that the sewage effluent will be used for the production of fodder crops under Municipal control as a managed system and not, as is present practice in Tripoli and projected for Benghazi, to provide irrigation water to farms.

Sea disposal

The opponents of sewage treatment for seaboard towns will ask why long sea outfalls were not considered. The overall policy of the Government has been one of re-use to supplement the dwindling supplies of potable water at present used in vast quantities for irrigation. In addition those familiar with the Mediterranean sea coast of Southern Europe will be only too aware of the problems of sea disposal within an almost land locked sea.

7. RE-USE OF TREATED SEWAGE

General

In Libya water is at a premium there being low rainfall, few rivers and limited groundwater resources in most areas. In spite of this agriculture was important in times past. With the advent of oil the drift from agriculture accelerated, but Government policy is reversing this trend and agricultural development is a very high priority. In the current five-year plan a high percentage of funds is earmarked for such development.

Policy is, therefore, to conserve water resources and the question of re-use is important. Part of this policy is to use treated sewage for irrigation purposes and where possible farms are being established near to sewage treatment works as part of the general countrywide farm development programme. The six Phase 1 works were therefore all designed with this in view, but so far effluent has only been used at Sebha and Tripoli due to the fact that farms have yet to be established in those areas. Of these two, the Author has knowledge only of the Tripoli scheme and even then not extensive as he has not been involved in the project beyond the stage of the effluent storage reservoirs. The policy of re-use for irrigation purposes has continued on the Phase 2 schemes.

Quality of treated effluent

The two most important aspects of quality of water for irrigation use are those relating to health risk and suitability for crop production. The former, although the more serious in relation to human life than the latter, is the most difficult of the two to deal with since much research work still needs to be done in this field and generally acceptable standards have not been settled. Some authorities, such as in India and America, have set their own standards, but these are few and in view of the increasing need to re-use treated sewage, there is an urgent requirement for research resulting in the fixing of standards in respect of health risk.

In the case of Libya the use of sewage effluent will be under controlled conditions at Government farms where piped potable water supplies will be available so that risk to health will be at a minimum; but still a risk.

The plans for irrigation projects were not very advanced at the Phase 1 treatment work design stage and the type of crop to be grown, irrigation techniques etc were not known, but decisions on treatment standards had to be taken. It was decided to design for treatment to a standard of effluent of 10 mg/l for both BOD and SS followed by chlorination to give an initial residual of 1.5 mg/l. These arrangements have apparently proved satisfactory at Tripoli since the initial proposals for a continuation of this standard for Phase 2 were accepted. A subsequent decision by the irrigation authorities to switch to fodder crops only led them to reduce their requirements to 15:20 standard.

Effluent quality in terms of the parameters which affect its usability for irrigation is largely predetermined by the raw sewage constituents. The one causing most concern in Libya is salinity which affects the majority of crops in varying degrees. Crops will be injured if there is an accumulation of salt in the root zone as a result of poor drainage, inadequate irrigation or use of water which is too salty. Other constituents and parameters such as sodium have to be taken into account, of course. It is difficult to predict what may take place in the complex mineral constituents of most soils, five factors being important:

- The ease with which the soil will take water.
- The drainage characteristics of the soil.
- The rate of application of irrigation water sufficient to prevent salt accumulation in the crop root zone.
- Crop tolerance to constituents of the water.
- The need for skilled agricultural management.

Because of the variability and uncertain inter-relation of the above factors, any standards set are merely guidelines and experimentation is necessary to establish what can be achieved with any particular water. The following guide given by the Salinity Laboratory of the United States Department of Agriculture was used in considering the potential of treated sewage effluent for irrigation purposes in Libya. Salinity is measured here in terms of electrical conductivity (micromhos per centimetre at 25^{o}C).

	Electrical conductivity (mmhos/cm 25°C)
Low salinity water - Can be used for irrigation with most crops on most soils	0 to 250
Medium salinity water - Plants with moderate salt tolerance can be grown	250 to 750
High salinity water - Permissible but only plants with high salt tolerance can be grown. Unsatisfactory where soil drainage is restricted.	750 to 2250
Very high salinity water - Not usually suitable for irrigation unless drainage is adequate, irrigation water is applied in quantities adequate to provide considerable leaching and very salt tolerant crops are grown.	2250 to 5000

The predicted salinity levels for treated effluents in the six towns were:

	Electrical conductivity mmhos/cm
Benghazi	3000
Tripoli	1500
Tobruk	1500
Derna	750
Misurata	1500
Sebha	1000

The figures for Benghazi are marginally acceptable, but with good management techniques and appropriately selected crops success could be reasonably expected.

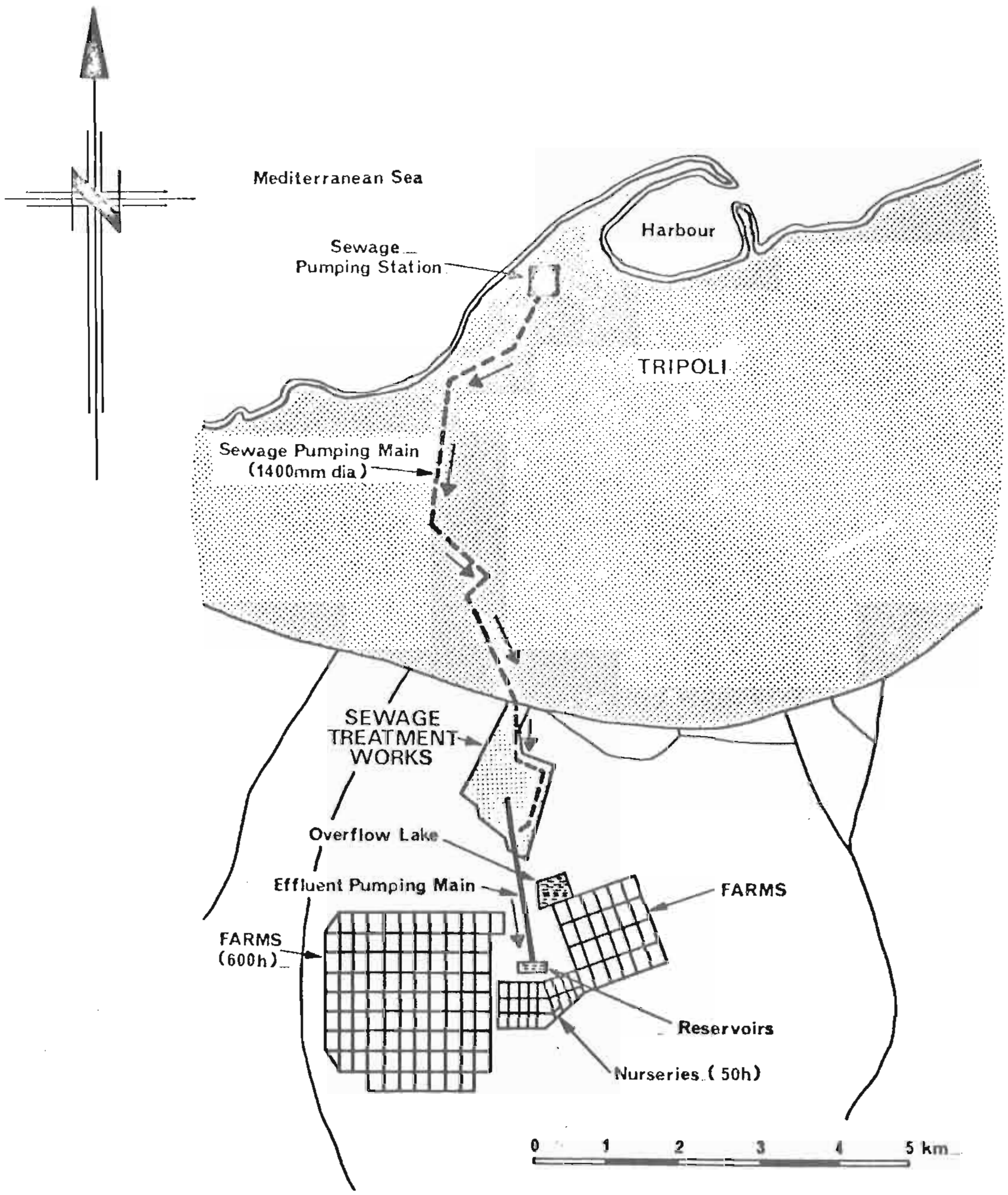
Data on actual daily salinities being experienced at Tripoli are not available, but an average appears to be 1000 mmhos/cm.

At Benghazi the current circumstances are unusual and temporary, various factors contributing to produce a very high salinity level. Due to over-pumping of groundwater the water supply is at present of the order of 4000 mmhos/cm. In addition, groundwater of very high salinity from contractors excavations is being disposed of to the sewers because of the difficulty of using other methods of disposal. This has been acceptable since water has not been required for irrigation. Figures of up to 5000 mmhos/cm have been reported for the treated effluent. However, there is now a need to reduce the salinity levels to permit the use of the effluent for irrigation.

Use of treated sewage at Tripoli

Only at Tripoli has re-use progressed to any significant extent, where farms have been set up, each six hectares and where a family lives and works. In addition to the farms (total area 600 hectares) there are 65 hectares of fodder crops and 50 hectares of nurseries. The area is continuing to expand but the supply of effluent is at the moment limited to 27 400 m^3 per day, the output of the Phase 1 works. The proposed extensions to the treatment works will add a further 110 000 m^3/day, but will not be available for at least 3 years. The layout of the present project is shown in figure 10. The crops which have been successfully produced are vegetables, citrus and other fruits, wheat, barley and alfalfa grass for cattle fodder.

FIGURE 10: Irrigation area - Tripoli



Typical analysis of the effluent is shown on Table 11. Data obtained on 18th July 1974 for chlorinated effluent gave free chlorine as varying between 0.2 and 1.2 mg/l during the day.

TABLE 11: Typical treated sewage analysis (Tripoli 1969)

	Final effluent (lagoons)		
(Results in milligrammes/litre)			
Alkalinity as calcium carbonate	225		
Hardness	310		
Carbonate	225		
Non-carbonate	85		
Dissolved solids dried @ 180°C	980		
Suspended solids	8		
Suspended solids volatile	-		
Oxygen absorbed (permanganate)	5.0		
BOD	7.0		
Ammoniacal nitrogen	6.6		
Albuminoid nitrogen	0.25		
Nitrite nitrogen	0.6		
Nitrate nitrogen	16.0		
pH	8.6		
Chloride	295		
Anionic synthetic detergent (manoxol O.T.)	5		
Iron	0.06		
Zinc	0.10		
Copper	Nil		
Lead	Nil		
Manganese	Nil		
Boron	0.5		
Electrical conductivity (micromhos/cm @ 25°C)	1450	1389	1600
(Results in milliequivalents/litre)			
Cations			
Calcium (Ca)	3.5	3.65	4.1
Magnesium (Mg)	3.2	3.45	3.8
Sodium (Na)	6.1	7.2	8.7
Potassium (K)	0.51	0.49	0.62
Anions			
*Carbonates (CO_3)	5.4	4.7	4.3
Sulphates (SO_4)	1.8	2.0	2.5
Chloride (Cl)	6.3	6.6	9.9
Nitrates (NO_3)	0.66	0.69	0.93

*Bicarbonate expressed as carbonate.

In general the irrigation has been a success and as already mentioned the effluent from the Phase 2 extensions will be used to provide irrigation water for a new area of some 2000 hectares. This area will use production farming to supply fodder crops only.

It has been argued that with a stricter control on the use of this effluent that a marginal reduction in effluent quality could be tolerated at the expense of a lessening of the certainty of adequate bacterial kill. This approach has been adopted and the effluent to be used for irrigation will be chlorinated final tank effluent.

8. CONTRACT DOCUMENTS

The subject of contract documents could form a paper on its own there being many problems which can arise during the course of a contract due to shortcomings in them. It is proposed here only to include some specific items which may be of particular interest in the total content of public health engineering.

All contracts on the Libyan projects so far have been on a fixed price and re-measure basis, the document comprising

- drawings
- conditions of tender
- form of tender
- conditions of contract
- specification
- bills of quantities

The conditions of contract have been based on the "Conditions of Contract (International) for Works of Civil Engineering Construction" prepared by the Federation Internationale du Ingenieurs - Conseils jointly with the Federation Internationale du Batiment et des Travaux Publics (FIDIC). These have been amended in certain respects and extended to suit local conditions and the requirements of the authorities.

All documents are required to be in Arabic which is the ruling language of the contract, but corresponding documents in the English language are issued to facilitate use by foreign contractors and indeed to assist generally in the understanding of technical terms which are difficult to translate into Arabic. Great care is necessary in translations as inaccuracies can be costly as well as confusing. In respect of drawings both Arabic and English were used together. Sewer sections involved hundreds of sheets of drawings which included a small number of repetitive words and notes such as "gradient", "pipe size", "concrete bedding" etc. which lent itself to a system of symbols which avoided translation except the key which described them. The sets of drawings were reduced in size and bound into books for tendering purposes and for general use.

Every contract allows for a mobilisation period of 2 or 3 months prior to the execution period which is made up of the construction period and the preliminary take-over period. The latter is a period during which the employer has an obligation to inspect the work and take it over and the contractor has an obligation to complete the work and to a standard acceptable for take-over. The provision has been included in the Phase 2 contracts to ensure rapid conclusion by all parties to a contract programme. Prior to such provisions take-over took place after the contract completion date and often continued for very extended periods.

Also based on previous experience and with the object of "pacing" the contractors" progress and also to keep the contractors' activities within reasonable physical bounds, the contracts are divided in sections each with a different completion time from the contract commencement date. Liquidated damages are payable for delay in the completion of any section.

"Simplicity" is a key word in the engineering of projects in developing countries and this applies not only to design but to other matters including contract documents. The application of this principle to the bills of quantities has been found to be advantageous to the expedition of the project as a whole and the total number of items has been reduced by aggregrating them. For instance the concrete items include in one item for the concrete, steel, shuttering, mortices, splays, small buxouts etc. This principle has been successful but the preliminary notes to the bills of quantities need to be very full and carefully written to ensure that the tenderer knows exactly what he has to be included in his rates.

It has been found that contractors often do not appreciate the need for special techniques and in some instances the contract documents have included a description of the method which the contractor would be required to use. An example of this is the construction of the twin 4 metre by 2 metre deep culvert across Sebca (lagoon deposits) areas at Benghazi where difficult dewatering and ground stability problems exist. The details included the specification of sheet piling and the minimum depth they were to be driven.

A feature of the Benghazi project is the very extensive site investigation and report mentioned elsewhere. This report was available to tenderers and gave invaluable assistance to them in tendering. In addition the contract documents themselves included borehole details relevant to the contract area as well as a geotechnical appreciation.

Regarding the conditions of contract, a few points of special interest may be mentioned. Clause 10 of the FIDIC Conditions has been modified to exclude the reference to the tender being based on data on hydrological climatic and physical conditions supplied by the employer. This was considered inappropriate to the present schemes where the contractor is able to ascertain reasonably closely the conditions under which he would have to work. No extension of time is allowed except for reasons of additional work, any extension to be based pro rata on the value of the additional work. The international arbitration clause is deleted and disputes are to be settled by reference to arbitration in Libya.

Experience has shown that local conditions make strong management essential for success. This has not always been realised by contractors and many have failed to achieve good results as a consequence. All Phase 2 contract documents therefore include a requirement for the contractor to provide a separate contract management team of appropriately experienced men to monitor progress and activities and advise the contractor's project manager.

In Phase 1 the principle of separate civil engineering and machinery contracts was adopted and on some projects the machinery was broken down into separate contracts for each type of plant. The problems of co-ordination were enormous. The Phase 2 contracts are therefore generally in the form of omnibus contracts to include everything.

9. CONSTRUCTION

General

The construction methods used and the problems experienced cover a field too large to be dealt with here to any significant extent, but certain features will be brought out which it is hoped will be of interest. It is perhaps important first to get the perspective right by realising the enormity of the task of installing drainage systems in fast growing towns where the need is not only to provide facilities for currently developing areas but to catch up on providing them in the older areas where streets are impossibly narrow and general congestion is the norm. Even if the funds for such expensive utilities are available, the physical disruption to the towns as a whole can set a limit on the rate at which construction can be accepted without serious breakdown. Where all the other utilities are also being renewed or installed at the same time, the effects on the life of the community can be imagined.

A major problem has been the control of dust raised during the moving of excavated soil and from temporary diversion roads in built up areas. This may seem strange in a land of natural dust storms but these are not as frequent as sometimes imagined. The re-routing of heavy traffic volumes for long periods through areas not planned for it also causes great inconvenience to the public and tests its patience to the limit. The limits are sometimes over-reached and the contractors with others concerned come in for some heavy criticism; some justified and some not.

Added to this are the effects of the difficulty of supplies of plant, materials, labour and skills generally, possibly further aggravated by unstable international political conditions. For good measure, climatic conditions may be thrown in. To continue in the pessimistic vein before going on to show that the impossible is possible if a determined approach is adopted, one could add to the list the problems of communications, acquisition and temporary occupation of land, ultimate taking over of projects, road closures and traffic diversions, lack of approved planning layouts, drying up of funds, hesitancy in decision-making, and delays in delivery of materials through port and other delays. Most of these factors are to be expected in any country where rapid development is taking place as they are a consequence of the "mushrooming" situation.

Many a tale may be told of unusual problems met during construction such as the dump of hundreds of all mustard gas bombs, buried in the sand, accidentally scooped up by the digger and the D8 which ran over a land mine and had its tracks blown off. The bombs held progress of a large culvert up for 12 months. Fortunately such warlike incidents are now very infrequent and it is more likely that a thrilling archeological find may be made revealing a Roman or Greek artefact to add to the wealth of the historic interest which exists in Libya. One way or another, in order to achieve objectives there is a need for constant alertness and application of effort and skill by the engineer.

The question of communications, or lack of them, causes great difficulty both on the site and between towns and countries, and much thought and planning is necessary in overcoming the resulting problems. On site it has been necessary to set up VHF radio and messenger systems to cover the work which can be extended over a very wide area. The international communications problem is improving with the increasing availability of the telex system. Communication by cable has been surprisingly good but telephone links are not.

In general, once a contract is signed the process of mobilising to full production is fairly slow. As the largest and most recent project, Benghazi again provides the most fruitful field for illustrative examples.

Contractors

The work is of a size which should interest international contractors but this has not been the case to a great extent. So far the nationality of contractors who have been involved in drainage work are, Libyan, Tunisian, Egyptian, Bulgarian, Yugoslav, Italian, Greek, Turkish, French, German, Lebanese and British. British contractors have been mainly concerned with machinery contracts, only one having carried out a civil engineering contract in Tobruk between 1963 and 1965. Local contractors have come more to the fore in recent years and have given creditable performance, being prepared to listen to advice and learn from experience. All contractors seem under local conditions to require a great deal of supervision and strong guidance. No doubt they take the brunt of the site problems particularly in built-up areas where their personnel are in the "front line" facing the public and police.

With a few exceptions the standards achieved are very good and sometimes outstanding in view of all the circumstances. This is a result of not only their own efforts but of the supervising engineers. Their methods of working in narrow streets can often be rather haphazard in respect of excavation work and it is here that maximum inconvenience to the public can be caused and evoke complaints.

The problem of manpower has been previously mentioned. This problem extends throughout all levels and even local contractors are staffed with mainly expatriate personnel which may consist of half a dozen nationalities. Management is often not of the highest calibre and advanced techniques such as critical path planning are not used although the sewage works contracts will require such control.

Construction plant employed is generally of good quality and is often new. The problem of keeping it in good running order is ever-present as conditions are arduous and maintenance difficult due to lack of spares and quality of mechanics. Drivers can also be heavy-handed and brutal with their machines.

Sewerage

Ground conditions are very variable being in hard limestone rock, rock with fissures carrying large quantities of water, firm dry clayey sand, silty ground with high water table and dry loose sand with boulders which hinder the driving of trench sheeting. Locations range from old narrow streets with ancient buildings with poor foundations to open areas, where sometimes even the road layout has not been settled!

The limestone rock is very variable in hardness and in certain areas where blasting was not permitted the normal rate of progress was reduced to a quarter and breacher points were being consumed by the hundred. The problem was so extreme that the contractor claimed a considerable amount for unforseeable physical conditions. The same contractor was also unfortunate enough to have to work in an area where there were a number of fissures in the limestone rock and had to deal with considerable quantities of water requiring many pumps.

In the areas lying close to the sea where the ground was silty sand with groundwater not far below ground level, sewer construction is difficult and only in some places is it possible to dewater by well point due to the fineness of the silt. Close sheet piling (or trench sheeting) with internal pumping has been the usual method adopted. Care not to draw down the groundwater table over a wide area is necessary so as to reduce the chance of the subsidence of buildings. Thus it is necessary to restrict the length of trench opened. Cases have occurred of subsidence and in one or two cases buildings have had to be evacuated. Many spurious claims by property owners have been made and cracks are pointed to which obviously originated many years ago.

Trench excavation is usually carried out by machine with final bottoming manually executed. Where necessary the trench sides are supported by timber or metal sheeting. In narrow streets and alleys excavation is by hand and all excavated material is removed. Extreme problems arise when a narrow alley contains septic tanks which have to be emptied, sterilized and broken out to permit the sewer to be laid. Meanwhile the flow from the property must be dealt with.

Where bitumen macadam road surfaces have to be broken out the specifications require that the metal be cut on the lines of proposed trench sides. This provides a neat edge to receive the final reinstatement.

Trench backfilling is an important part of the operation and good compaction is insisted upon in order to avoid subsidences which can cause danger to traffic, particularly during the rainy season. The road authorities and the police take a serious view of the condition of trench reinstatement.

Pipes have been laid on concrete, sand or granular beds. The sand is dune sand and being fine care in its case is necessary. Granular fill is crushed limestone being a 50/50 mix of 20 mm and 40 mm stone. This had proved successful particularly in excessive groundwater conditions and can be compacted by the labour with a rammer. Sand is not used below ground-water level.

Pipelaying with asbestos cement pipes has now been proceeding in Libya almost continuously for 12 years and has proved to be an easy pipe to lay and pass watertightness tests successfully. All sizes up to 2000 man diameter have been used, the larger sizes being initially developed for the Benghazi project some years ago by the Lebanese factory. On the larger pipes junctions are made by cutting holes in the pipe with a special machine and joining the saddle to the main pipe with epozy resin adhesive. This has proved a neat and successful method, the original method being to bolt the saddle on to the main pipe.

Supplies of asbestos cement pipes are currently coming from the Lebanon, Germany, Italy, Austria and Belgium. Asbestos cement pipes are made in Libya but with ordinary partland cement and are not lined. Damage to pipes in transit varies, but on the whole only a small percentage are affected. The larger pipes suffer most and great care in lifting them is necessary.

One of the contractor's biggest headaches is the illicit connection of properties by their owners before construction is complete. Not only does this practice create a danger and interfere with progress but it creates problems of inspection and take-over. At peak production a total rate of laying by three contractors of some seven kilometres in a month has been reached.

Plastic pipes are sometimes used for property and road gully connections.

The main pumping station at Benghazi was constructed in Phase 1 by driving a ring of sheet piles into the rock, supported by reinforced concrete ring beams. Although the water table was high, little pumping was necessary. The rectangular station was built inside the piles. No leaks have appeared in the station so far.

The two large stormwater pumping stations SW1 and SW2 in Sebka deposits were built by the diaphragm wall method using bentonite. This speeded up their construction considerably although there were many snags. Other smaller, circular stations were also built in this way.

Culvert construction

Two three-year contracts have recently been completed in Benghazi comprising a total of 23 kilometres of reinforced concrete culvert of sizes ranging from twin 4m x 2½m to 2m square. The work was carried out by Greek and Turkish Cypriot contractors respectively. The work had basically two aspects; major excavation and major structural work. Depths of excavation reached 10 metres and in parts the whole carriageway was removed. Much of the work was fortunately in dry sandy clay which presented no particular problem except when existing water mains followed the edges of the excavation which caused subsidences in parts resulting in fractures and discharge into the excavation. A substantial length was in hard rock and initially blasting was envisaged. Test blasts were carried out and the effects checked by vibrograph readings which were negligible. However, the granting of permission to blast as a routine was protracted and the contractor elected to use compressors.

It was important with such deep and wide excavation in important highways to ensure that backfilling was carried out carefully to obtain good compaction to provide a stable road base. The specification which detailed the methods to be used included for density testing to achieve a result of 95% of the B.S. standard test result.

Dewatering was generally by pumping with 6"/8" electric or 4"/6" diesel pumps from sumps within the excavation fed by side drains. The Hudig well point system was tried in one place but was unsuccessful because the tubes could not penetrate the rock layer and therefore could not be placed deep enough to draw down the water table.

Across the Sebka areas in the highly sensitive clay interlocking sheet steel piling was used and driven into the porous rock (calcarenite). Wells were sunk into the rock at intervals outside the sheeting and pumps dewatered through the rock. The disposal of excavation water was a constant problem and where available existing sewers were used after the settlement of sediment in tanks. On occasions a pipe system had to be laid to carry the water sometimes up to 500 metres.

The quantities of concrete to be placed in floors, walls and roofs (separate operations) were considerable and good planning and control was necessary. The length of section was 30 metres and the floor or roof of a twin 4 metre wide by 2½ metre deep culvert contained 165 m^3. Both contractors used central batching plants of $50m^3$/hour and $70m^3$/hour in conjunction with five transit mixers serving each hour. One contractor used concrete pumps in conjunction with skip placing only. The maximum quantity placed by one contractor in a day was $300m^3$.

Specially designed shuttering was imported by both contractors, both systems using a track on which the shuttering could be rolled on to the next section. This facility was rarely used in practice and lifting by crane was employed.

Sewage treatment works

There has been no experience of treatment works construction for some years since the main work on the Phase 1 project at the Guarchia site was completed, but it may be of interest to recall a few aspects although the work was carried out in a mainly conventional manner.

The experience of having seven machinery contractors and a civil engineering contractor involved on one site has led to the conclusion that one composite contract is to be preferred or at the most one civil engineering and one machinery contract.

The circular dry stone wall filters at Tobruk, Sebkah, Misurata and Derna proved successful in that they employed local materials and avoided the potential cracking problem of the reinforced concrete walled filter.

The filter media available in Libya is a limestone and careful selection is necessary to ensure the achievement of test results called for by the British Standard. Wadistone is often the most suitable if in large enough quantities. This was not so in Benghazi and quarried stone was used. Tests on media stone were initially carried out in the UK and it was necessary to send heavy bulky samples by air freight. Also at the peak of production the quantity to be tested was more than the UK laboratories could cope with in a reasonable time. Arrangements were therefore made on site for testing facilities using the rapid method developed by the Water Research Centre. After some experimentation to overcome technical problems such as control of both temperature, a successful routine was achieved.

Fine stone and dust are a problem and careful sieving and probably washing is necessary. Placing methods must be carefully planned and an arrangement for further dust removal at the bed immediately prior to placing was found necessary at Benghazi.

The curing of concrete in the hot season is important and membrane curing has been used with success. The very hot conditions at Sebka created particularly difficult problems of shrinkage and cracking.

Floor screeds on the conical floor of tanks have given problems in terms of accuracy of profile and crazing. It is probably best to wait for the scraper bridges and arms to be erected so that they can be used to help set the finished screed levels.

Site investigations

A proposal that an extensive site investigation should be carried out at Benghazi was accepted, and great credit is due to the authorities for being prepared to proceed with a necessary, but not always seen as such, basic investigation.

At a cost of £580 000 a contract for 18 months was let in 1974 to carry out 5000 metres of drilling in 500 boreholes. At peak production 600 metres were drilled in a day. Detailed logging, core analysis, an appreciation and a detailed report in English and Arabic was also required. The contract was let to a Yugoslav firm and difficulties arose over language and differences between Yugoslav and British terminology and practices. Conversion to Arabic can be imagined. After much effort by the consulting engineer's staff things were straightened out. The information was required to permit design work and to assist contractors tendering. The work also supplies useful data for other projects and provides information on the geology of Benghazi. Even this contract had its problems with rigs being ejected from private land, bogged down in mud and even catching fire.

10. OPERATION AND MAINTENANCE

General

From the inception of all the Phase 1 projects it was obvious that a large problem would present itself when the time came for the authorities to take over the installations and operate them. With no tradition of skills in the water pollution control field, coupled with an overall situation in which the supply of skilled men and indeed unskilled men was almost non-existent, the prospect of operating and maintaining such extensive systems was daunting. Also, no professionally qualified men experienced in water pollution engineering of local origin existed. The need for training was obvious, but even if training was instituted it was clear that a comparatively large proportion of the operating staff would have to be imported from outside Libya. Also, the organisation and resources required to manage and support operating staff required to be built since even where an embryo organisation existed it was not sufficiently strong to form a basis of the larger structure required for the new project.

At an early stage a report on requirements was made to the authorities, but serious difficulties always seemed to present themselves and obstruct positive action. In the case of one of the smaller projects, two men were sent to Britain for training on sewage treatment works. The exercise was basically successful and the two men returned to produce results which were good, having regard to the fact that they were hampered by being the only two with any "feel" for running a works among many who, understandably, were without it.

In the case of Tripoli, eighteen skilled men were sent to Britain for training at various sewage treatment works, but within a few months of their return had turned to fields other than that of water pollution control. Most of the men were basically good material, but the case illustrates the lack of attraction that exists in this discipline.

At professional level the smaller works have been managed over short initial periods by expatriates who have since handed over to local managers. The latter have done well in the face of great odds, such as lack of spares, consumable stores and good skilled operators. The vital importance of water pollution control systems has taken a long time to establish in the industrial nations and it is not surprising that the younger nations are going through the same sequences of development. It is hoped that frequent mention of the difficulties experienced is perhaps of use in making progress towards a solution.

At the larger Tripoli treatment works the initial professional management was provided by an expatriate official assisted by a works manager and an electrical/mechanical engineer seconded from the Consulting Engineer's staff. Currantly the works is managed by a Libyan engineer who leads a mixed local and expatriate staff. Operation has settled down to a fairly successful level but the perennial problems of skilled labour, spares and consumables persist. The level of achievement gives cause for congratulation under the circumstances.

Benghazi is an interesting divergence from the other projects in that on the advice of the author's firm the authorities opted to contract the operation and maintenance of the treatment works and the ten town pumping stations for a period of two years.

Benghazi operation and maintenance contract

In early 1973 the Consultants were instructed to prepare a tender document for a two year operation and maintenance contract for the 27 400 m^3/day biological filter sewage treatment works and 14 pumping stations (10 foul water and 4 stormwater) to include for the training of staff. Such contracts are not common and the documents need to be carefully written. The situation was complicated by the following circumstances:

a) Civil engineering construction works had still to be completed at some of the pumping stations.

b) Properties had been connected to sewers for some years and due to the relative levels of the lagoon into which the pumping station overflow discharged and the sewers, the latter had operated under surcharge conditions at low velocity permitting the settlement of solids.

c) Maintenance work not carried out by a contractor in liquidation at the treatment works.

d) Machinery was still being erected, tested and commissioned, including the generators, the only source of power at the treatment works.

e) Certain machinery only partly erected (years beforehand) and some erected but not tested or commissioned.

f) Painting contract not let.

All the above problems had their roots in the delays and complications which resulted from the non-completion of the original construction contract by the first contractor. Apart from the obvious difficulty of overlap of responsibility between the construction and operating contractor, there was no certainty as to when the various parts would be complete for take-over by the latter. Also the effects on the pumping stations of the movement of rubbish in the sewers on draw-down when the pumps were started could be serious.

The essence of the contract is probably contained in one of the clauses which reads:

> "During the Contract Period it shall be a prime duty of the contractor to develop the operation, maintenance and management of the installations from their initial putting into use to a full working condition with proved system and procedures ready for handing back to the Employer. Such development shall be carried out with particular reference to local conditions and to suit the eventual objective of operation by the Employer's staff".

The following are some of the obligations of the operating contractor:

a) Subject to any remaining obligations of other contractors, to take the installations as he found them, bring them into operation and develop them and the processes for which they were designed to an acceptable level.

b) To bring the works to a maturity and optimum operational standard in accordance with normal accepted practice.

c) Plant gardens and carry out landscaping work.

d) Train staff to a level to permit them to assume the operation and maintenance of the works at the end of the Contract. A Training Officer to be appointed to supervise.

e) To pay damages for non-operation or improper operation of units or plant.

f) To compile instruction manuals for all grades of staff covering operation and maintenance procedures.

g) To supply all consumables and spares and leave a supply of the former sufficient for six months operation and replace all used of the latter.

h) To operate the works on a shift system, covering 24 hours per day.

i) To maintain operating logs, records and data schedule and diaries.

j) To make detailed weekly, monthly, quarterly and annual reports.

k) To establish systems and routines.

l) To develop and maintain safety systems.

m) To provide and maintain a suitable technical library.

n) To provide staff in accordance with the minimum requirements set out in the Contract documents.

o) To carry out regular sampling and testing and maintain full laboratory service. Special tests which could not be performed in Libya to be carried out in another country if necessary.

p) To provide a service for sampling and testing trade wastes at industrial premises.

Pricing of the Contract was based on an all-in rate per month of operation set against each pumping station and the sewage treatment works.

The Contractor selected was a Libyan firm who brought in trained expatriate personnel. The combination of the various factors involved in this unusual contract could have justified the occurrence of great difficulties and below average achievement. However, in the event although there were some problems the Contract was carried out successfully founded on the basis of a carefully prepared Contract Document. The least satisfactory part was the training element which did not succeed due to the lack of good material.

The question of spares presented a constant problem due to unobtainability or long delivery periods.

Works performance

At the time of writing it has been difficult to obtain data on performance but average values for 1976 at Benghazi for four categories of data are:

	Raw sewage	Humus tank effluent
BOD_5	120	19
COD	382	70
SS	225	26
Amm^1.N.	25.3	2.5

Average values for Tripoli are:

BOD_5	140	19
COD	291	52
SS	277	29
Amm^1. N.	19	2.7

(All in mg/1)

The above are indicative only. Further data is given in sections 6 and 7.

11. CONCLUSION

It is hoped that the foregoing gives a very broad view of what comprises nearly the sum total of the first steps in providing the main towns of Libya with modern sanitary facilities. The work is a challenge in its size and associated problems particularly in the absence of results from established and tried systems and practices.

There is a great need for discussion amongst engineers of their experience of problems and their solution in the Arab countries.

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