A REVIEW OF ADEN WATER SUPPLY

A DISSERTATION

Submitted in partial fulfilment of
the requirements for the M.E. (WRD) Degree

By

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1973

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CERTIFICATE

Certified that the dissertation entitled " A [illegible] OF [illegible] " which is being submitted by [illegible] in partial fulfilment for the award of the degree of Master of Engineering in Water Resources Development, of the University of Roorkee is a record of candidate's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is to further certify that he has worked from April 1972 to April 1973 for preparing this dissertation.

Maheshwari
([illegible])

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Dated: July 21, 1973.

ACKNOWLEDGEMENTS

The author wishes to acknowledge with gratitude the invaluable assistance of his supervisor, Dr. Mahesh Varma, Associate Professor (Plant & Machinery) of W.R.D.T.C., University of Roorkee, Roorkee, in the preparation of this dissertation.

He is also grateful to his colleagues for their co-operation in furnishing him with reports and statistics, etc. on the subject matter of this report.

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CONTENTS

<u>ABBREVIATIONS</u>

P.C.W.	= Public Corporation for Water
P.C.E.P.	= Public Corporation for Electric Power
S.A.D.	= South Arabian Dinar (approximately equal to £1)
S.Y.D.	= South Yemen Dinar (Same as S.A.D.)
S.W.L.	= Static Water Level
T.W.L.	= Top Water Level
m.g.d.	= million gallons per day
M.C.M.	= Million Cubic Metres
p.p.m.	= parts per million
UNDP	= United Nations Development Programme
K	= Permeability
T	= Transmissibility

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SUMMARY

A piped water supply system was started in Aden in 1929 when the first borehole was successfully completed at the Sheikh Othman headworks. In the following two decades several more boreholes were drilled at the same headworks, which by 1950 were supplying nearly two million gallons per day. Aden water supply has increased many fold since then and the consumption nowadays is about 10 million gallons per day, about 80 per cent of which is raised at the Bir Nasir headworks which were developed from 1956 onwards. The other headworks in the system are at Bir Ahmed. These were commissioned in 1954 to supply water to the old refinery town of Little Aden.

This dissertation attempts to present a systematic review of the Aden water supply. The first chapter presents a background of the Peoples Democratic Republic of Yemen from the view points of geography, topography, hydrology, geology and economy.

The second chapter describes the location of Aden, its climate, the growth of its population over more than a century and the history of water supply of Aden.

The third chapter describes the Wadi Tuban catchment area, from the ground water resources of which all the Aden and Little Aden supplies are withdrawn. The aspects of topography, rainfall, drainage, floods and geology are described.

The fourth chapter goes into the details of the ground water reservoir. The depths of the ground water and the fluctuations in levels are discussed. The Aden water supply withdrawn from the reservoir about 12.5 mil per annum whilst the recharge is estimated to be of the order of 140 mil per annum. However water is also pumped from this reservoir for irrigation and it is planned to withdraw about 30 mil annually for this purpose. This is likely to affect the levels in the Aden supply wells. The quality nature of the Aden supply water is also discussed in this chapter.

The fifth chapter describes the Aden and Little Aden water supply systems in outline. Water from Bir Nasir and Sheikh Othman supplies the towns of Crater, Maalla, Tawahi, Khormaksar, Sheikh Othman, [illegible], the village of Bir [illegible], and the shipping supply station at [illegible] [illegible]. Bir Ahmed water supplies Little Aden, the Little official capital known as Madinat Ash'ab, and the villages of Bir Fuqum, Al-[illegible], Bir Ahmed and Imran.

The last chapter discusses the difficulties of the Aden water supply system, as run by the Public Corporation for Water, which is also responsible for water supply systems throughout the country. Like many other organisations in the Republic, the P.C.W. is suffering from financial difficulties, as a result of the economic crisis through which the country is passing. The P.C.W. is also suffering from an acute shortage of qualified personnel, from organisation and planning difficulties and from a number of technical problems. Some of these shortcomings are discussed, and in some cases remedies are suggested based on the experience of the writer in the Aden Water Authority and the Government Administration in Aden.

CHAPTER - I

A BACKGROUND OF THE COUNTRY

1.1. General:

The Peoples Democratic Republic of Yemen occupies the Western part of the southern coast of the Arabian Peninsula. It lies between latitudes 12.5° north and 19° north and longitudes 43.5° east and 53° east. The country is bounded by the Yemen Arab Republic on the north-west, by the sand sea of the Rub-al-Khali in Saudi Arabia on the north, by the States of Muscat and Oman on the east, and by the Gulf of Aden on the south. The Republic has an area of about 125,000 sq.miles. It comprises a coastal plain varying in width between 4 and 40 miles leading to steep bare rocky mountain ranges rising to about 6000 feet above sea level.

The country gained its independence from British rule in November 1967. Politically, the Republic is now divided into six governorates or counties. The first governorate consists of the capital, Aden which is an urban village plus the islands of the Republic. The other governorates lie in a numerical order with the second governorate furthest west and the sixth furthest east.

1.2. Population:

No census has been held in the Republic except in Aden where the last census was held in 1955. A general census is being planned for to be held in a year or two. The population is estimated by the Central Statistics Office to be about 1.475 million of which about 300,000 inhabitants live in Aden. The population is irregularly distributed with an average density of about 4.5 people per square km. The population distribution as estimated by the Central Statistics Office, Aden is as in Table-1 below:

Table-1

Population Distribution

Governorate	Area sq.km.	%age	Population	%age	No./sq.km.
First	7,000	2	301,000	20.4	43.0
Second	13,000	4	206,000	14.0	17.0
Third	21,000	7	290,000	19.6	14.0
Fourth	70,000	22	169,000	11.0	2.4
Fifth	125,000	38	435,000	29.5	3.6
Sixth	89,000	27	80,000	5.5	0.8
Totals	325,000	100	1,475,000	100.0	4.5

1.3. Topography and Drainage

The western part of the Republic has a north-south width of about 30 to 37 miles. The coastal region has a flat land shape. However, the northern area of this western part contains the highest mountains in the Republic (altitudes of up to 8000 feet). Eastwards the country becomes wider with a north-south width of about 500 km. An east-westerly watershed divides this part into two precipitation areas, one draining into the Indian Ocean while the other into the Bab-el-Mandab. The low and high features of the country may be summarized as follows :

A. Low features:

(i) The coastal plains varying up to about 60 km. in width and extending all along the coast and incorporating the deltas of the wadis.

(ii) The inland alluvial plains around Lahej, the Wadi Maifa'ah and the western catchment of the Wadi Hadramaut.

(iii) The valleys of the wadis in the western part of the country and the canyons in the east.

B. High features:

(i) The mountains of the west

(ii) The escarpment running from the mountains of the west almost to the Maifa'ah valley and the high lands north of it.

(iii) The plateau of the Fifth Governorate with the out-lying masses in the Hajr and Maifa'ah catchments.

1.4. Climate:

The country lies within the monsoon belt. There are two distinct seasons; a warm season from May to September and a cool season from October to April. The coastal climate is warm and in Aden, for instance, the temperature varies normally from a minimum of 64°F (18°C) to a maximum of 106°F (41.5°C). In the plateau and mountain region it is cooler with greater diurnal range. For instance Mukeiras, which is about 7000 ft. above sea level, has a range from 28° F (-2°C) to 89°F (31°C). A south-westerly wind blows during the warm season, and a north-easterly wind blows during the cooler season.

1.5. <u>Rainfall:</u>

The available records of rainfall for the country are very scanty as very few stations exist for recording rainfall. Moreover, the records available from most of these stations are incomplete. Few of these stations are in the mountainous areas where the rainfall is significant. The average rainfall in the coastal low lying areas like Aden and Ahwar (3rd governorate) is less than 2" per year, while in Seiyun and [illegible] (both in the 5th governorate) it is only about 2½". At high elevations, where the precipitation is far more significant, the scanty available records indicate for instance an average annual rainfall of about 18" at Mukeiras (3rd governorate) which is at an elevation of 6600 feet, and about 15" at Dhala (2nd governorate) which is at an elevation of about 5000 feet. The map of mean annual rainfall in the country which was prepared by the Department of Agriculture and Irrigation, Aden in 1972 is included as Figure 1.

For computation purposes, the following average figures have been suggested for the various catchment areas (1) p.9:

Elevations over 2000 m		400 or 600 mm
"	1000 to 2000 m	150 mm
"	below 1000 m	40 mm

A large portion of the rainfall at high elevations funnels down as surface runoff into broad alluvium filled wadis or low lying alluvial fans sometimes flooding them and replenishing the ground water reservoir. Underground flow in the wadi alluvium to low lying coastal fans is of considerable importance. The Wadi Hajr (5th governorate) and the Wadi Masila (5th and 6th governorates) are the only perennial small rivers. There is also water flowing perennially in several wadis like the Wadi [illegible] (3rd governorate), the Wadi Tuban (2nd governorate), and the Wadi Maifa'ah (4th governorate).

Most of the rain falls in the spring and in the summer and early autumn periods. The heavier rainfalls occur during the monsoon season and the lighter rains fall during the March-May period. The rain frequently occurs as downpours making it difficult for the farmers to make use of the water.

3.0. Geology:

The rock systems are discussed in some detail by Geer (1) pp.8 to 25. The geology of the western part of the country known before independence as the Federation of South Arabia which incorporated the 1st, 2nd, 3rd and most of the 4th governorates, is discussed by [illegible] (2). The localities of the various rocks may be summarized as follows:-

A. The Recent, Pleistocene and Pliocene Rocks;

The sedimentary rocks are confined to the wadi beds, the coastal plains, and the [illegible] part of the wadi

Hadhramaut catchment except for the sand-dunes on the low hills and the sand-sea of the Rub-al-Khali.

The extrusive rocks occur in relatively small patches on the coast line near Aden and west of it. Also they occur over a large area in the north and east of the Wadi Bayhan catchment, in the west and south of the Wadi Ahwar catchment, in the Maifa-Hajr coastal catchment area, and in small patches along the coast well to the east of Mukalla, the capital of the 5th governorate, and in the Wadi [illegible].

D. The Oligocene-Miocene Rocks:

The most important location is along the coast just east of Mukalla. Small patches occur west of Mukalla and in the Hajr catchment.

C. The Eocene Rocks:

These cover the greater part of Hadhramaut. A small area is found in the extreme east of the Wadi Ahwar catchment area.

B. The Cretaceous and [illegible] Systems:

The sedimentary rocks are found bordering and underlying the Wadi Hadhramaut and its tributaries and also along the coast from east of Mukalla westwards to the catchments of the Wadi Hajr and the Wadi Mayfa'ah. Also small patches are found in the Wadi Ahwar and the Wadi [illegible] catchments.

Intrusive rocks are found along the Wadi [illegible] which feeds Abyan delta, north of the Tuban delta catchment area is underlain by the Cretaceous lavas except for that of the Wadi Abrain. Another area occupies the extreme north-west corner of Oubchi, in the 3rd governorate.

6. The Jurassic System:

These are found around Shibam in the Wadi Hadhramaut catchment. Patches occur in the coastal hills behind Mukalla. They are also found in places in the Wadis Hajr, Maifa'ah, Ahwar and Hubobiya.

7. The Pre-Cambrian and Igneous Rocks:

These are found in the coastal strips around Mukalla, in the southern parts of the Wadis Hajr and Maifa'ah, and underlying parts of the catchments of the Wadis Ahwar, Hassan, Bana and Abrain. They underlie most of the western part of the Wadi Hadhramaut catchment area. Granite occurs near Ahmad, Mukairas and Lodar.

A geological map of the Republic (scale 1:2,000,000) is shown in Figure 2.

1.7. <u>Economy</u>:

Before Independence Aden was a flourishing free port, with an economy depending on services rendered to the British military base, British Petroleum Refinery, port services and bunkering, entrepot trade and commerce. The other governorates lived at near subsistence level on agriculture, mainly of cotton and grains, and on fisheries.

The country has been suffering an economic depression since 1967, and, according to the Central Statistics Office

In Aden, the GNP (gross national product) has decreased from 107.4 million SAD(South Arabian dinar, approximately equal to £) in 1966, to 90 million SAD in 1967, and has reached 73.9 million SAD by 1969. The depression was caused mainly by the following factors:

(i) The closure of the Suez Canal in 1967 leading to the diversion of shipping from Aden.

(ii) the withdrawal of the British base which was providing employment to some 1[illegible],000 persons.

(iii) the termination of the British budgetary aid which had arisen to 22.9 million SAD for the year 1967/68.

The government resorted to very stringent measures to cope with the crisis. Firstly, government expenditure was cut down by more than 50% from 1968. Secondly, all banks and foreign firms (except the B.P. oil refinery and the bunkering companies) were nationalised in 1969, with the aim of using the profits from these concerns in an economic development plan. In the following years the government seized all farm tractors in the country, fishing boats, hotels, cinemas, taxis, and most of the houses. The government also turned to friendly countries and international organisations for loans for the first 3-year economic development plan.

CHAPTER - II

THE GEOGRAPHICAL [illegible]

2.1. Aden:

Aden, the capital of the People's Democratic Republic of Yemen, is situated in the first governorate in the south western part of the country on the Gulf of Aden at a distance of about 100 miles from the Straits of Bab-al-Mandab on the southern coast of Arabia. It lies on longitude 45° 10 E and latitude 12° 47' N. The area of Aden is about 75 sq. miles. Before independence Aden was a British colony as distinct from the other five governorates which previously constituted the Western and Eastern Aden Protectorates.

Aden comprises:

(i) The peninsula on which are situated the old main town known as Crater, the well known harbour known as Tawahi or Steamer Point, and the dhow harbour area known as Maalla,

(ii) The isthmus known as Khormaksar,

(iii) the area of land extending to the Little Aden peninsula. The towns of Sheikh Othman, Al-Mansura, Madinat Al-Sha'ab and the village of Imran are on this area,

(iv) The Little Aden peninsula on which lies the B.P. oil refinery. The villages of Al-[illegible] and [illegible] lie on the extreme ends of this peninsula.

The Aden and Little Aden peninsulas are rocky and of volcanic formation, Jebel Shamsan, the summit, being 1725 feet high. Dwellings and buildings are constructed on the ridges of the mountains and in the valleys between them wherever the land is level. Crater Aden inside an extinct volcano on the east of the peninsula at a distance of about 5 miles from the harbour which lies on the western part of the peninsula.

2.2. Climate:

There are practically only two distinct seasons during the year, a very warm season and a cooler season each lasting about 6 months. The temperature in Aden varies normally between 61°F and 106°F. The annual rainfall is extremely scanty. 1" to 2", and in some years no rain falls at all, but as much as 6" have been known to fall in one year.

2.3. Population:

The population of Aden has fluctuated throughout the ages with its rise and fall. The rise and decline of Aden may be linked with the rise and decline of the Yemeni ports, particularly the port of Mocha and to a much lesser degree the port of Hodeida. For instance, Aden was flourishing around 600 B.C. and again around 1300 A.D. under the Rasulids, and had a sizeable population in those days, although no population count was officially made until British occupation. By the time the British conquered Aden in 1839, it had dwindled to a small fishing village and the census taken that year revealed that the population was 1927 of whom 680 were female. The population continued to increase sharply as can be seen from the results of the six censuses taken thereafter (3).

Table-2

Population Censuses of Aden

Year	Population
1856	20,736
1901	43,080
1911	46,211
1931	48,380
1946	80,576
1955	138,441

The population in 1964 was estimated to be 225,000. However, the population began to decrease after 1964 due to the political uncertainty of the future of the area, and again there was a decrease at Independence mainly due to the withdrawal of the British base, but there was a heavy increase afterwards due to the movement of population from the up-country into Aden. The population at the moment is between 250,000 and 300,000 people.

2.4. Historical:

A civilisation based on the management of water flourished in south-west Arabia possibly as far back as the first millennium before Christ, in the days of the legendary Queen of Saba. The remnants of the historically famous Marib Dam, the bursting of which drowned a civilisation in the Northern Yemen around that era, can still be seen. On the other hand in Southern Yemen, the most important archaeological features are the Tawila Tanks. There are 18 tanks known, constructed in a gorge one below the other so that when the highest is full it overflows into the next lower tank. The approximate capacities of some of these tanks were estimated as follows (b):

Table-1

Capacities of Some of the Tawila Tanks

Name of Tank	Capacity in Gallons
The Upper Tank	1,3[illegible],[illegible]
Pool below Main Weir	6[illegible],000
Small Tank in Aqueduct	1[illegible]6,000
Small tank right and left of aqueduct	[illegible],000
Coghlan Tank	4,0[illegible]3,000
Playfair Tank No.17	3,[illegible],000

The tanks seldom ever become filled but it is recorded that they were filled in 1877 and again in 1907 and probably a few other times in between. It is still not certain to when the construction of these tanks is to be attributed, but most probably they were constructed over several eras starting from pre-Christian times.

The population of Aden depended on them as well as on open wells for their water supply at one time. Mention of some 50 open wells and a few springs in Aden was made by some historians.

It is useful to follow up the historical development of the existing water supply system to be able to consider the present problems and their possible solutions.

The rapid increase in population which took place after British occupation resulted in an acute shortage of water, but nothing was done to remedy the situation until 1867 when an aqueduct was constructed to convey water from two open wells at Sheikh Othman to Aden. Also, a distillation plant was erected. (A few privately owned small distillation plants were also erected about 90 years ago and sold water to the public through the owners of camel-driven tankers).

Up to 1924 several reports and schemes were prepared to up-date the system which had become seriously inadequate long before that date but none of these schemes was followed through. Between 1924-26 a deep borehole was sunk to 1700 feet in Sheikh Othman but had to be abandoned after the drilling shoe jammed in, although a small artesian flow had been found. In 1928-29 a 150 feet deep shallow borehole was successfully completed, and a fresh water supply was delivered to [illegible] through the Royal Air Force 6" main previously laid to replace the old aqueduct. Between 1929 and 1931 five more bores were sunk in Sheikh Othman. In 1931 the government of Bombay approved the allocation of 8 lakhs of Rs. to cover the cost of these bores and a piped distribution system. Between 1931 and 1950 ten more bores were sunk in Sheikh Othman. The population had increased by 1950 to 110,000 and the demand to 1,900,000 gallons per day. The next expansion of this system was completed in 1954 at a cost of £ 195,000 increasing the daily output to about 3 million gallons. This consisted of five additional boreholes in Sheikh Othman, a 9" diameter main to Isthmus where a new pumping station and a high level reservoir were proposed together with new feeder mains to Crater and Tawahi. A new shipping supply along Dubble Round was also proposed to relieve Tawahi of this heavy load.

In the same year i.e. 1954 the Little Aden water supply system was commissioned at a cost of £ 700,000. The development of this system has been directly related to the development of the B.P. Refinery. The system consisted of 12 shallow bore holes on 3 parallel lines running east-west a little to the west of the village of Bir Ahmed. The system was designed to supply up to 2.5 m.g.d. but the demand at that time was only just over half that quantity.

In 1956 the Bir Nasir Wellfield was commissioned to supply Isthmus pumping station. This consisted at that time of 14 shallow boreholes 10" in diameter, and having a maximum output of 3.5 m.g.d. These wells are on an east-west line at 1000 feet intervals situated between the Wadi Al-Kabir and the Wadi As-Saghir, the two distributaries of the Wadi Tuban, and at a distance of about 7 miles to the south of the town of Lahej, the capital of the 2nd governorate. 15 H.P. submersible pumps are installed in them.

In 1961 the second line of Bir Nasir Aden water supply wells was constructed. This consisted of 14 shallow type boreholes on a line parallel to the previous line and 2000 feet to the north of it. Submersible pumps of 30 H.P. were installed in these boreholes.

In 1966 two larger boreholes were drilled between these two lines with the idea of replacing four bores, two from each line, with one of these bigger holes. However, a trial in which the writer participated to run a 100 H.P. submersible pump in one of these holes showed that the permeability of the aquifer was not sufficiently high, for the pump began to pump up air within a few seconds from switching on. Later on 30 H.P. pumps were installed in these bores.

A similarly larger bore, 10" diameter, was drilled in the Bir Ahmed field and was unsuccessful for a 100-H.P. pump. This well was later on handed over to the Department of Irrigation.

In 1971 two more wells were drilled in the Bir Nasir field bringing the total number of wells in that field to 32 wells.

At the present the total number of wells that are or can be made operative in the Aden water supply system is 8 boreholes at Sheikh Othman, 32 boreholes at Bir Nasir, and 12 boreholes at Bir Ahmed.

C H A P T E R - III

THE WADI TUBAN CATCHMENT AREA

3.1. The Source:

All of the water of the Aden supply emanates from the underground water resources of the delta part of the Wadi Tuban catchment area. This includes the Sheikh Othman borewells, the Bir Nasir tubewells and the Bir Ahmed tubewells.

3.2. Location and Topography:

The delta of the Wadi Tuban falls between latitudes 12° 45' N and 13° 15' N and longitudes 44° 7' E and 45°05' E. It has a triangular shape, the base, about 35 km long, lies along the Gulf of Aden, and the apex is near the village of Al-Anad which is about 120 metres above sea level. From Al-Anad the plain slopes down to the Indian Ocean about 50 km away. The Wadi Tuban catchment area is shown in Figure 4.

In addition to the delta, the catchment area includes the hills, which start just north of Al-Anad and lie parallel to the coast and which are about 2,500 metres high rising to 3,000 metres at Jebel Jihaf near Dhala. The catchment area also includes piedmont plains about 8 km. wide and extends, approximately between the Wadi Tuban and [illegible] i.e. a distance of about 15 km.

3.3. [illegible]:

Three wadis feed the delta area:

Table 15

Average Annual Rainfall at Stations close to the Tuban

Station	Elevation m.	Av. Rainfall mm/year	No. of observation yrs.
Aden	27	49	62
Dhala	1,400	309	5
Taiz (North Yemen)	1,350	521	6

The Wadi Tuban receives much of its water from the rains which fall on the mountains north of the border. The rainfall in Yemen is fairly appreciable. (It is about 300 mm in Sanaa, the capital).

For computation purposes, the following rainfalls may be assumed, (5),p.3.

Elevation m	Rainfall mm
Over 200, west & central areas	600
Over 2000, centre & north areas	400
1000 to 2000	150
Under 1000	40

The flood seasons are March to May and July to September. Only during very heavy floods do the flood waters of the Wadi Al-Kabir reach the sea near the village of Imran. The floods of the Wadi Tuban last 10 to 20 hours while the floods of the Wadi Saghir last 5 to 6 hours. The average annual perennial discharge in the Wadi Tuban is estimated to be about 100 million cubic metres, whilst the flood discharge is about 125 million cubic metres, (5) p.4. During the

(i) the Milh, draining from the eastern side,

(ii) the Abrain, draining from the western side, and

(iii) the Tuban, the most important of the three, draining from the central region.

All three wadis flow to the south-east. The wadi Tuban splits into the wadi Al-Kabir and the wadi As-Saghir near the village of [illegible]. The wadi Al-Kabir is on the west of the wadi As-Saghir) Kabir in Arabic means large whilst saghir means small).

A perennial flow continues in the Tuban between [illegible] and Lahej except after a succession of dry seasons when the flow continues only in the underlying boulders.

Gear produced the following table, (5) p.2.

Table 4

Catchment Areas (Sq.km).

Elevation in metres	North of Al-Anad Abrain	Tuban	Milh	South of Al-Anad	Totals
Over 2000	-	2100	-	-	2100
1000 to 2000	75	2090	110	-	2275
Under 1000	375	855	305	1210	2745
Totals:	450	5045	415	1210	7120

3.4. Rainfall and Floods.

Table 5 shows the average annual rainfall of the three stations close to the Wadi Tuban area, (6) P.4.

Table 15

Average Annual Rainfall at Stations close to the Tuban.

Station	Elevation m.	Av. Rainfall mm/year	No. of observation yrs.
Aden	27	49	62
Dhala	1,400	369	5
Taiz (North Yemen)	1,350	527	4

The Wadi Tuban receives much of its water from the rains which fall on the mountains north of the border. The rainfall in Yemen is fairly appreciable. (It is about 500 mm in Sanaa, the capital).

For computation purposes, the following rainfalls may be assumed, (5),p.3.

Elevation m	Rainfall mm
Over 200, west & central areas	600
Over 2000, centre & north areas	400
1000 to 2000	150
Under 1000	40

The flood seasons are March to May and July to September. Only during very heavy floods do the flood waters of the Wadi Al-Kabir reach the sea near the village of Hiswa. The floods of the Wadi Tuban last 10 to 20 hours while the floods of the Wadi Saghir last 5 to 6 hours. The average annual perennial discharge in the Wadi Tuban is estimated to be about 100 million cubic metres, whilst the flood discharge is about 125 million cubic metres, (5) p.4. During the flood season much silt is carried by the water.

3.9. Geology

The geology of the part of the catchment area that lies within the PDRY is available and is shown in Figure 4. Alluvial deposits are found in the coastal plains up the Wadi to just beyond the village of Mahfid. Recent lavas occur as isolated hills near the coast while the weathered Cretaceous lavas cover most of the area except the catchment area of the Wadi Abrain which is underlain by pre-Cambrian rocks. East of the village of AlAmad and also in the Wadi Al-Kabir can be seen a patch of granite. On the whole the geology here favours high run-off and low infiltration.

In the catchment basin there is much faulting particularly NE-SW. Also a number of dykes occur east and north of Al-Amad. Also, north and east of Al-Amad Cretaceous lavas outcrop and to the west can be seen pre-Cambrian rocks lying upon a granitic basement. Earth movement resulted in elevation and faulting, after the lavas had consolidated.

Logs of wells drilled in the delta indicate that the sedimentary rocks of the area consist of beds of silts, clays, sands, gravels and boulders, all these beds are of irregular thicknesses. The silts are often 30 to 50 feet thick. At Bataj the logs indicate that beneath the surface silts boulders and gravel form the bulk of the rocks. Near Middle Abyan [illegible] to 100 feet consists of clays, sands and lava boulders. A considerable degree of cementation has taken place in the rocks of this area mainly by calcium carbonate [illegible] Figure 5 depicts a typical strata log for the [illegible] area, (7).

3.5.1. [illegible]

The logs of the boreholes in the [illegible] Othman [illegible] shown in figures 6A & 6B indicate alternating series of clays, fine sands and gravels with the lower layers consisting of cemented sands and [illegible] sticky clays. Gravel beds were found at two or three depths particularly at 135 feet and 200 feet below ground level, varying between 3 and 15 feet in thickness and water was struck at [illegible] these depths. There is only one deep borehole in this field reaching 1740 feet in depth. This showed a boulder bed 14 feet thick at a depth of 700 feet and a clay layer at a depth of 800 feet. This field occupies an area of about 1400 feet by 2000 feet.

3.5.2. [illegible]

The thickness of the top silt layer varies between 1 5 feet and 60 feet according to the logs of the boreholes which were drilled in 1956 shown in figures 7A and 7B. Below the top layer of silt are layers of boulders with thin beds of clay, sand and gravel extending the full depth of the bores, 250 feet and more.

3.5.3. [illegible]

For the top 150 feet [illegible] are fine-grained sediments and alternating layers of clay and sand and gravel beds, rather than boulder beds. The logs of the boreholes are shown as figures 8A & 8B.

CHAPTER - IV

THE GROUND WATER

4.1. Occurrence and Depth of the Ground Water:

Both confined and unconfined aquifers are present in the area. The confined aquifer waters are under some pressure and the piezometric levels of the water are about equal or perhaps a few feet higher than the static level of the water in the unconfined aquifer above. The best available evidence is that from the deep bore No.1 at [illegible] 1740 feet deep. Water was struck at several depths, however, the rest level from the layers at depths 80', 140', 240' and 700' were 13', 14', 15' and 7' respectively. The prospects of finding artesian flowing water in this area is most unlikely except perhaps in small quantities from isolated localities, which had built fixed level pressures that would soon drop; (8). With the existing limited hydrostatic pressures and a climate that is too [illegible], only the above mentioned sub-artesian conditions are encountered. Depths of unconfined waters are shown in Figure 9.

Boulder layers are found in the northern area and down to the [illegible] and [illegible] and ensure free movement of the ground water. In [illegible] sediments, silt and clay bands are obvious from the well logs of the area and may suggest that the vertical drainage to the unconfined aquifer is important; however, the seasonal fluctuations of levels in the above boreholes are small, indicating little local connection between the confined and unconfined aquifers.

The static water level of the ground water in this area varies from 6 feet to about 100 feet. Near the coast and to seven kilometres from it the static water level is less than 20 feet deep. To the east of this area it is usually 20 to 40 feet deep. Around Al-[illegible] and to the west of it and even close to the [illegible] the level drops suddenly to more than 60' and also the water is less saline suggesting a high permeability layer, possibly coarse gravel.

The static water levels in some of the boreholes at [illegible], [illegible] and [illegible] were found sometimes to be as indicated in Tables 61, 62 and 63 below:-

Table 61

([illegible] of [illegible], 1955)

Bore No.	Water Level
2	25' 9"
3	23' 9"
4	27' 9"
5	29' 9"
6	29' 0"
7	25' 0"
8	18' 6"
9	30' 6"
10	21' 5"
11	28' 6"

Table: 68

S.W.L. at Dir Nasir, (1958)

Bore No.	Rest Level
1	71'
2	66'
3	70'
4	72'
5	62'
6	62'
7	70'
8	72'
9	70'
10	70'
11	74'
12	70'
13	[illegible]
14	90'

Table: 69

S.W.L. at Dir Ahmed, (1961)

Bore No.	Rest Level
1	79' 0"
2	75' 6"
3	75' 0"
4	73' 6"
5	69' 0"
6	71' 6"
7	77' 0"
8	75' 0"

The available logs particularly those of Shaikh Othman boreholes indicate the presence of a number of confined aquifers lying below each other separated by relatively impermeable layers. The main two such layers appear from the Shaikh Othman records to be at about 135' and 200' below ground level.

Bir Ahmed bores were drilled using a rotary drill and, therefore, the records do not give those water-supply and geologic information; however, the perforated parts of the casings usually were set with their top 190' to 250' below ground and their bottom at about 300' below ground level.

At Bir Fadhl data on aquifer depths were not collected when the bores were drilled, however, the perforated casings were set between 160' and 350'.

Figure 19 shows the well depths in the fields
(5) Fig.19.

4.1.1. Fluctuations in the Static Water Levels

The long period variations of S.W.L. may be studied from the data in Tables 21 and 22 extracted from the statistics kept by the P.W.D., Aden.

Table 21

Fluctuations in S.W.L. of Shaikh Othman

Bore No.	1956	[illegible]	1971
3	26'9"	38' 9"	40' 3"
4	27'9"	45'3"	40'6"
8	10'6"	42'1"	35'6"
11	20'6"	29'9"	45'9"
12	-	30'9"	37'10"

Table: [illegible]

Fluctuations in U.W.L. at Mir [illegible]

Bore No.	1958	1963	1972
2	66'	58'	89'
8	72'	58'	88'
13	80'	-	85'
14	90'	-	100'
19	-	57'	85'
21	-	57'	90'

Assuming that these measurements were reasonably accurate it seems that there are marked long period fluctuations in root levels. The levels of 1972 indicate a fairly appreciable drop in U.W.L. This drop is not, however, fully understood but partly explained later (p.55). However, the levels at Mir Tank in 1963 are several feet higher than the levels in 1958. Figure II shows the fluctuations in the water levels in the older 14 boreholes at Mir [illegible]. Also the following study was once made for that line of boreholes, (9), p.9:

Table [illegible]

Long Period U.W.L. Fluctuations at Mir [illegible]

Date	Depth of U.W.L. Below Ground
June 1956	66' to [illegible]
June 1957	62' to [illegible]
June 1958	56' to [illegible]
Dec. 1959	69' to [illegible]

Now the annual discharge in million cubic metres during the same period was as follows, (9), p.4.

Year	1957	1958	1959
Flood discharge	59.2	40.0	100.7
Perennial discharge	117.5	91.5	97.7

From these results the relationship between the flood volume and the actual rise in level is not clear, since the rise from 1956 to 1957 was of the order of 2' and that from 1958 to 1959 was of the order of 10' whilst both 1957 and 1959 seem to have been good flood years.

There is no obvious sign of annual fluctuations in the confined aquifer levels; however, in the confined aquifer the levels rise 3 to 7 feet within 12 to 48 hours after floods, and in some areas of deeper rest-level rise of about 15' have been reported, but there are wells near Sheikh Othman in which the levels have been reported to be unaffected by the floods.

4.2. Quantities of Water Extracted:

Fairly good statistical records have been kept of the quantities of water raised and billed by the P.W.D. since the tubewell supply was started in 1939. The statistics for the last 20 years are fairly complete with only few gaps. As already explained in Chapter 2, population censuses were rare and it is difficult to estimate with accuracy the present population, let alone make future forecasts. Figure 12 is a graph of water raised, water billed, and population against time. The population curve beyond 1964 is difficult to complete in the absence of more reliable information.

L. Jackson in 1954 plotted graphs of population and consumption against time, (9) App. VII. He estimated a demand of 10 m.g. per day in 1970 and a population of 200,000 to 240,000. Such a situation was in fact reached by 1964. The graphs which were drawn by J. Jowsley in 1960 for the Aden Water Supply (excluding Little Aden) predicted a mean daily demand of 6.3 m.g. by 1965 and 10 m.g. by 1970. (10) App. I. Jowsley also predicted a mean daily demand of about 1.6 m.g. by 1965 and about 2.55 m.g. by 1970 at Little Aden, (11) App. A. The prediction for 1965 was quite close with the actual figures higher by only 0.5 m.g.d. Because of the major changes that took place due to independence by predictions beyond 1967 were found to be inaccurate.

Table 9 shows the water raised at the three headworks for the years 1955 through 1970.

With reference to Table 9 it can be seen that the quantity raised at Sheikh Othman has been decreased from about 1000 m.g. in 1960 to about half that quantity in 1970. This is because this source has been increasingly saline, and because the Bir Nasir source had been developed sufficiently by 1962 to take over the major role with Sheikh Othman as a supplement with which it is mixed before distribution. The water raised at Bir Nasir increased from 132 m.g. in

[illegible]

[illegible]

Year	[illegible]	[illegible]	[illegible]	[illegible]
1955-56	[illegible]	[illegible]	392.6	[illegible]
1956-57	727.0	[illegible]	403.0	[illegible]
1957-58	692.0	683.5	465.2	1901.5
1958-59	935.5	835.1	391.0	2161.6
1959-60	970.0	[illegible]	412.0	2311.9
1960-61	1108.7	[illegible]	413.1	[illegible]
1961-62	1282.6	[illegible]	507.9	[illegible]
1962-63	[illegible]	[illegible]	513.9	3079.6
1963-64	910.0	2010.5	[illegible]	[illegible]
1964-65	[illegible]	[illegible]	591.7	[illegible]
1965-66	[illegible]	[illegible]	[illegible]	[illegible]
1966-67	[illegible]	[illegible]	726.9	[illegible]
1967-68	[illegible]	[illegible]	[illegible]	3720.7
1968-69	477.6	[illegible]	[illegible]	3913.9
1969-70	[illegible]	[illegible]	551.0	[illegible]
1970-71	[illegible]	[illegible]	[illegible]	[illegible]

1955-56 to a peak of 2730 m.g. in 1963-64 and then decreased a little during the following three years mainly due to the withdrawal of the British Base, but again started to increase after that to about 3046 m.g. in 1970-71 due to the movement of population from rural parts into the Capital. Water raised at Bir Ahmed increased gradually from 400 m.g. per year during the first few years of operation of the system to a maximum of 767 m.g. in 1966-67 and after some drop following Independence increased again to 604 m.g. in 1970-71.

The monthly variations in demand during the year may be studied from Table 10 which shows that the demand increases appreciably during the summer.

Table-10.

Distribution Water Statistics (1967-68) Gallons.

Month	[illegible] Total	[illegible] Total
April 1967	56,552,000	50,690.200
May 1967	65,504,000	53,777,000
June 1967	59,725,200	32,730,900
July 1967	64,735,000	35,415,500
Aug. 1967	61,471,700	33,024,000
Sept. 1967	53,455,000	30,692,100
Oct. 1967	52,271,300	33,489,100
Nov. 1967	49,356,000	30,265,100
Dec. 1967	49,455,700	26,949,300

Contd.

January 1960	46,685,900	35,147,600
February 1960	45,149,300	35,697,900
March 1960	39,495,400	30,591,200
Totals:	631,679,900	510,956,900

From Figure 12 and from Table 11 it is seen that the loss i.e. the difference between water raised and water billed for the years between 1955 and 1960 lies between 16% and 23% and has an average value of [illegible]. A maximum of 30.7% was reached in 1966-67, a year during which political violence was approaching a maximum and curfews were often enforced even on the waterworks staff, resulting in difficulties in the detection and checking of waste.

Table-11

Water Billed in Million Gallons:

Year	Water Raised	Water Billed	% Loss
1955-56	1560.6	1267.0	19.0
1956-57	1857.0	1444.0	22.0
1957-58	1961.6	1512.6	23.0
1958-59	2101.6	1772.0	17.0
1959-60	2311.6	1931.5	16.0
1960-61	2440.2	20 9.6	17.1
1961-62	2597.5	2150.1	17.1

Contd.

1965-66	3079.4	2809.4	89.0
1966-67	4133.6	2372.3	30.7
1967-68	3722.7	2790.5	25.0

4.3. Recharge and the Potential of the Aquifers

The average annual precipitation on the catchment is given in Table 12, (5), p. 19

Table 12.

Average Annual Precipitation on Catchment in M.C.M.

Elevation metres	Wadi Abiad	Wadi Zerqa	Wadi Mujib	Totals
Over 2000	-	1,010	-	1,010
2000 to 1000	11	403	16	430
Under 1000	15	10	13	38
Totals:	26	1,423	29	1,478

Of a total average annual precipitation of 1,478 million cubic metres about 370 M.C.M. reach the [illegible] from the three Wadis, and of this about [illegible] actually sinks underground beyond the reach of the plant roots, about half into the deeper confined waters and the other half into the shallower ones, (5) p.[illegible] According to [illegible], (6) p.6 the average annual flood to the [illegible] is [illegible] M.C.M.

Barber, (12) p.2. assumed a similar figure for the mean annual recharge equal to 130 M.C.M. He mentioned that the extraction rate by the Aden [illegible] during 1953 to 1969 was about 10 M.C.M. per year without unacceptable draw-down, and that the gross withdrawal during 1971 had increased to 13 M.C.M. This figure is more accurately 12.6 M.C.M. (13) p. 1.

It is appreciated in P.D.R.Y. that the Delta region of the Wadi Tuban is one of the most important agricultural areas in the country and that it has appreciable potentialities yet to be developed. The United Nations Agencies were, therefore, approached for assistance to develop the area, and a Project was identified in November 1969, and a request submitted in April 1970. Already this U.N.D.P. Project is underway making studies and conducting pilot projects, and has also engaged consultants to do part of the work.

At the time of the submission of the request i.e. April 1970, in addition to the [illegible] tubewells at the [illegible], Bir Fadl and Bir [illegible], there were another 30 tubewells of an average depth of 70 m. and about 350 hand-dug wells in the Delta. The gross extraction from all these wells including tubewells was estimated to be 20 M.C.M. per annum, (13) p. [illegible]; the two years that followed the request an additional 30 [illegible] tubewells were drilled or planned, all to a depth of about 70 m. The gross water withdrawal when the new developments become fully operational is estimated to be approximately 51 M.G.M. per annum, (12) p. 5. This total was estimated as follows:

Aden Water supply	13 M.G.M.
State Farms	10 M.G.M.
Private Wells	28 M.G.M.
Total:	51 M.G.M.

However, since the above estimate was made, most of the private farms were taken over by the Government together with the private wells, and were converted into state farms. Thus it is not expected that more private wells will be drilled under the present circumstances, and therefore, the gross withdrawal may tend to be less than 51 M.G.M.

All the available data indicate that the ground water reservoir is enormous and assuming that the recharge is in fact approximately 150 M.G.M. per year, then it is probable that the management of the ground water reservoir on the annual cycle should not present difficulty, the annual extraction being about one third the recharge only. Figure 13 shows the UNDP Land and Water Utilization and Conservation Project and also the main bore holes and wells in the Delta.

4.5. Quality:

Well sample analysis used to be carried out more or less annually in the U.K. for many years before independence.

However, since Independence only routine tests for bacterial contamination of the water and measurements of residual chlorine are conducted daily in the W.S.D. laboratory at the Sheikh Othman. Also conductivity measurements are made, and such records are available for many years as far back as 1937. The results of full sample analysis conducted in October 1969 by the Counties Public Health Laboratories, U.K. for six samples, two from each [illegible], are included as Tables 13 A, 13 B, & 13C.

The following comparison was made in 1959 of the quality of the water from different sources within the Aden region, (9), p.4.

Table 14.

Total Solids in Different Sources within Aden Region 1959.

Source	Total Solids, p.p.m.
Average of Sheikh Othman Supply	1040
Average of Bir Ahmed Supply	1500
[illegible] at Bir Nasir	1230
Surface well at Bir Nasir	1000
Surface well at Lahej	1640

Table: [illegible]

Chemical Analysis of [illegible] Water [illegible] 1965

Results in Parts per Million (mg/l)

	Bore No.6	Bore No.14
Appearance	Bright with a few particles	Bright with very slight yellow-brown deposit.
Microscopical Exam.	-	Few mineral particles
Turbidity	Less than 5	Less than 5.
Colour	Nil	Nil filtered
Odour:	Rubber from bottle cap.	Rubber from bottle cap.
P.H.	7.6	7.4
Free carbon dioxide	0	7
Electric conductivity	1090	4600
Dissolved solids dried at 180 C:	1810	3700
Chlorine as Chloride:	400	1090
Alkalinity as Calcium carbonate	105	100
Hardness: Total	550	2220
Carbonate	105	100
Non-carbonate	365	2120
Nitrate Nitrogen	16	14
Nitrite Nitrogen	Less than 0.01	Less than 0.01
Ammoniacal Nitrogen	0.08	0.05
Oxygen absorbed	0.4	1.2
Albuminoid Nitrogen	0.04	0.05
Residual chlorine	-	-
Metals: Iron	0.1	0.1
Zinc	0.5	0.6

Contd.

Table Contd.

Copper & Lead	-	-
Fluoride (F)	1.1	0.5
Silica	45	40
<u>Mineral Analysis:</u>		
<u>Cations,</u> Ca	70	304
Mg:	85	350
Na:	225	530
K:	6	7
<u>Anions,</u> CO3	99	60
SO4	345	525
Cl	480	1090
NO3	71	82
<u>Hypothetical combinations:</u>		
Calcium carbonate:	165	100
Calcium sulphate	16	745
Calcium chloride	-	125
Magnesium sulphate	421	-
Magnesium chloride	-	1,369
Sodium chloride	653	1292
Sodium nitrate	97	85
Potassium chloride	7	13
Silica	45	40
Total	1922	3769

Table 13 D

Chemical Analysis of [illegible] 19[illegible]

Results in Parts per million (mg./L)

	Bore No. 14	Bore No. [illegible]
Appearance:	Bright with yellow-brown deposit	Bright with yellow-brown deposit
Microscopical Exam:	Mineral particles and traces of organic matter	Mineral particles
Turbidity	3	Less than 3
Colour	Nil filtered	Nil filtered
Odour:	Rubber from bottle cap	Rubber from bottle cap.
P.H.	7.6	7.5
Free carbon dioxide	25	10
Electric conductivity	1500	1900
Dissolved solids dried at 180 C:	1260	1550
Chlorine present as Chloride	280	320
Alkalinity as calcium Carbonate:	315	320
Hardness Total	325	335
Carbonate:	315	320
Non-carbonate	10	15
Nitrate Nitrogen	9.0	7.5
Nitrite Nitrogen	Less than 0.01	Less than 0.01
Ammoniacal Nitrogen	0.15	0.11
Oxygen absorbed	1.0	0.80
Albuminoid Nitrogen	0.10	0.08
Residual Chlorine	-	-

Contd.

Metals: Iron	2.6	1.6
Zinc	0.23	0.10
Copper & Lead	-	-
Fluoride	0.6	1.1
Silica	55	70
Mineral Analysis		
Cations: Ca	69	98
Mg	37	46
Na	310	405
K	3	1
Anions: CO_3	109	192
SO_4	340	405
Cl	230	320
NO_3	43	33
Hypothetical Combinations		
Calcium carbonate	170	145
Magnesium carbonate	128	140
Magnesium sulphate	7	15
Sodium sulphate	447	582
Sodium chloride	375	525
Sodium nitrate	59	46
Potassium chloride	5	3
Silica	55	70
Total	1240	1554

Table 13 C

Chemical Analysis of Bir Ahmed [illegible], Oct. 1965

Results in Parts per Million (mg/l)

	Bore No.1	Bore No.2
Appearance:	Bright with very slight yellow-brown deposit	Bright with very slight yellow brown deposits
Microscopical exam	Mineral particles	Mineral particles
Turbidity	less than 5	less than 5
Colour	Nil-Coloured	Nil-Coloured
Odour	Rubber from bottle cap.	Rubber from bottle cap.
P.H.	7.6	7.5
Free carbon dioxide	0	9
Electric conductivity	1960	2000
Dissolved solids dried at 100 C.	1540	2000
Chlorine present as chloride	460	740
Alkalinity as Calcium carbonate	170	170
Hardness: Total	535	690
Carbonate	170	170
Non-carbonate	365	520
Nitrate Nitrogen	15	22
Nitrite Nitrogen	less than 0.01	less than 0.01
Ammoniacal Nitrogen	0.05	0.06
Oxygen absorbed	0.20	0
Albuminoid Nitrogen	0.02	0.03
Residual Chlorine	-	-

contd.

Contd. Table

Soluble Iron	0.10	1.6
Zinc	0.1	0.1
Copper & Lead	-	-
Fluoride	1.0	0.9
Silica	55	55
Ionic Analysis:		
Cations Ca	63	152
Mg	70	129
Na	209	300
K	5	4
Anions CO3	102	102
SO4	340	410
Cl	400	740
NO3	80	97
Hypothetical combinations:		
Calcium carbonate	170	170
Calcium sulphate	51	252
Magnesium sulphate	360	292
Magnesium chloride	5	171
Sodium chloride	647	673
Sodium nitrate	110	133
Potassium chloride	0	10
Silica	55	55
Total	1600	2101

American Standards set total dissolved solids at a permitted maximum of 500 ppm, but in the British Isles waters containing more than double that quantity have been used for many years without ill effect, (14) p. 105. Hall, (15) p. 105, however, states that total solids permitted by American Standards are 1000 ppm. In all cases it is clear that the Aden Supply water is unacceptable by American Standards. Moreover, the dissolved solids are not readily removable. Sodium and Magnesium are the important cations, and sulphate and chloride are the main anions. Calcium cation and bicarbonate anion are also found but in a lesser degree of importance. As can be seen from tables 13A, 13B and 13C the ground water in the Aden delta is slightly alkaline with a p.H. of about 7.5.

The following comparison was made in 1961 between the conductivities of the confined waters in the delta, (5), p.11.

Table 15

Conductivity Variation with Area – Confined waters, 1961

Location	[illegible]
Lahej	2200
Bir Nasir	1000-2000
Bir Ahmed	2000-25000
Sheikh Othman	1500-5000

The electrical conductivity varies directly with the total solids along the graph shown in figure 14.

It is seen from Table 15 and from Figure 15 which shows the variation of the conductivity of the unconfined waters with the area, that the conductivity micromho value has a range between 1100 and 9000 and the conductivity contours are roughly parallel to the coast, with the conductivity increasing towards the coast, except for the contours of the deeper less saline waters of Al-[illegible] area. The difference in conductivities of confined and unconfined waters is little except in Sheikh Othman, and possibly in Bir Ahmed where the confined waters are of a better quality (5), p.11.

The increase of salinity coastwards is probably due to the absorption of mineral salts from the earth by the ground water as it flows towards the coast, and due to the sub-surface flow which remains within the capillary zone and hence is affected by the evaporation. The salinity increases further near the sea because of the added effects of intermingling with the sea water and of the sea-water intrusion. In Sheikh Othman there is the secondary effect of the salt pans in the Khormaksar area nearby. These caused the water of a bore which was drilled in their vicinity to be higher in salinity than sea-water itself, (9) p.9. The salinity of the Sheikh Othman increased considerably over the years because of over exploitation of the limited aquifer which is close to the sea and the salt pans. Moreover, the bores had been drilled so close to each other, resulting in sea-water intrusion or invasion of the deeper waters by the more saline shallower waters.

The salinity of the Sheikh Othman bores improved appreciably after the commissioning of the Bir Nasir Headworks which resulted in a decrease of pumping of Sheikh Othman Water.

It appears that the waters improve slightly with depth in the northern area of the Delta and also in the Sheikh Othman and Bir Ahmed areas, (5), p.13.

4.4.1. <u>Temperature of the Water:</u>

The temperatures of the well waters range from 29°C to 35°C for unconfined waters as can be seen from Figure 16, (5) Fig.6. The temperature of the confined waters range between 34°C and 41°C and the temperature was found to increase by 1°F for every 57 feet depth in a borehole in confined waters, (5), p.17.

These high temperatures cause some difficulties for the pumping, and for instance the P.W.D. Annual Report 1958-59, (16) p.17, mentions that some difficulties were experienced during that year with submersible borehole pumping units at Bir Nasir headworks and a full supply was not possible from those headworks and additional supplies had to be taken from Sheikh Othman to avoid restrictions of supply.

CHAPTER - V

THE WATER SUPPLY SYSTEM OF ADEN

5.1. General:

The supply of water to Aden is vested in the Public Corporation for Water. This self-financing body was formed in 1970 out of the Water Authority which was a department within the Ministry of Works and Communications. It is responsible for the water supply systems in the country as a whole, the system serving Aden being by far the largest and most important one. The layout of the Aden water supply system is shown in Figure 17.

The Corporation is headed by an executive chairman who is simultaneously the chairman of the board of directors, which is appointed by the Minister of Works and Communications.

The Corporation employs more than 530 persons to deal with all technical and administrative work involved. The P.C.W. has sections for planning, drilling, pumping, distribution, mechanical and electrical workshops, building maintenance, stores, establishment, accounts etc.

5.2. Wellfields

As can be gathered from the previous chapters, there are three locations all consisting of shallow boreholes, located at Sheikh Othman, Bir Nasir and Bir Ahmed.

5.2.1. Sheikh Othman wellfield:

These works are the oldest of the three the first borehole having been first put into operation in 1929. There are 17 boreholes altogether varying in depth between 200 and 350 feet. Only bores No. 3, 4, 6, 7, 8, 10, 11 and 13 are still in use. The layout of the Sheikh Othman Wellfield is shown in Figure 10. 10- H.P. submersible pumps are usually used in the boreholes. Previously Aden depended entirely on this source for its water, however, it is now of secondary importance and is used to supplement the Bir Nasir supply to Aden. Sheikh Othman water is mixed with the much less saline water from Bir Nasir before supplying the towns of Crater, Tawahi, Maalla, and Khormaksar. Sheikh Othman itself with the towns of Mansura and Dar Saad are supplied with unmixed Bir Nasir water. These wellfields were originally designed to supply up to 3 m.g.d. However, after the construction and expansion of Bir Nasir wellfield, the supply from this source was decreased from about 1200 m.g. in 1960-61 to about 560 m.g. in 1969-70. It was 494.0 m.g. during 1970-71.

There is a one million gallon low level masonry reservoir, 11 feet high, in the Sheikh Othman Wellfield Gardens in which several of the boreholes are located. The tank collects all the water raised in the wellfield through a common 18" ring main. A booster station with four boosting units ranging in capacity between 65 H.P. and 40 H.P. are used to boost water from Sheikh Othman to [illegible], and the Public Fuel Shipping Supply Station. The level of Sheikh Othman is about 40 feet above sea-level, whilst Bir Nasir is less than 10 feet above sea-level. Water is supplied to the headworks by the Public Corporation for booster power, and there is a 250 k.v. diesel generator at the headworks on stand-by.

5.2.2. [illegible]

The first part of these boreholes was commissioned in 1955. This consisted of a line of shallow boreholes 15 in number 10" diameter each at 1000 feet intervals along the same line. This line runs approximately along an east-west direction perpendicular to the line of flow of ground water. 15 nos. 10 H.P. submersible pumps set at an average depth of 120 feet below ground pump water through 4" dia. rising mains to two 18" dia. collecting mains which feed water into the reservoirs.

The second part of the boreholes was commissioned in 1961. This consisted of 15 boreholes each having an average depth of 350 feet and a diameter of 15" lined with 10" diameter post slotted tubes. The boreholes are at 1000 feet intervals along a line parallel to the old line and 2000 feet to the north of it. [illegible] H.P. submersible pumps are used in these wells, the water being fed into the reservoirs via two 18" dia. collecting mains.

The first line was designed for a total extraction of 2.5 m.g.d. while the second line was designed for about 5 m.g.d. All these wells have pumps which can be operated by either remote control from the headworks or from the individual pump houses.

In 1966 two more wells of a slightly larger diameter were drilled in between the existing lines, the idea being that each of these wells was to replace their corresponding wells. This idea did not succeed and the boreholes were fitted with 30 h.p. pumps. Two more wells were drilled in 1971 directly by the [illegible], but these have not been fitted with pumps or pump houses.

An elevated sectional steel tank with a capacity of 100,000 gallons was constructed with the first line of boreholes in 1956. The tank has a height of 37.5' above ground and 231.5' above sea level. The water was delivered by gravity to [illegible] via [illegible] and [illegible] through a 10" main constructed of spun iron piping with bolted gland joints, but with the second line of wells a 15" asbestos cement main was laid between [illegible] and [illegible] via [illegible], to deliver to [illegible] by gravity.

Power is supplied by the [illegible] and the submersible pumps are fed through individual pole mounted transformers. A 350 k.v.a. standby diesel generator is used during power failures.

5.2.3. [illegible]

Three [illegible] were completed in 1959 to supply [illegible] Town. These works consist of the [illegible] of 10 shallow boreholes situated on [illegible] running in an [illegible] direction. The wells are equipped with 10 h.p. submersible pumps which feed a main 6" dia. collecting main through 4" dia. rising mains. The water is collected into a low level welded clearwater tank, from which it is distributed to the [illegible] by pumping through a 12" dia. steel pipeline. There are four 5-stage centrifugal boosting pumps each rated at 350 g.p.m. at 500' head, driven by 100 H.P. motors which pump to [illegible] tanks. There are also two single stage pumps in the same pump house delivering to the village of Bir Ahmed a short distance away. The town of [illegible] is also supplied from Bir Ahmed.

The submersible pumps can be controlled from the bore-yard or from the individual pump house. Electricity is supplied by the [illegible] and the borehole pumps are fed through 11 KV/ 400 volt transformers. There is also a 150-K.W. standby generator at the [illegible].

5.3. The Pumping Stations

As already described pumping takes place at both Sheikh Othman and Bir Ahmed [illegible]. The other main pumping stations are at [illegible]. There are other very small stations like the one in the army camp near Bir Fuqum which boosts from the reservoir that supplies Bir Fuqum village.

5.3.1. [illegible]

This is the largest pumping station within the system. It supplies the [illegible] and [illegible] areas. Water from Sheikh Othman and Bir Ahmed is stored in two low-level 33 foot high welded [illegible], each having a capacity of 5 million gallons. [illegible] water is pumped after chlorination to the main [illegible] high-level reservoir and to the two [illegible] high-level [illegible]-section tanks.

The pump house incorporates 9 centrifugal booster pumps operated by electric motors of different capacities varying between 100 and 270 H.P. There is also a 900 H.P. stand-by diesel generator for use during failures of power which is supplied by the [illegible] at 11 kV and transformed down by the [illegible] [illegible].

At these works are situated the main stores, the mechanical and electrical workshops, the meter repair shop, the laboratory which carries out daily routine tests, and other sections. The vehicle repair [illegible] section is located at the [illegible] buildings. Chlorination is effected through V-notch chlorinators, the chlorine being obtained from overseas in cylinders under pressure.

5.3.2. [illegible]

These works are located at the end of the [illegible] from [illegible] on the [illegible] [illegible]. Water is pumped from the [illegible] through a [illegible] pipeline into the low-level [illegible] tanks ([illegible] one million gallons capacity in [illegible]). There is a pump house in which there are three [illegible] H.P. centrifugal pumps that pump the water to [illegible] after it is [illegible].

There are [illegible] [illegible] by the [illegible] [illegible] the [illegible] as [illegible] from the [illegible]. [illegible], the [illegible] fishing village at the western end of the Little Aden peninsula, through a 6" dia. steel pipeline.

Power is supplied to the [illegible] house works through two motors and there is no standby generator.

5.4. Distribution

5.4.1. The Main System

Water travels by gravity from Bir Nasir to [illegible] via Sheikh Othman through a 10" open iron pipe and a 12" asbestos cement pipe. The ground level at Bir Nasir is 175 feet above sea level. At Bir Nasir there are two reservoirs, a low level welded circular reservoir of 1 million gallons capacity and a high level sectional steel reservoir of 0.1 million gallons capacity with a T.W.L. of 97.5 feet above ground. Sheikh Othman is at 40 feet A.M.S.L. It has an old masonry tank 22 feet high with a capacity of 1 million gallons. Sheikh Othman water is pumped off to [illegible]. In addition to the 12" A.C. and 10" open iron pipes running between Bir Nasir and [illegible] via Sheikh Othman there is also a 9" A.C. pipe running between Sheikh Othman and [illegible].

A 9" A.C. pipe runs from the Sheikh Othman township to the shipping station at Little Aden. A low-level welded circular tank was installed at Little Aden in 1967 but has never been commissioned due to the drastic drop in the number of ships calling at the harbour since the closure of the Suez Canal and the proposed [illegible] operation has not been pursued.

[illegible] is about 10 feet above sea-level. From the two low-level walled circular tanks, each 38 feet high and with a capacity of 5 million gallons, water is pumped to the high level tanks constructed on the ridges of the mountains over-looking Crater, Maalla and Khormaksar. The masonry tank of the Main Pass was partly constructed on the old Turkish fortification walls which run along some of the ridges surrounding the town of Crater. The reservoir has a T.W.L. of 320 feet. It has two compartments, one about 1.0 m.g. in capacity for supplying Maalla and Tawahi, and one about 1.2 m.g. in capacity for feeding Crater. This tank was commissioned in 1954. It is supplied from [illegible] via two rising mains one 20" in dia. and the other 15" in dia. Water is also pumped from [illegible] via a 16"/18" dia. rising main to the two Jebel Hadid tanks constructed with sectional steel tank plates at the top of Jebel Hadid mountain. Each of these two tanks has a capacity of 0.5 m.g., a height of 18 feet, and a T.W.L. of 370 feet above sea level.

From the Main Pass and Jebel Hadid tanks water is supplied to Crater, Maalla, and Tawahi via 18" pipelines in duplicate and to Khormaksar via a 18" dia. main.

There are several small [illegible] tanks particularly in the military areas in Tawahi and Khormaksar. A 1 m.g. walled circular balancing tank was constructed on a ridge in the [illegible] area of Maalla in 1959 but has not been commissioned till now.

The Aden water supply system has more than 200 miles of mains varying in diameter between 3 and 24 inches, and has several hundreds of miles of galvanised iron service pipes connecting supply to houses. House connections are individually metered, whilst bulk meters are used for the major consumers such as military camps, public corporations, factories, etc. The total number of meters in the Aden system (as distinct from the Little Aden system) is about 22000 meters.

5.4.2. The Little Aden System

Water is pumped from the Bir Ahmed reservoir via a 12" steel pipeline to the two low-level tanks of [illegible] house, each having a capacity of 1 m.g. from which it is pumped to the service reservoirs for the Little Aden township and also to the two 1 m.g. capacity welded circular tanks at Cathedral Hill which service the B.P. Oil Refinery. The distance from Bir Ahmed to [illegible] house is about 28000 feet and the distance from [illegible] house to the township tanks is about 8,000 feet. The distribution is carried out both at [illegible] and [illegible] units.

[illegible] Little Aden water is supplied to a few places and a few standpipes in the villages of [illegible] and [illegible]. [illegible] supplied by [illegible].

5.5. Cathodic protection:

Magnesium anodes are suspended in the water in the steel reservoirs at [illegible], Bir [illegible], Bir Ahmed, Slaughter House and Middle Aden to protect the inside of the tanks against corrosion. Also, silicon iron anodes are used with impressed current for the protection of the outside of some of these tanks such as the case of [illegible] and Bir Ahmed. Bir [illegible] tanks are not given external cathodic protection because the soil at Bir [illegible] has a high resistivity.

5.6. Communications

There are asphalt roads to practically all parts of the network. Telephone and radio communications connect all the main parts of the system with the head-quarters at Crater and with each other.

CHAPTER- 6

[illegible]

6.1. Introduction:

With an organisation like the public corporation for water as such a wide range of problems and shortcomings could be encountered and as several years have elapsed since the setting up of this corporation from a small water supply department, one would expect that it should not be too difficult to find data to consider these problems and study ways and means of combating them. However, this assumes that records and statistical data have been kept and that there are the necessary qualified personnel to analyse them.

Like any similar organisation in a developing country there could be problems of a financial nature, shortage of qualified manpower, and a multitude of other problems of various degrees of importance. It is perhaps noticeable that the W.S.C. [illegible] and any such other organisations in [illegible]. So that the difficulties seem to be increasing day after day. This is no doubt a reflection of the economic and other circumstances of the country as a whole.

6.2. [illegible]:

[illegible] responsible only for the [illegible] water supply. [illegible] the sudden departure of the British expatriate technical staff with the rest of the British civil servants) was made responsible for water supply systems throughout the Republic. However, many of the up-country towns and villages which had so far no water supply systems demanded such systems immediately after independence, and started to bring considerable pressure upon the central Government to give in to these demands. However, the new financial situation of the country did not permit such expenditure. To gain time, the Government dispatched the already depleted staff of the Aden Water Authority to these various places to make technical reports.

The Aden Water Supply System has been normally a money making concern. A U.N.D.P. consultant wrote in 1969 about the economic aspects of the Aden Water Supply: "There are about 30,000 consumers and the charge is [illegible] 0.850 per 1,000 gallons. Revenue in 1966-1967 was [illegible] 770,000 and expenditure [illegible] 681,000 including [illegible] 197,000 [illegible] payment on various loans totalling approximately [illegible] 3,000,000 (17) p.5. However, there were times when the Authority ran at a loss as was the case in one year [illegible]. Despite an overall reduction in unit costs of production from [illegible] to [illegible] per 1000 gallons sold, the undertaking continued to run at a loss, the deficit for one year being [illegible] 46,688. The basic reason for this [illegible] lies in the fact that due to the large capital expenditure incurred in recent years, interest and redemption of loan charges have appeared in the balance sheet for the first time, in the history of the undertaking" (10) p.15. One of the most important developments concerning the urban water supply were the transformation of the organisation into a self-financing corporation in 1970, and the introduction of a 5-year National Development Plan. To begin with, the plan helped relieve the N.W.S.A. of the pressure of the politicians from the various up-country places, as development from then onwards had to follow the plan. Unfortunately, the plan was far too ambitious as can easily be seen in retrospect. Most of the projects to be financed by the N.W.S.A. have already been cancelled or postponed to be included in a future plan. This may tend to encourage up-country politicians to resume putting pressure on the N.W.S.A. The 5-year plan states that over 9.0 million [illegible] nearly 10% of the total allocations for the plan- are to be allocated from the reserves of the public corporations, of which probably only the Port Trust, the Public Corporation for Electric Power, and the N.W.S.A. have some, and the sum of the 9.0 millions represents most of these reserves. As the N.W.S.A. is suffering from an accumulation of large bad debts because some organisations and persons are not paying their bills and the N.W.S.A. is not able to disconnect their supply because of political and social reasons, the loss of the reserves [illegible] have grave [illegible]. The [illegible] may have to resort to financing [illegible] which would clearly decrease [illegible] development as predicted.

6.3. Organisation and Management Problems

The transformation of the [illegible] water supply organisation from a department within the same Ministry of Public Works and Communications into a self-financing Public Corporation in 1970 was no doubt a bold step in the right direction, and was preceded by a few deliberations. This idea was toyed with before Independence but the State P.W.D. was reluctant to release its hold over a money making concern, for though the revenue went directly into the central treasury, yet the P.W.D. probably felt that it could get a larger annual budget since one of its departments was making money. The Corporation was setup to deal with water supply throughout the country and not merely in Aden. An Executive Chairman was appointed to run the organisation with the help of a Board of five part-time members. Unfortunately, this Board has been suspended for over a year now and the Chairman has to refer to the Minister of Works and Communications in all important matters, and this situation should not be allowed to persist for the sake of efficiency. Moreover, the Chairman has already been changed three times during a short period of about two years. In addition, the present appointment has been mostly on political grounds since the present Chairman has no technical or administrative background to help him in discharging his duties. It is, therefore, not surprising that most of the senior technical and administrative staff of the P.W.C. have been sacked in August, 1972 leaving the organisation in a critical position.

The question of merging the P.W.C. with the well established P.C.E.P. is currently under study by the Government. A report is being prepared by the Executive Chairman of the

P.W.A. on this subject. In the [illegible] preceeding Independence, the Water Authority was negotiating with Aden Electricity Corporation (which was transferred after Independence to the P.W.A.) the question of having a combined monthly bill to the consumer. After Independence the Water Authority changed from monthly to bi-monthly billing to reduce overheads a little. Even if it is decided not to merge the two corporations they should consider common billing and common meter reading, etc.

As an independent corporation the P.W.A. has now the advantage of being able to order any necessary spare parts and equipments without having to go through the very slow government financial procedures which often take between one and two years, due to the economic difficulties of the country.

6.4. Personnel Problems

The corporation employs [illegible] 530 persons. There is no difficulty in obtaining unskilled labour, but there is an acute shortage of qualified personnel, particularly engineers, accountants and technicians. This shortage has been existing even in the pre-independence days but of course in a much milder degree. [illegible]

* In the introduction to this report mention was made of the urgent need for additional staff. I must apologise, therefore, if in my conclusions I [illegible] to the matter again, but I consider it one of the most pressing problems facing the Water Authority at the present time. The idea that

Aden's water supply can continue to function satisfactorily irrespective of the number of senior staff may have had its origins in the lack of restrictions during the past 6 years, but such ideas are false. The water supply has only continued to be satisfactory because a number of conscientious officers were prepared to work such long hours to avoid failures. With the increase over the past 6 years of installed mechanical and electrical plant, plus that proposed in this report, the ability of staff to prevent interruptions to the supply depends increasingly on adequate maintenance of installations. This can only be achieved with sufficient supervisory staff and hence until such additional staff are made available the risk of failure will continue to increase ", (10) p.14.

After the departure of the British supervisory staff the water works was run by their local assistants some of whom were of not adequate experience. A UN consultant reported in 1969 that there was only one qualified Engineer directing a staff of 556 including meter-readers, clerical and construction staff, and that operation, maintenance and construction was carried out under five inspectors of works. He also stated: " The organisation does not include a senior administrative officer or an accountant and the Waterworks Engineer is consequently burdened with executive administrative and petty routine details. He also lacks a mechanical-electrical engineer" (17) p.8. The staff situation has considerably improved since that report was written due to the expansion of the duties of the organization to cover the whole country, and due to the termination of the services of a number of the senior employees. The effects are a lower efficiency of the system and poor maintenance of assets.

The Corporation has to recruit local and foreign senior staff to improve the situation. It has also to give considerable attention to the question of training. Local and overseas training programmes [illegible] will be evolved to produce senior and supporting staff of a satisfactory calibre. Such programmes used to be followed before independence.

6.9. Planning Problems

The Aden water supply system was started about forty years ago and was gradually built up into a fairly sophisticated system. Before that, several preliminary reports had been prepared on suggested schemes such as the report of Messrs [illegible] and [illegible] dated 26th April, 1912, and the report by Major [illegible] and Captain Taylor dated 15th April, 1919, and the notes by Doctor [illegible] in 1917; however, usually no action was taken upon the recommendations of these reports. Development of supply tended to lag behind the increasing demand as can be read in the report by Jackson in 1956: "In these times, with the exception of the report of Messrs. [illegible] which was not acted upon, no real attempt has previously been made to provide more than palliative measures, usually very much in arrears of requirements", (9) p.2. The fact that planning tended to be short term in nature until at least 1960 is inferred from Jennings statement in 1963: " Unfortunately, the present policy of short term planning combined with the fact that senior staff strength is always lagging well behind minimum requirements, makes it impossible to achieve the proper standard of planning and design", (10) p.1. Jackson and Jennings themselves managed to achieve some degree of forward planning and perhaps the fact that water rationing and restrictions of supply were not resorted to after the water rationing during 1952/53, except for occasional short periods particularly during the last phase of the Independence struggle, supports this statement.

Due to the withdrawal of the British forces, the Aden water supply was left with spare capacity. This spare capacity, however, has now been used up due to the increase in population as a result of the movement of up-country population into Aden, and the A.W.S. has to plan for development. Planning for development should be rather difficult because of the difficulty in estimating future demand.

The present population is not known to any degree of accuracy and this difficulty will be solved when the proposed country wide census is completed. Future increase is difficult to estimate at the moment. It is unjustified to assume that increase would be following previous trends due to the major political and economic changes in the structure of the country. Furthermore, the 5-year plan envisages the establishment of several industrial projects such as factories for spinning and weaving, fish canning, cement production, soap, bicycles, [illegible], animal feed, etc. and mills for flour and cotton seed oil. However, up till now, the capacities of several of these projects have not been finally decided upon, although more than half the duration of the plan is already over. Moreover, several of the projects have been cancelled or postponed.

Another problem facing planning is that the P.W.A. does not know clearly the state of its assets and does not have a schedule for replacements, although many of these assets are approaching the end of their useful life. The concentration on up-country development distracted attention from the need to maintain the Aden system properly. The P.W.A. has to draw up preventive maintenance schedules and to conduct a major review of the system.

A U.N. expert estimated that the whole of the industrial plan would require an additional 1 million gallons/day, and that the present capacity should suffice up till about 1982, (10). On the other hand the water works engineer estimated that the requirement by 1980 should be 13.5 mil per annum i.e. almost twice the present consumption, (11) p.1 As both these estimates were made until the middle of 1978 this very wide difference in opinions goes to show the difficulty in planning in the absence of adequate data.

A small statistics section exists in the P.W.D. but it is at present manned by only one junior clerk, whereas a considerable amount of statistical data and useful information concerning the quantity and quality of the water, the wells and sources, the pumping, etc. can be collected and classified if the necessary qualified staff were found to run the section. A planning section has recently been set up to be run together with the design section and the drawing office by the most experienced engineer in the P.W.D. This is no doubt a good step, and it is suggested here that the statistics section be also placed under that section. It may also be suggested here that the P.W.D. should develop a reasonable library which should include copies of all reports on the water supply systems in the country and some useful reference books and catalogues connected with water supply, and the library be placed under the planning section.

So much work is awaiting this planning section such as :-

(a) Following up the progress of the 5-year plan and its modifications,

(b) developing the statistics section so that various useful data is recorded, sorted out and classified,

(c) bringing up to date the drawings of the water supply systems of the country,

(d) surveying the assets of the P.W.D. and in the light of the findings coming up with comprehensive maintenance and replacements schedules,

(e) Drafting out local and overseas training programmes,

(f) evolving standards to be followed particularly in the purchase of equipments, as after independence equipments from various sources and not always conforming to the British standards previously adhered to have been obtained,

(g) development of a library for the Corporation,

(h) development of an embryo research section to investigate matters such as the effects of local climatic condition on the different types of pipelines, cost comparisons of different types of pipelines taking into account initial and running costs, the possibility of local manufacture of well slotted casing, etc.

(i) introduction of more up to date techniques.

It is only with forward long term planning that expensive mistakes might be avoided. Thus, for instance, only by keeping in close contact with the irrigation projects in the [illegible] area that the effects of these projects on the water levels in the area water supply wells can be followed and a dangerous drop which can render these wells useless may be avoided. The selection of locations for future boreholes is another example of problems that call for long term planning. [illegible] suggested that the new water supply wells should be sited in the sand [illegible] areas in order to reserve the areas of good soil for ground water irrigation development (10) p.3.

6.6. Technical Problems:

The P.S.A. has several technical problems which require consideration and which can be solved provided there are the necessary funds and the necessary qualified people. Time has not made it easy to look back and examine any technical weaknesses in the system. The technical points which seem to require consideration by the P.S.A. are discussed below.

6.6.1. Depth of Wells:

Parker states, " It is somewhat surprising that a well depth of 70 metres has become so generally accepted in the delta. It appears to have been established in the Bir [illegible] area where there is a fairly thick silty clay at about this depth. This clay may be expected to be of limited thickness and a return to coarser material may be forecast at greater depth." (11) p.6. He goes on to say, " It should be noted that the replacement wells in the future should penetrate to about 150 metres, thus providing hydrological data on the deeper part of the system. The Bir Ahmed oil exploration well may provide some data on the complete thickness of the alluvial deposits in the lower delta. Several wells in the upper delta already penetrate to the crystalline basement and [illegible] may undertake some deep exploratory drilling ", (11) p.7. Parker also states, " The Bir Nasser well field for [illegible] water supply represents the largest single [illegible] in [illegible]. However, these wells must be approaching the end of their useful life and will in any event require replacement

during the next few years. They are therefore to be gradually phased out and replaced by wells to a better design, distributed on a more effectively spaced well field (12) p.6
It should be remarked here that only the first line of wells, 15 in number, goes back to 1956, while the second line, also 15 in number, was constructed in 1961, the other remaining wells being only a few years old. As to spacing of the wells, the [illegible] report on p.2 states " within each line, the wells are spaced at 250 metre intervals. Despite this close spacing, unacceptable interference and drawdowns were not experienced" (Incidentally, the spacing is 100 feet and not 250 metres). Jackson wrote about the spacing at Sheikh Othman, " It is, therefore, most unfortunate that such a concentration of wells has been sunk at Sheikh Othman. As these bores tap the water flowing through an underground aquifer of a limited capacity, it is not wise to sink wells too close together In fact all authorities are agreed that a spacing of 1000 feet is the least that is desirable. This has in fact been proved in tests carried out in connection with the [illegible] Town supply " (9) p.5, the spacing of the wells at Sheikh Othman can be seen in Figure 12.

[illegible] states, " According to Mr. [illegible], [illegible] hydrologist, water levels have fallen about 5 metres in the [illegible] during the past years. The reasons for this fall in water level are not fully understood. Increased pumpage at Lahej, [illegible] and elsewhere has undoubtedly contributed. It is also possible that these years were of below average recharge". (18) p.3. As the [illegible] ground-water is developed for irrigation, the levels are expected to fall further. The yield of the wells, particularly the older ones, has decreased due to corrosion, and it is not possible to increase yield by using more powerful pumps because the sand would shorten the life of the pumps considerably.

Barber suggests that the most suitable design of new wells appears to be wells 150 metres deep consisting of 12" casing and screen to about 100 metres with a 6" liner of casing and screen from 100 to 150 metres, without the necessity for screens in the uppermost part of the aquifer as these will be non-effective due to decline in levels. This is suggested as a temporary standard until optimum well design has been determined, (18) pp. 3 & 6. Perhaps the [illegible] should investigate the possibility of deepening some of the wells particularly the newer one, possibly by the use of a rotary drill as this should be easier to use in such a case.

[illegible] suggested that if a third line of wells be drilled at Bir Nasir it should be sited at least 5000 feet north of the existing second line of wells to avoid interference, (14) p.13.

6.6.2. [illegible]

The permeabilities of the aquifers at the [illegible] are practically not known. [illegible] in 1960 stated clearly that the permeability of [illegible] [illegible] was unknown, (10), p.13. The [illegible] project being conducted in liaison with the Department of Irrigation for the development of [illegible] [illegible] for agriculture is making a study of permeability in this area. It appears that the values for transmissibility and permeability for the [illegible] well field has been found to be of the order of T = 7000 ft^2/day, and K = 30 ft/day (12) p.5. The permeability for the [illegible] [illegible] should be determined as this value is needed for determining the proper design and spacing of future wells in the area.

6.6.3. Corrosion and Incrustation

The water supply system of [illegible] suffers from both corrosion and incrustation. The salinity and humidity of the atmosphere enhance corrosion [illegible], whilst the hardness of the water is responsible for the high rate of incrustation which affects the water conveyance system quite adversely. Asbestos-cement pipelines suffer considerably less than the metallic pipelines in the system from either of these effects, and this explains the wide use of asbestos-cement pipelines in the [illegible] system.

Incrustation causes appreciable decrease in the internal diameter of the pipelines, and in some cases warrants regular cleaning of the pipeline. Incrustation of the [illegible] [illegible] pumping main [illegible] [illegible] so great that it was necessary to clean the main annually to maintain [illegible], (24) p.5. Incrustation also affects the water meters considerably and the rate of meter replacements is very high. During 1958-59 for instance, 5% of all the meters in the system were overhauled and repaired. Shortly before Independence, the Waterworks Engineer was considering seriously the introduction of the use of distributing cisterns in place of water meters in some of the districts, at an experimental level.

The dependence less and less on [illegible] water and more and more on the [illegible] water will produce the combined good consequences of less encrustation in the conveyance system, and water of a better quality to the consumer.

The replacement of cathodic protection anodes and the repainting of the various assets regularly are particularly essential in the Aden Water Supply System because of the climatic conditions which tend to promote the rate of corrosion.

6.6.b. Water Sample Analysis:

Annual analysis of water samples from the three localities used to be carried out by the [illegible] before Independence. Regular sample analysis should be resumed, so that deterioration and improvement in the quality of a source can be noticed in good time and appropriate steps to be taken. The suitable [illegible] between tests can be determined by the statistics section of the [illegible] by examining the trend in all areas.

6.6.5. Chlorinations.

Disinfection of the water is carried out with chlorine gas, but some of the chlorinators are no longer functioning properly, and it is most essential that they should be repaired or replaced without delay. Cholera and other water borne diseases are not unknown in this part of the world and every precaution should be taken to ensure the safety of the water for drinking.

6.6.6. High pressures.

The mountainous topography of the Aden peninsula is responsible for the high pressures of water particularly in the distribution system of the town of Crater which receives water from the Main Pass high-level reservoir which has a T.W.L. of about 320 feet. These high pressures necessitate the use of the more expensive class-B pipes in most part of the Aden system, and cause the usual problems that go with high pressures such as higher leakages and more difficult valve operation. Where the topography permits, offtakes for storage reservoirs and balancing and service tanks should be selected so that both too high and too low pressures are avoided.

6.6.7. Waste Detection.

Waste in the system is running at over 20% and is possibly closer to 25%. During the period that preceded Independence waste ran at over 30%, as rioting, political disturbances, and curfews curtailed movement within the country exceeding that of the expatriate staff, even though they belong to the essential services.

The Water Authority used in the past waste detection meters advantageously and it is suggested here that waste detection should be carried out in the various districts, beginning with those where higher waste is suspected.

6.6.8. The 16" Pipeline from [illegible]

The technical problem seems to exist in the 16" spun iron gravity main between [illegible] and [illegible]. This pipeline was laid to ground levels as opposed to a continuous gradient and in consequence it was found necessary to install automatic air valves at the high spots to improve flow characteristics, (19) p.12. And although the flow improved considerably upon the installation of these valves, yet there still seems to be difficulties with this pipeline. Considerable vibrations are felt in the pipeline. This problem deserves investigation and no doubt these vibrations can be eliminated or reduced if the proper remedy measures are taken. It is likely that the air valves installed are not able to get rid of all the entrapped air.

6.6.9. Maintenance

It is worth while to mention again the importance of maintenance which, if properly and rigorously carried out, can reduce many of the existing problems, and can stop many other new problems from occurring. Negligence of maintenance might not show its consequences immediately or in a very obvious manner but they are there all the same in the shape of rapidly depreciated equipment, overtime work, etc.

Maintenance schedules should be drawn out and followed strictly. Corrosion should be fought by the regular painting of assets and the regular replacement of cathodic protection anodes, etc. The stores of the P.W.D. should be correctly stocked with spare parts, spare units (such as spare submersible pumps) and materials of all types that may be needed ranging from steel pipes to chlorine gas cylinders.

6.7. Optimum Use of Resources.

The problems discussed above are merely indicative and do not form a comprehensive list of problems facing the P.W.D. Two 1-million gallon reservoirs which were completed in 1967 have still not been commissioned five years later. This gives an indication of the problems facing the P.W.D. No doubt, these problems can be tackled if the necessary funds and qualified staff were available. However, meanwhile, with improved organization, the P.W.D. can make the most optimum use of the available resources to greatly reduce its difficulties.

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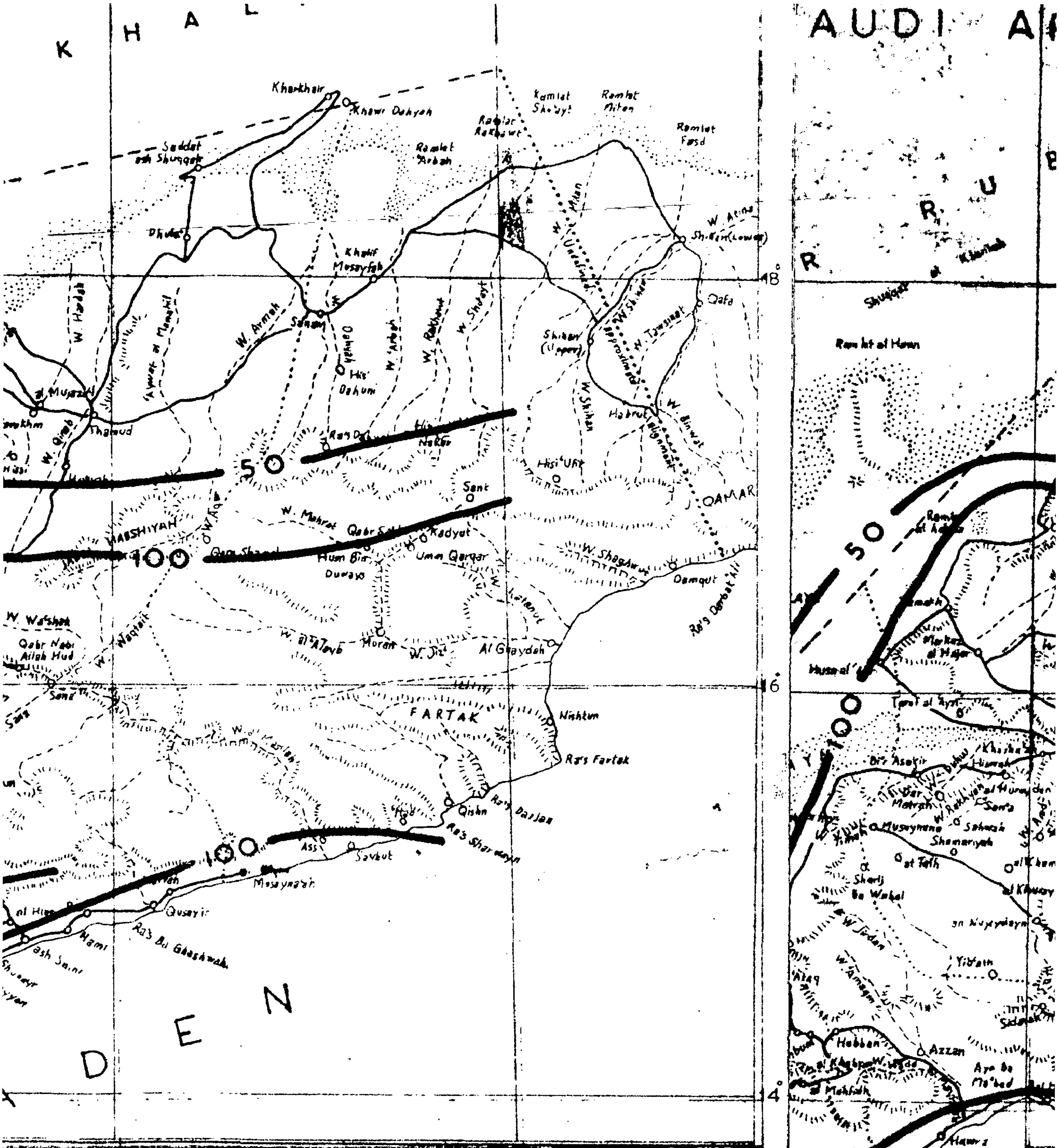
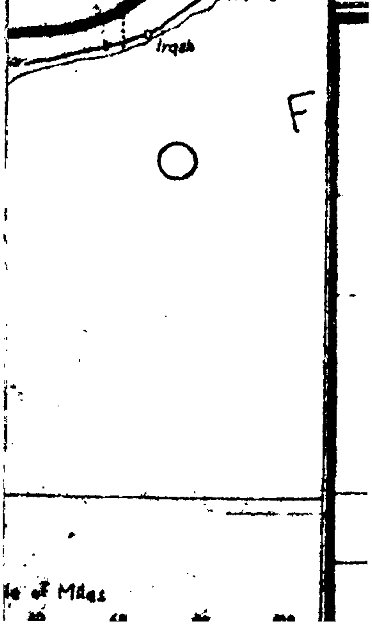




DEPARTMENT OF AGRICULTURE
&
IRRIGATION

FIGURE 1

GENERAL

REPUBLIC OF SOUTHERN YEMEN MAP

ANNUAL RAINFALL OF P·R·S·Y

DATE

OCTOBER 1970

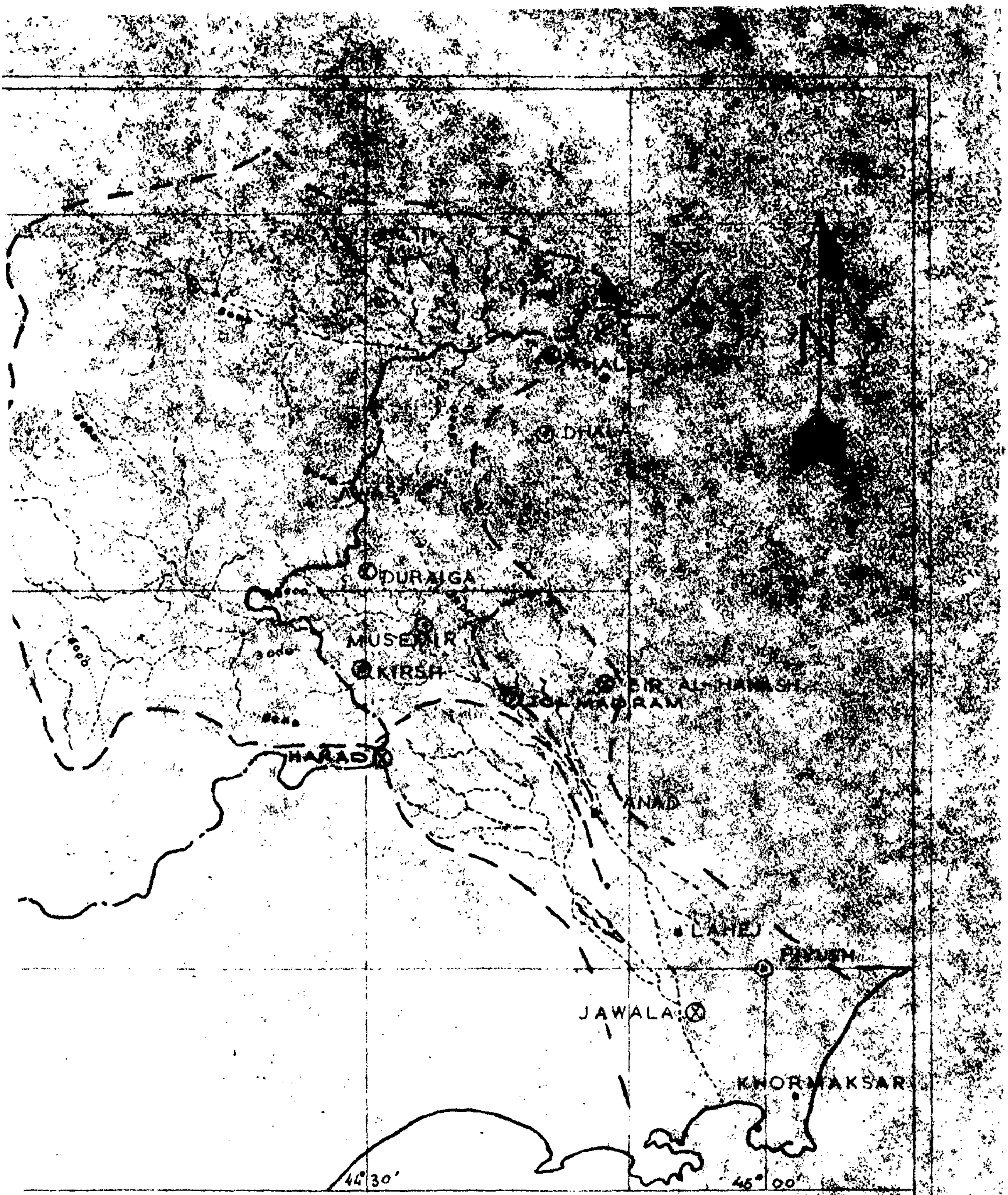
SCALE

DRG· NO·
10,000 / 34

SAUDI A
R U B
A R
50
100
300
JAWW AL MULAY
M E N
Habban
Azzan
Ahwar
Irqah
Mahfidh
ADEN
Little Aden
Perim I.
G U L F O F
Scale of Miles


45°
46°
Wādī Khabb
Jabal al Burm
Ar Raşīb al Aswad
Umm Jawdān
Beni Ji'ās
Wahaţān
Mushayniqah
Al Qu'ayfah
Al Kharāb
Waqr Maryamah
Al Jabal al Ahmar
Al Qu'aymah
Jam
Ash Shahlā
Jam?
Abraq al Khaliqah
Hadbat al Jid'ān
Radm al Amir
Barqā' al Ashqar
Ta'ām
Dhī Bayn
Jawf Ibn Nāşir
Wādī al Jawf
Ma'īn
Jabal al Lawdh
Duhaydat Umm al Mā'
Munqidhah
Al Libānāt
Al 'Alam al Abyad
Bāb al Manqadah
Banī 'Abid
Mishām
Raydah
Qutbini
Qanbarah
Barrān
Milh
Banī Khayrān
Wādī al Abrād
Jabal ath Thaniyah
III–I
Şāfir
Qe
Ramlat
Ma'rib
Şirwāḥ
Amrān
Qa
Tm
Darwān
Rawdah
SAN'Ā
Jabal Nuqum
Ghaymān
Dhanāh
Jabal Hufāsh
Zaylah
Ḥazyaz
Tgr
Manākhah
Ar Rijlah
Sūq al Jum'ah
Al Wuţayy
Nuşayl Zarājah
Khodārah
Jabal Harāz
Zubaybān
Al 'Ubaylāt
Bayt Nāqil
Zarājah
Ma'bar
Dawrān
Ḥamrā'
Rad'ān
Jabal Dawrān
Ribāt
Al Manşūrīyah
Khubayr
Madīnat al 'Abīd
Hammām 'Alī
Ad Dāyā
Ad Durb
Dhamār
Radā
Al Marāwi'ah
Bayt al Faqīh
Bayt al Mudr
Sūq al Ithnayn
Jabal Masna'
Yamānah
Al Qafrah
Laḳhf
Dathīnah
Al Manşūrī
As Suwādī
Madārī
Al 'Ādan
Sāyah
Jabal Zahr
Rawdah
Al Ribāţ
'Arjūd
Tarīfah
Zabīd
Ad Darbah
Jabal Sūrah
Bani 'Alī
Ṣafwān
Shaqab 'Ammār
Jabal Hadrī
Sawdā
Ḥarādah
Damt
Mūsayjīdah
Sūq as Sabt
Jabal al Manār
Al 'Udayn
Sawbah
Ibb
Jurbān
Balāsān
TKt
Qa'tabah
Jubaylī
Mawshij (Mawza')
Al 'Amikiyah
Jabal al Hashā
Mimlā
Wādī Rawdān
Kumādah
Janadiyah
Ad Dāli'
Mawlyah
Qu
TAIZZ
Zahārī
Bārib
Siyārah
Jabal Şabir
Al Musaymīr
Aş Şurrah
Lawdar
Umm Farh
Jabal Rib
Qa
Al Fadli
Mudaybirah
Dār Dābikah
Bi'r Miflāb
Qubbat Jumbah
Shuqrah
Al 'Asalah
Al 'Anad
TKt? Thawbānī
Jabal Thawbānī
Dār Shuja'ah
Al Turbah
Jam
Aş Şanāmī
Qanbarīyah
Jabal Nawlān
Hunayshah
Dhubāb
Dār Murshid
Dār Dūdī Sarshah
Al Wahţ
Lahj
'Awāshib
Zinjibār
Bi'r 'Alī
Al Kawd
Ra's Saylān
Ghubbat Saylān
Umm Rijā'
Al Majīl
Bi'r Thābit
Dār Umm Sayyālah
Bi'r Ahmad
Al Aqrabī
Ash Shaykh 'Uthmān
Bi'r Umm Makhnūq
ADEN ('Adan)
At Tawāhī
LITTLE ADEN
Al Burayqah
'Azīz
Ra's al Qā'
Dār Mujahhar
'Alī 'Abd Allāh
Jabal Kharaz
Dār al 'Umayrah
Khawr al 'Umayrah
Ra's 'Ārah
Bi'r Ra's 'Ārah
Bi'r Sugayyah
Bi'r al Hajarī
Ash Shaykh Sa'īd
At Turbah
Perim (Mayyūn)
BĀB AL MANDAB
Ras Siyyān
Khor Angar
200
500
1000
1500

QUATERNERY		Qe	Eolian sand
		Qu	Alluvium on related surficial deposits (May include rocks of Pliocene age)
		Qa	Aden Volcanic Series (May include rocks of Pliocene age)
TERTIARY	Oligocene and Miocene	Ts	Shihr Group and equivalents
	Eocene	Tha	Habshiya Formation
		Thj	Habshiya and Jeza Formation
	Paleocene	Tu	Umm er Radhuma Formation
		TKt	Trap Series
CRETACEOUS			Tauilah Group
		[illegible]	Mahra Group
JURASSIC		Ju	Jurassic Rocks
PRECAMBRIAN TO PALEOZOIC		[illegible]	Precambrian (?) Synkinematic an Paleozoic postkinematic granitic rocks



THE WADI TUBAN CATCHMENT AREA.

MAP SHOWING METEOROLOGICAL STATION

ilometres 0 10 20 30 40 50 60

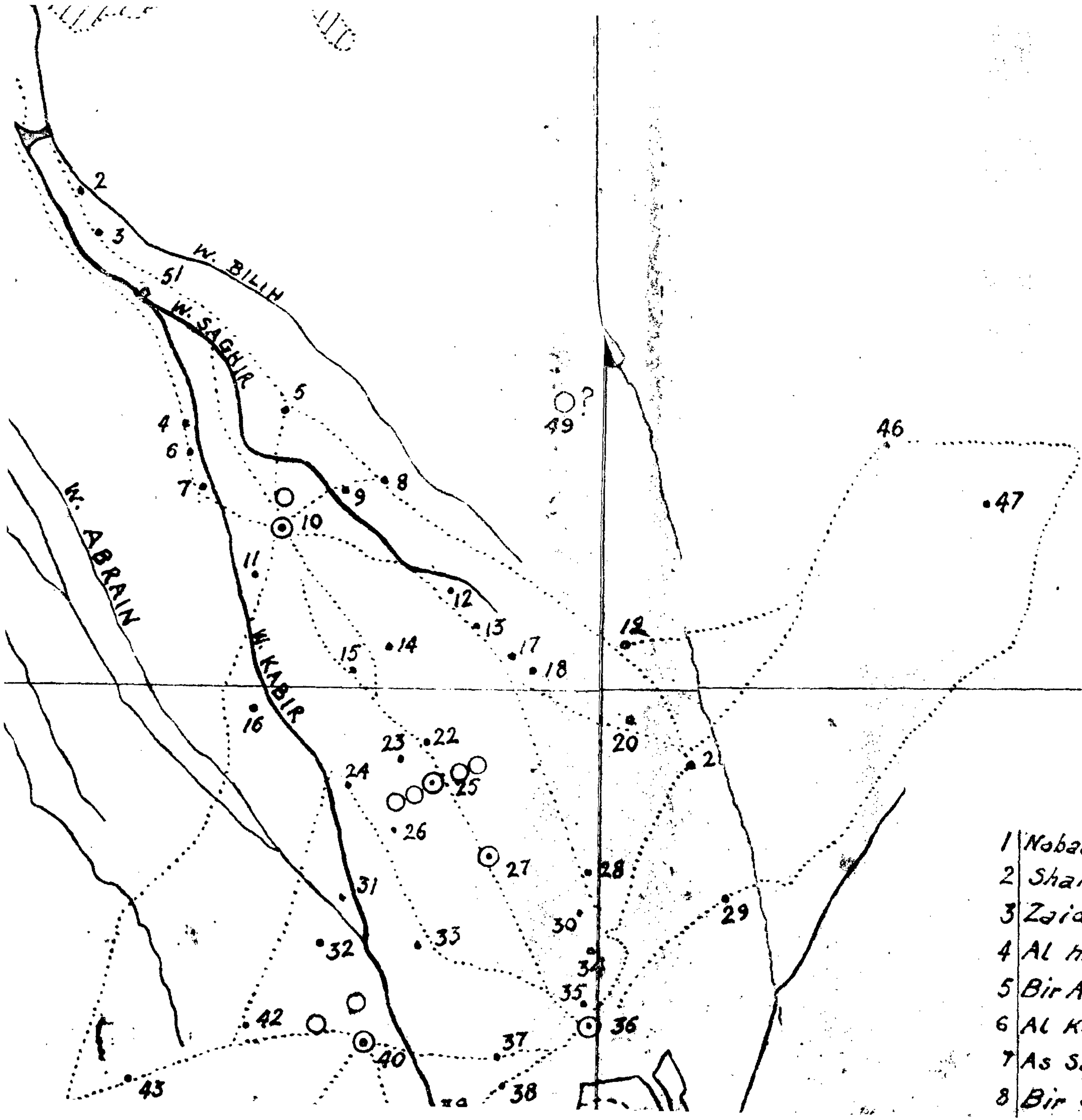
Elevations in metres

ERNATIONAL BOUNDARY
ERSHED BOUNDARY
MARY MET STATION
GAUGE STATION

SCALE 1: 820,000 (APPROX)

FIGURE 3

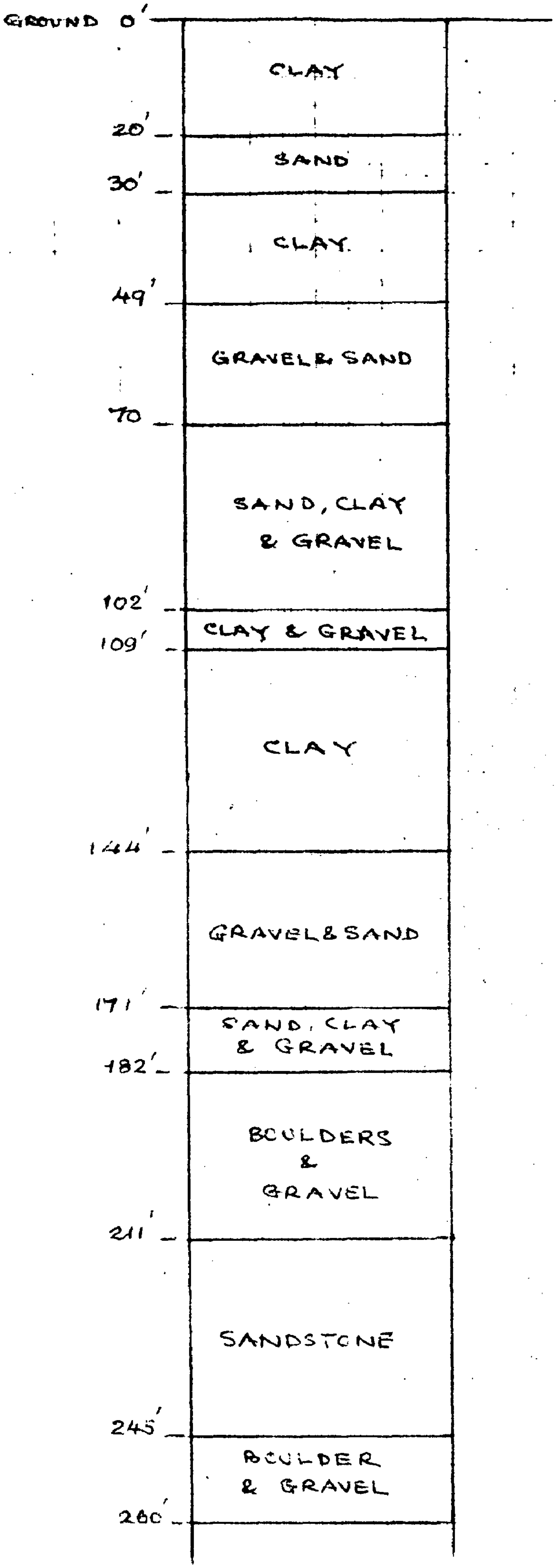
TRACED BY: A.H. BASHIEB. [redacted]



Cretace... Lavas
Pre. Cambrian? gneisses and schists.
Undifferentiated granite
Faults
Wadis
Tracks, roads
Well locations
Borehole locations

LOCATION NAMES

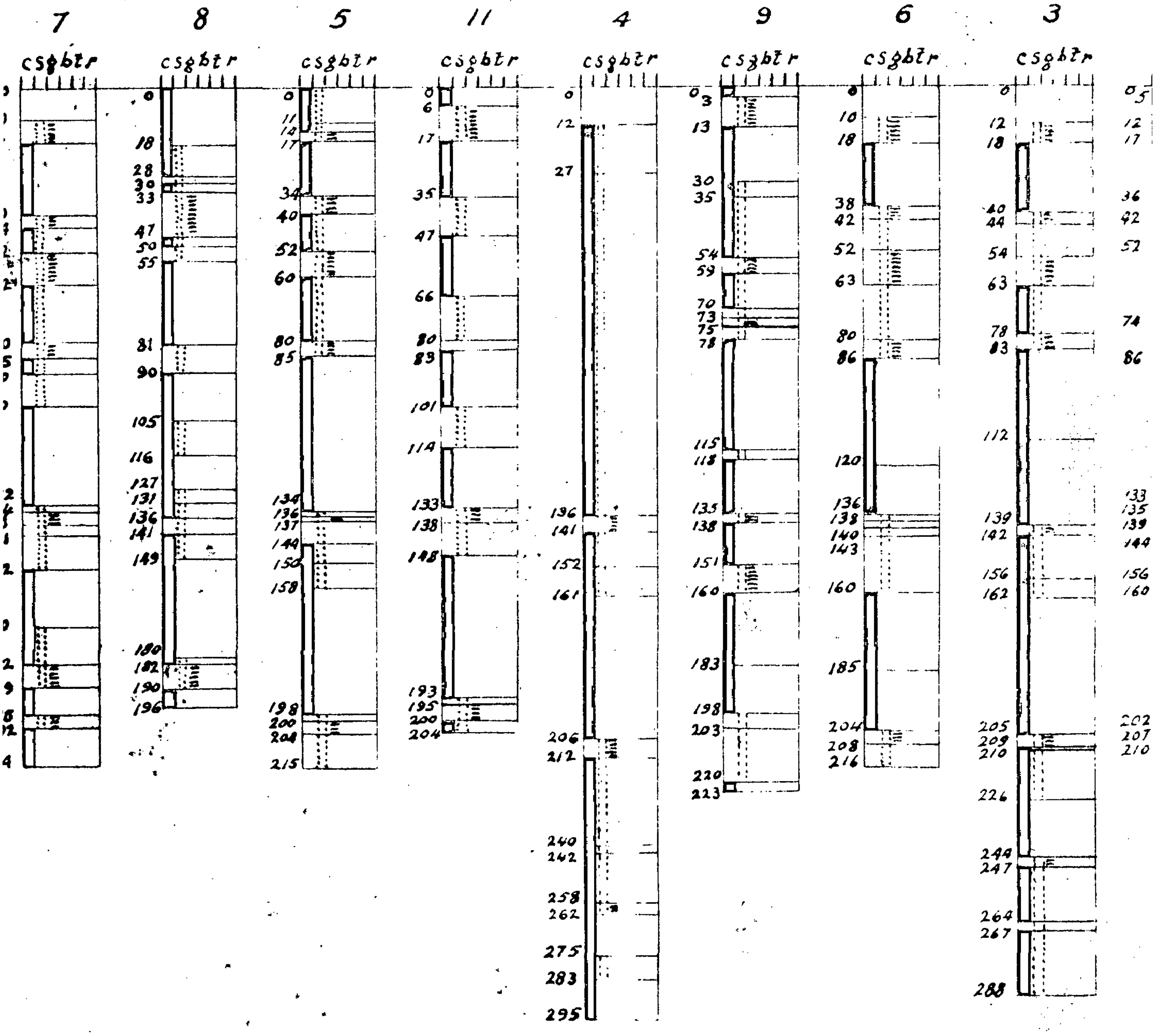
1	Nobat Dakim	18	Bir Hubil	35	Dar el A
2	Shaka	19	Bir Amr	36	Shaikh
3	Zaida	20	Manat	37	Bir Fad
4	Al Hasiki	21	Bir Jabir	38	Bir Jebi
5	Bir Am Saafi	22	Bir Amr	39	Hiswa
6	Al Kureishi	23	Nobat al Ubeda	40	Bir Ama
7	As Sa'dain	24	Waht	41	Bir Rub
8	Bir Salim	25	Bir Nassir	42	Bir Fad



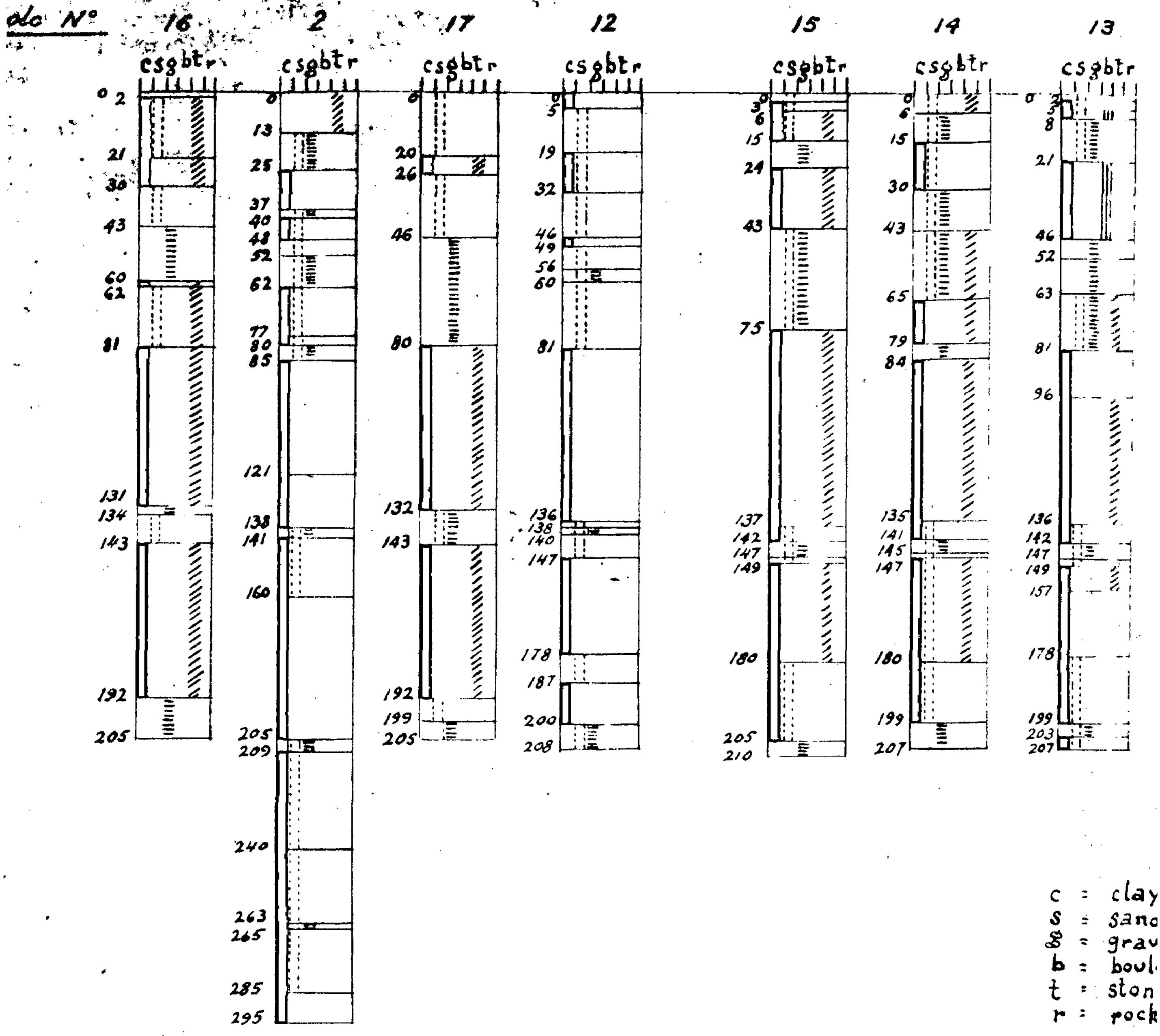
WADI TUBAN

TYPICAL STRATA LOG

FIGURE 5

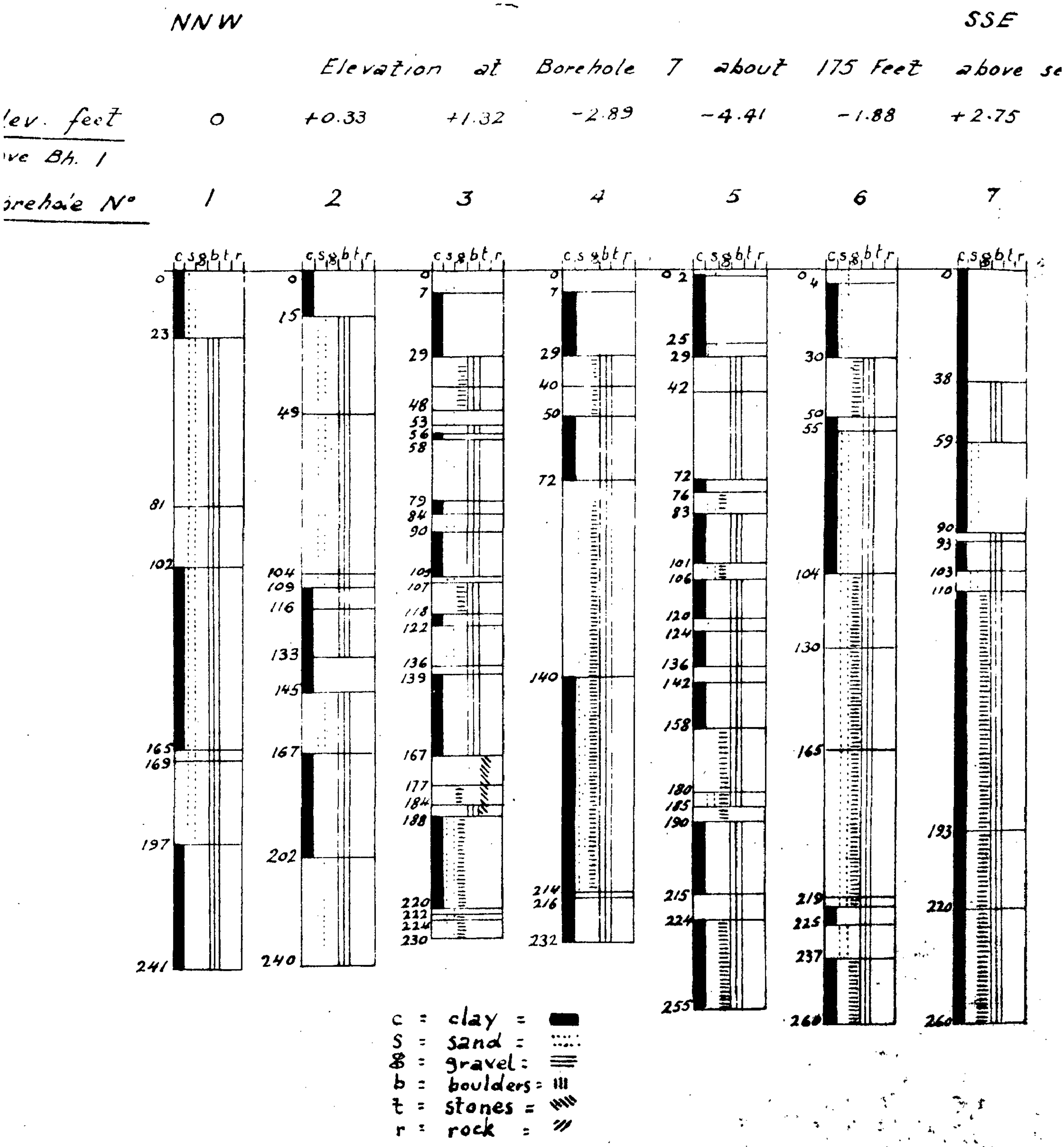


DRILLER'S LOGS OF THE SHEIKH OTHMAN BOREHOLE.
(DEPTHS IN FEET)



DRILLER'S LOGS OF THE SHEIKH OTHMAN BOREHOLES

(DEPTHS IN FEET)

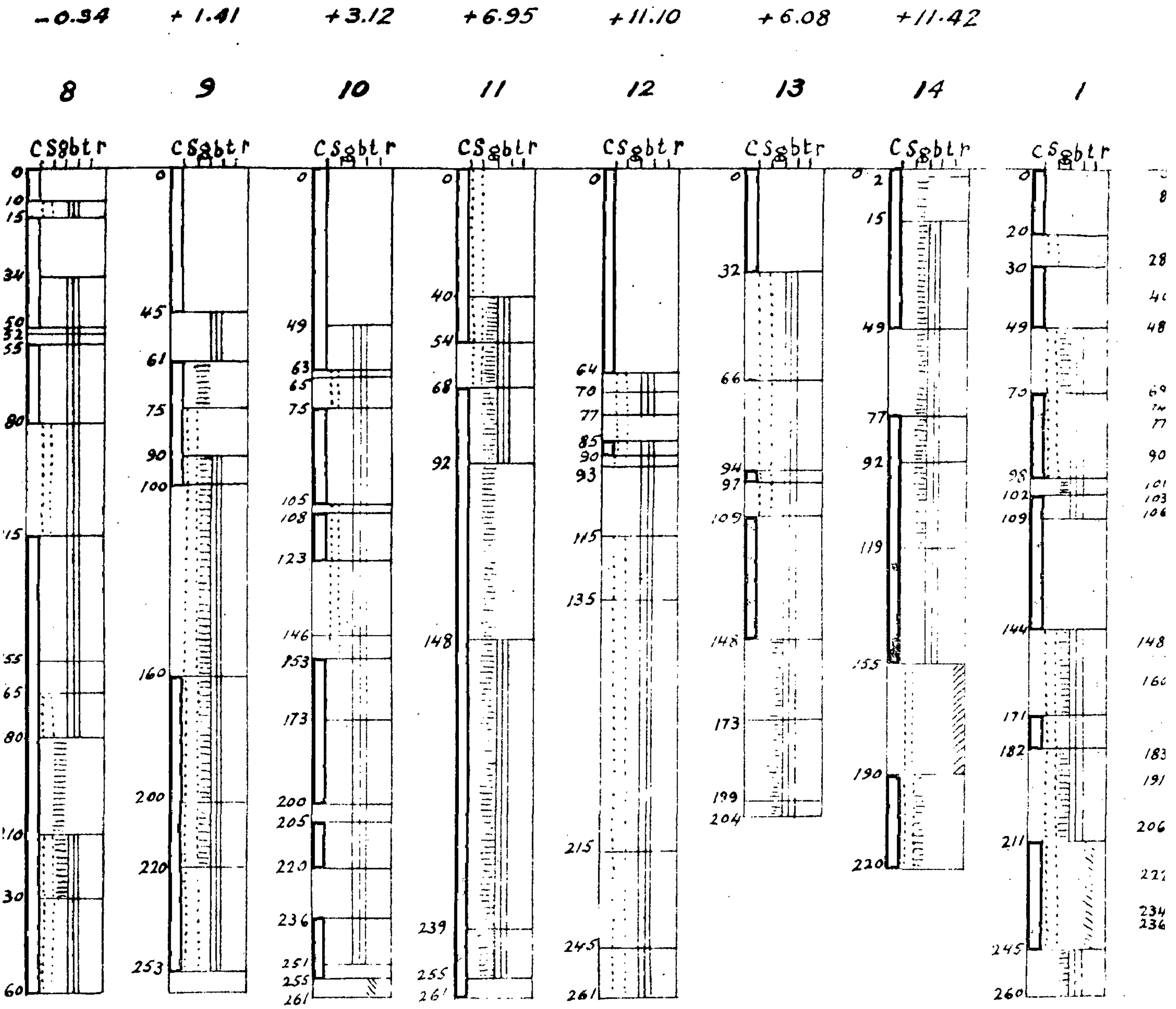


DRILLER'S LOGS OF THE BIR NASIR BOREHOL

(DEPTHS IN FEET)

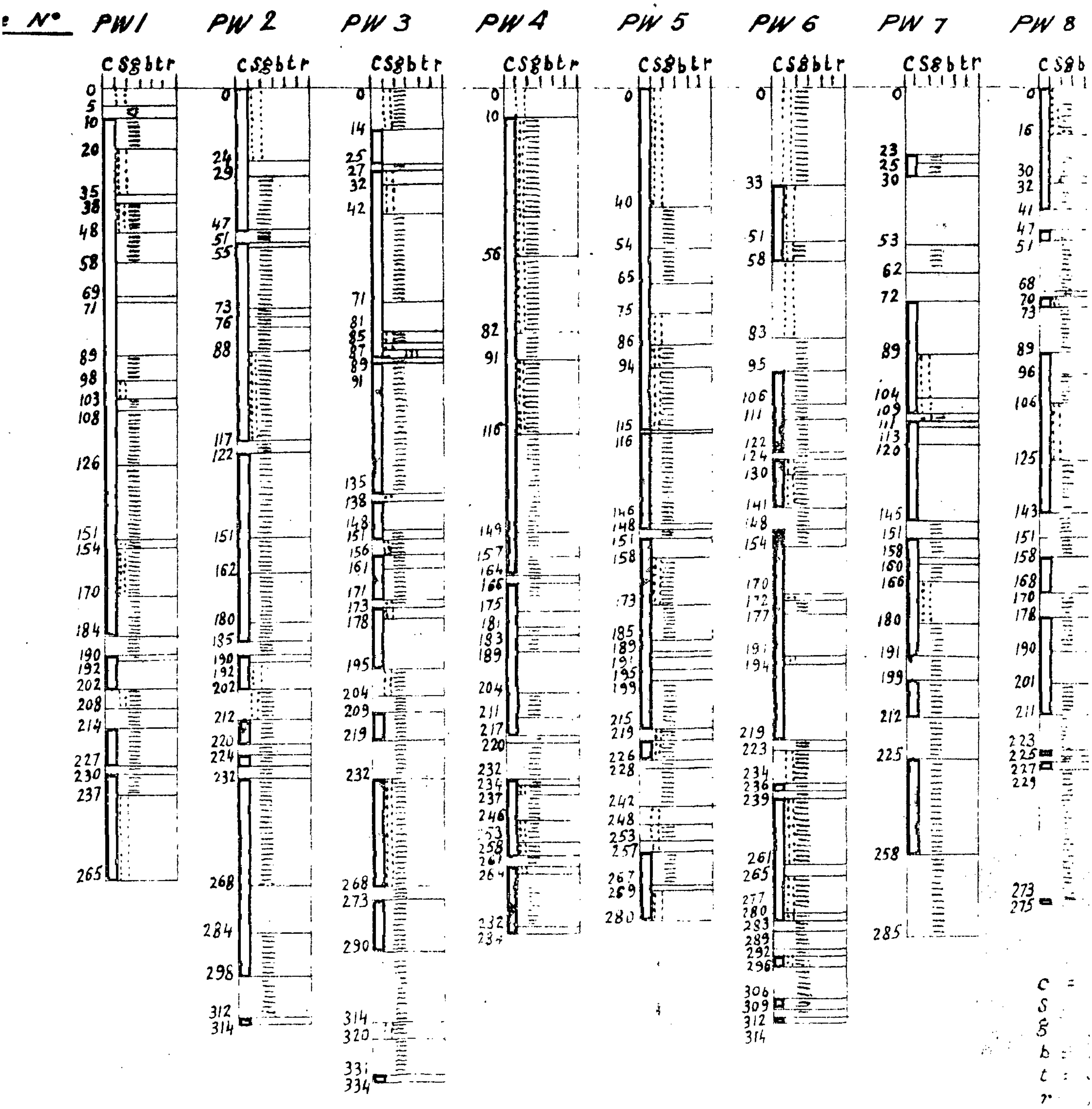
NNW

Elevation at Borehole 7 about 175 Feet



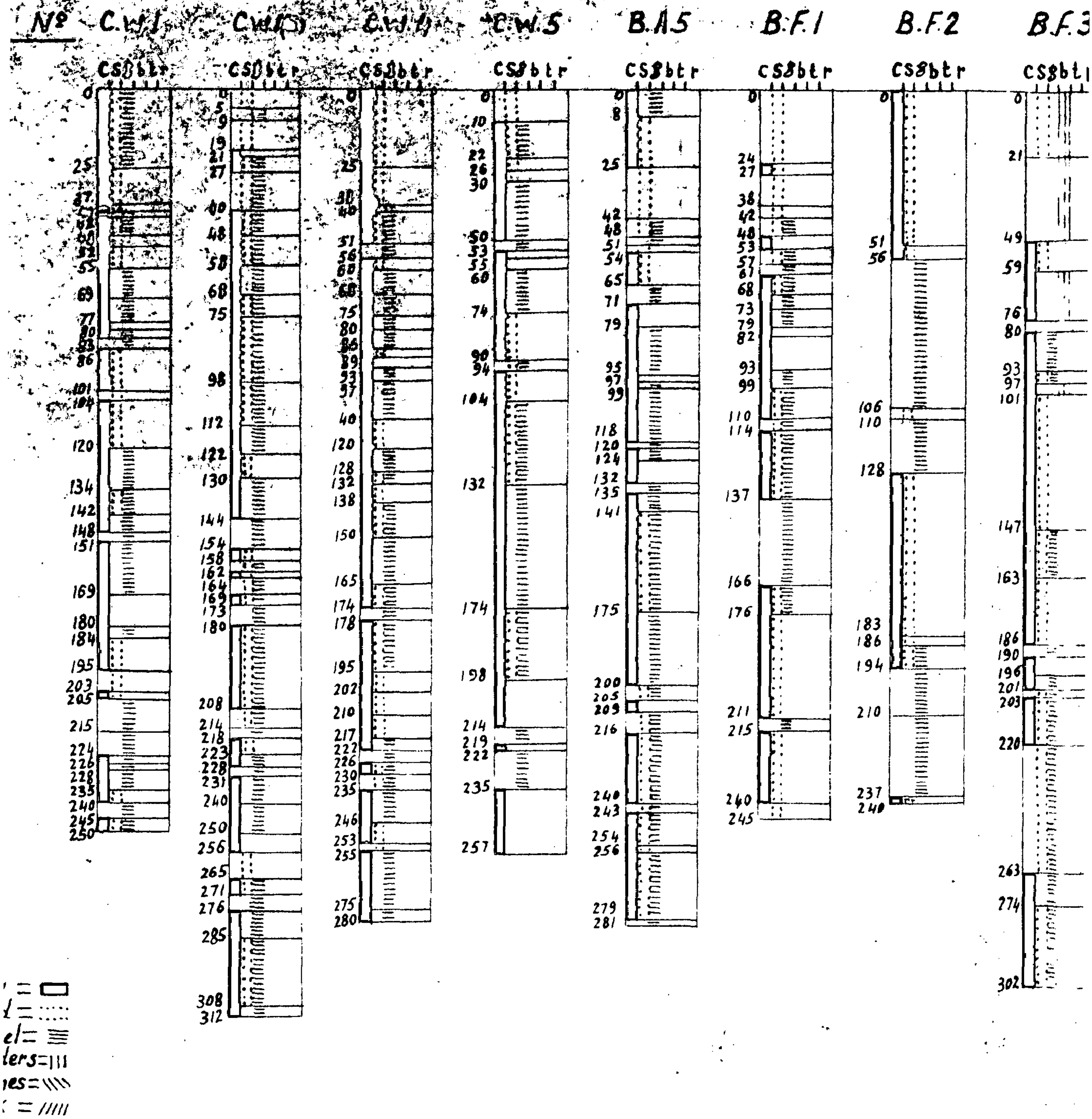
DRILLER'S LOGS OF THE BIR NASIR BOREHOLE

(DEPTHS IN FEET)



DRILLER'S LOGS OF THE BIR AHMED BOREHOLES

(DEPTHS IN FEET)



DRILLER'S LOGS OF THE BIR AHMED BOREHOLES

DEPTHS IN FEET

WELL-DEPTHS IN THE WADI TUBAN DELTA

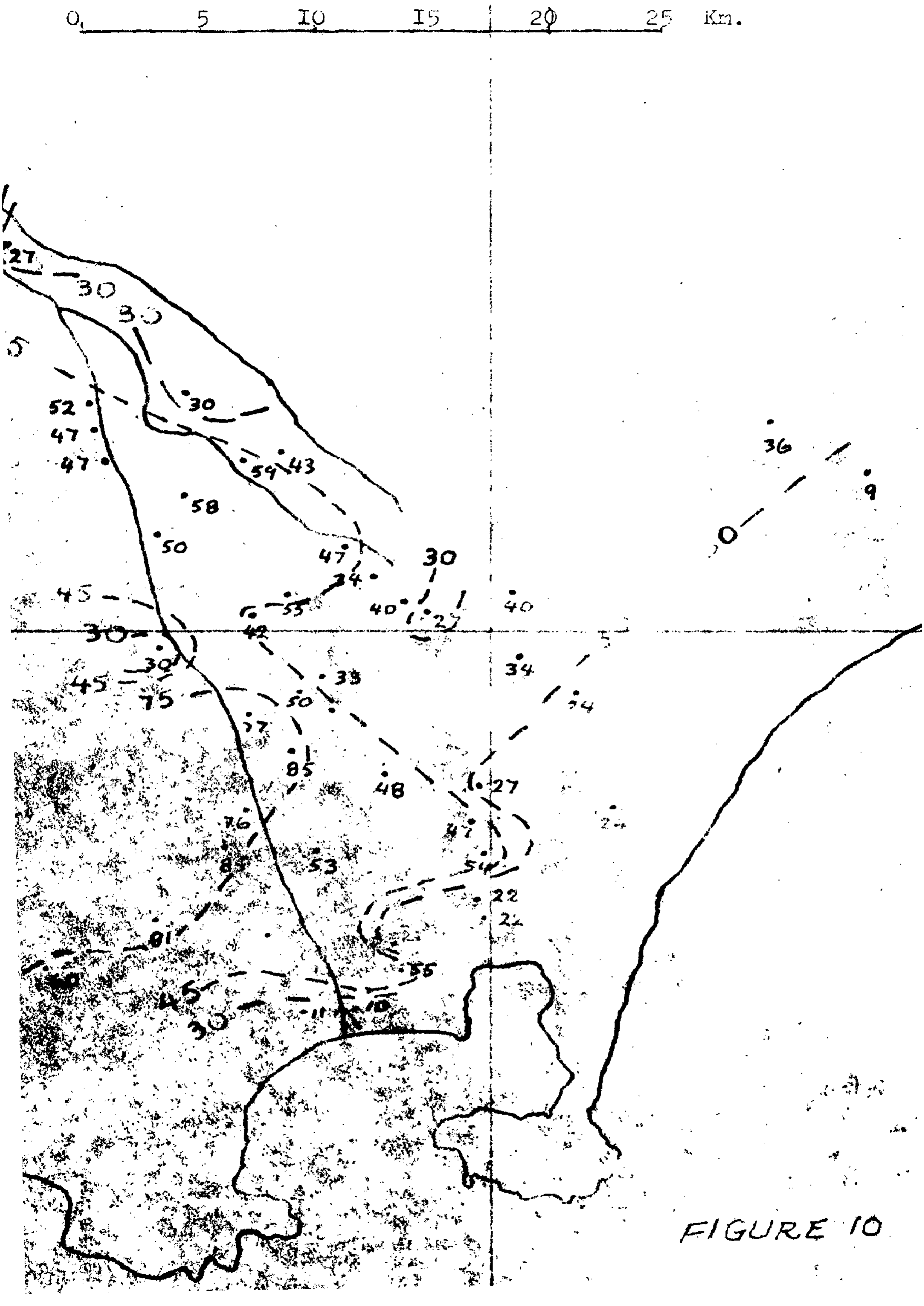
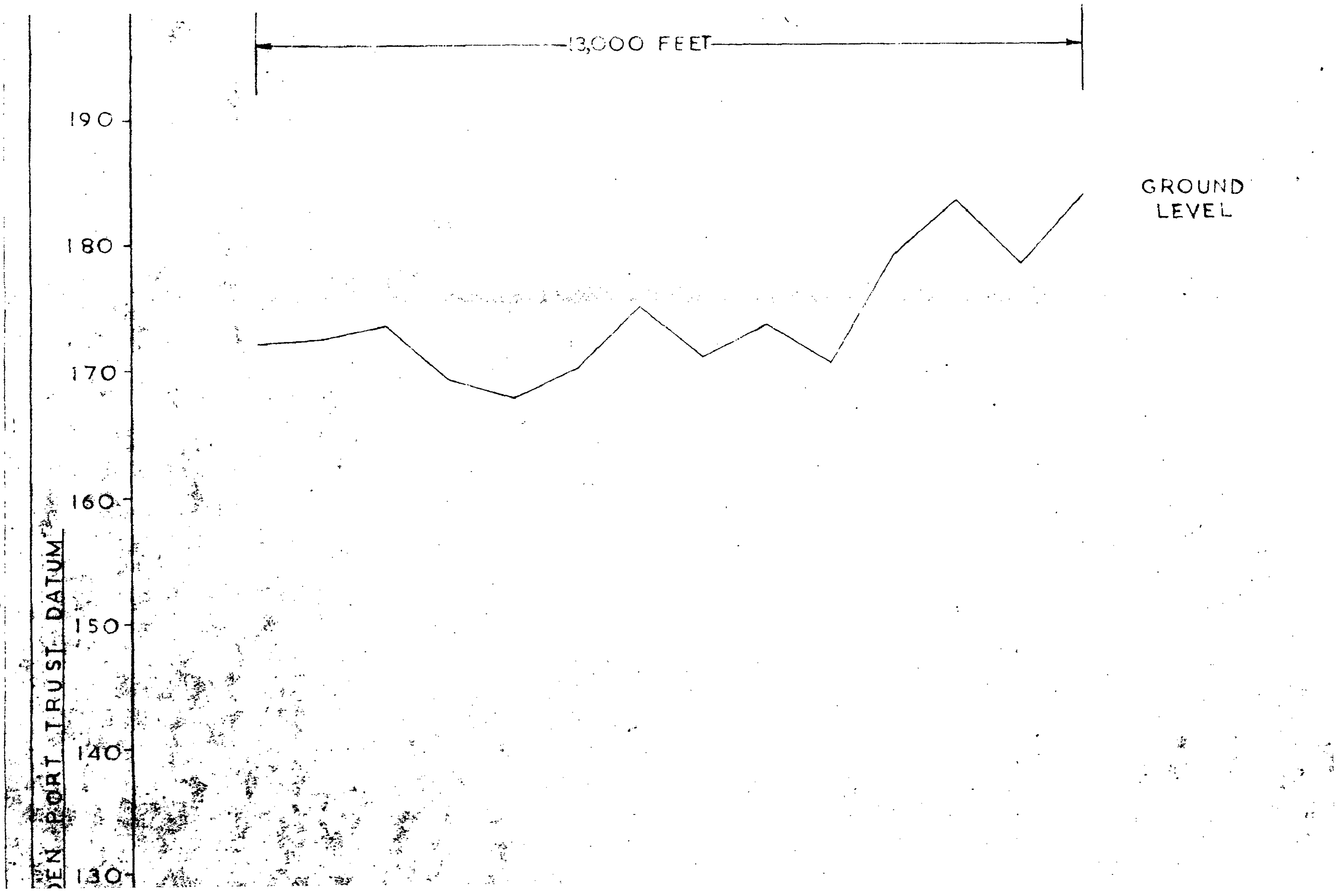
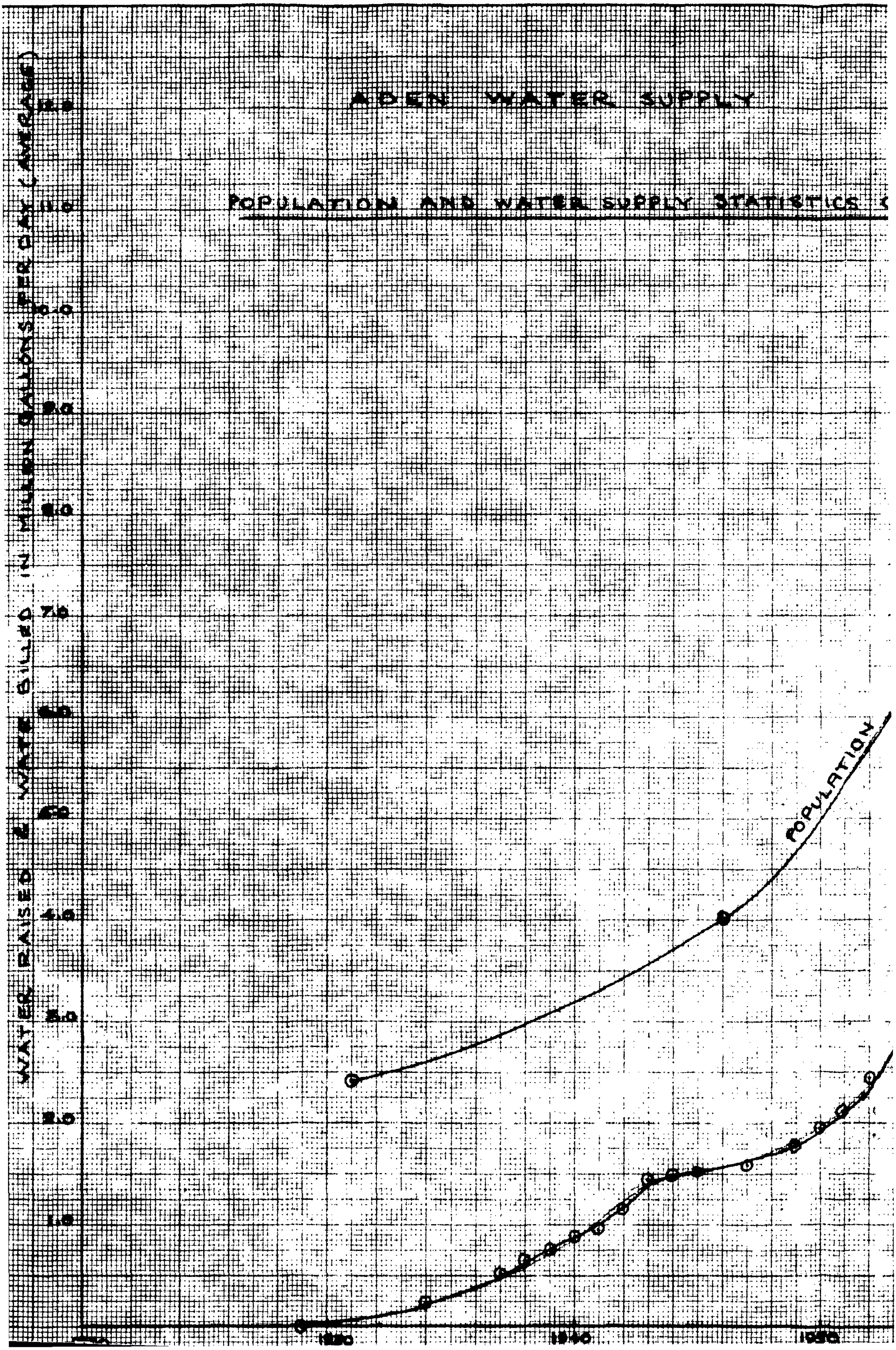
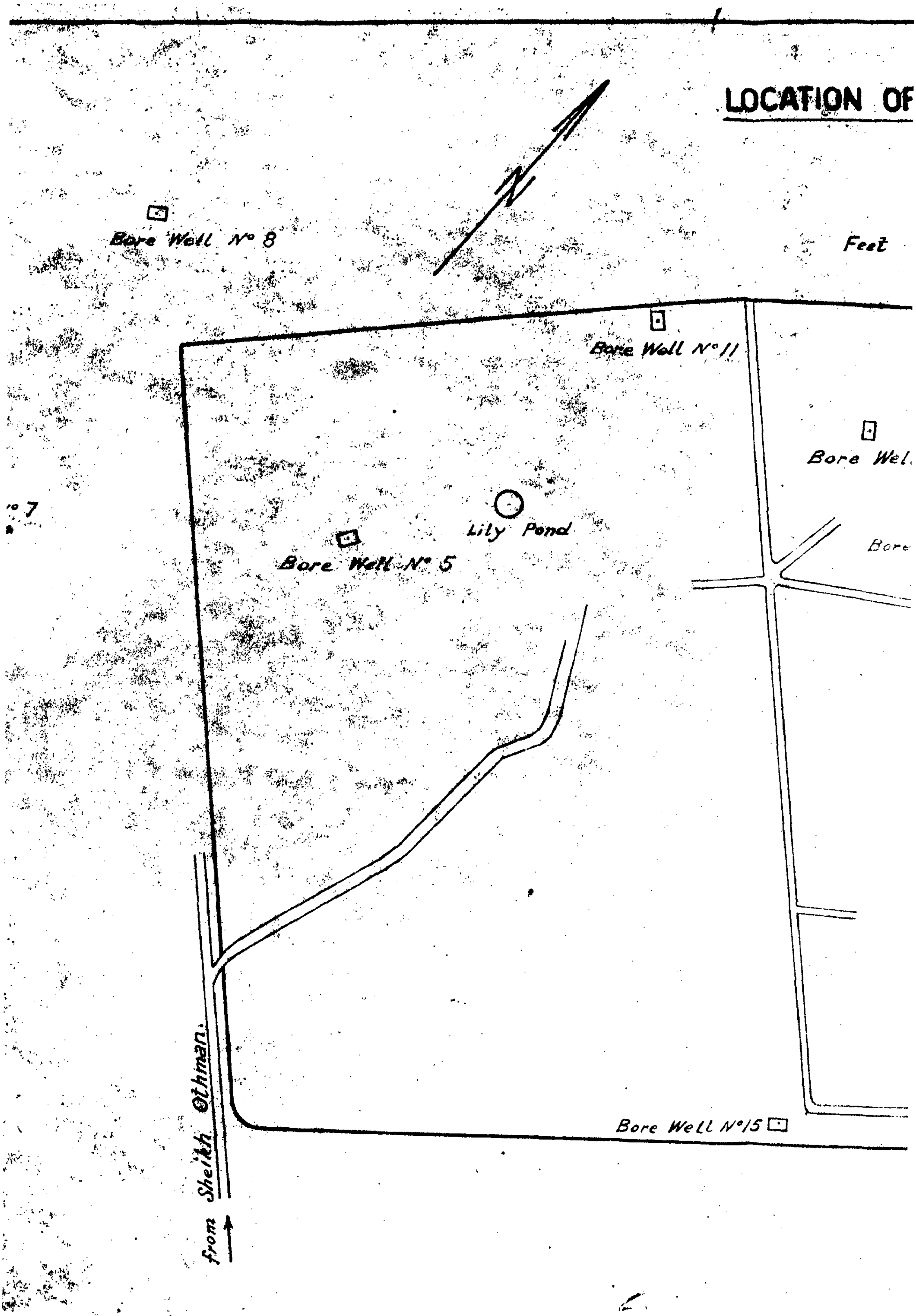


FIGURE 10


13,000 FEET
GROUND LEVEL
190
180
170
160
150
140
130
DEN PORT TRUST DATUM



ADEN WATER SUPPLY
POPULATION AND WATER SUPPLY STATISTICS
WATER RAISED & WATER BILLED IN MILLION GALLONS PER DAY (AVERAGE)
POPULATION
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
1930
1940
1950



LOCATION OF
N
Feet
Bore Well N° 8
Bore Well N° 11
Bore Wel
'° 7
Lily Pond
Bore Well N° 5
Bore
Bore Well N° 15
from Sheikh Othman.

[illegible]

••••

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