THE GREAT MAN-MADE RIVER PROJECT

النهر الصناعي العظيم

جهاز تنفيذ وإدارة مشروع النهر الصناعي العظيم

SOCIALIST PEOPLE'S LIBYAN ARAB JAMAHIRIYA

THE GREAT MAN-MADE RIVER PROJECT

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ERRATA

Page No		
vi	Line No. 1	Replace "October" with "Al-Tumour"
4	Line No. 3	Replace "250" with "350"
4	Line No. 8	Replace "October" with "Al-Tumour"
4	Line No. 9	Replace "March" with "Al-Marich"
4	Line No. 9	Replace "April" with "Al-Taier"
4	Line No. 9	Replace "May" with "Al-Mah"
4	Line No. 9	Replace "December" with "Kanoun"
4	Line No. 10	Replace "January" with "Ai-Alnar"
10	Line No. 2	After "good", insert, "the percentage of soluble salts being approximately 300 parts per million"
10	Line No. 2	After "excellent", insert, "the percentage of soluble salts being approximately 250 parts per million"
11	Line No. 20	After "buried in a", add, "six to"
13	Line No. 9	After "high", add, "and three kilometres in circumference"
13	Line No. 25	Change "6.4 million" to "6.8 million"
13	Line No. 34	After "trenches", add, "six to"
14	Line No. 17	After "long", add, "and 18 bar pressure rating"
14	Line No. 17	Change "80 tonnes" to "86 tonnes"
19	Line No. 30	After "alternative", add, "the unit price per cubic metre of water is between 70 and 160 dirhams while the same volume produced by desalination of seawater would cost between 320 and 620 dirhams. The difference between the upper and lower limits includes for the capital investment costs"
21	Line No. 17	Replace "April" with "Al-Taier"
21	Line No. 35	After "is", insert, "four times"

FOREWORD

It is not an easy task to describe the Great Man-made River Project now being constructed in the Libyan Arab Jamahiriya. The project embraces many technical details and is of such complexity that it is difficult adequately to summarise or illustrate it in this short book.

The project is, in fact, the largest civil engineering project currently under construction. In this book, its objectives are briefly defined and its technical basis will be explained. There are also sections dealing with the sources of underground water upon which the project will draw, including their potential for renewal and continuity. The cost of the underground water will be compared with the cost of desalination, and the economic benefit of the project for agriculture, industry and in the social field will be examined.

At the outset, it can be stated that the project will convert thousands of hectares of semi-desert into rich agricultural land. It will also protect and enhance the fertility of existing agricultural land, increasing its output and moving the Jamahiriya one step nearer to agricultural self-sufficiency. Additionally, the project will make further water available to the processing and manufacturing industries, to factories and to professional and vocational training centres, increasing their production and encouraging industrial expansion along the routes of the pipeline. A supply of fresh potable water will be made available to the inhabitants of many cities and villages along the pipeline route. Oil revenues are, therefore, being invested in the construction of a substantial project to the benefit of all the community in this generation and for many generations to come.

This project was not implemented without considerable forethought; many studies were undertaken before it was decided to proceed. They all confirmed the presence of a huge reservoir of fresh water beneath the dunes of the country's vast desert areas, and they encouraged the Libyan people to make plans and allocate significant sums of money to implement the project. To achieve this goal a public authority, the Great Man-made River Authority, was established on October 6th, 1983. This was followed immediately by the inauguration of Phase I of the project.

The project consists of five phases, of which the first two are main phases, the remaining three supplementary.

Phase I will deliver two million cubic metres of water a day along massive pipelines, four metres in diameter, to the coastal agricultural strip between Benghazi and Sirt. The second phase will deliver one million cubic metres of water a day along a similar pipeline in the western region for the development of the fertile Jeffara plain.

The purpose of the three supplementary phases is to expand the project so that all areas of the country are covered, and as much underground water as possible is exploited. In Phase III the water flow in the Phase I system will be increased to 3.68 million cubic metres a day. Phase IV will deliver water from the project to Tobruk, along a pipeline laid from Ajdabiya to Tobruk. Ultimately in Phase V, the Phase I and II systems will be linked by a pipeline from Sirt to Tripoli, and the water flow in Phase II will be increased to two million cubic metres a day by the addition of two more wellfields to that system.

This great and important project has called for the largest concentration of construction equipment and machinery ever assembled. Together with the application of the most modern technology and up-to-date irrigation, storage and distribution systems available, this will maximise the benefits of the investment in the water that the project will provide.

In this book a full description is given of the two main phases of the project, together with a brief outline of the three further phases.

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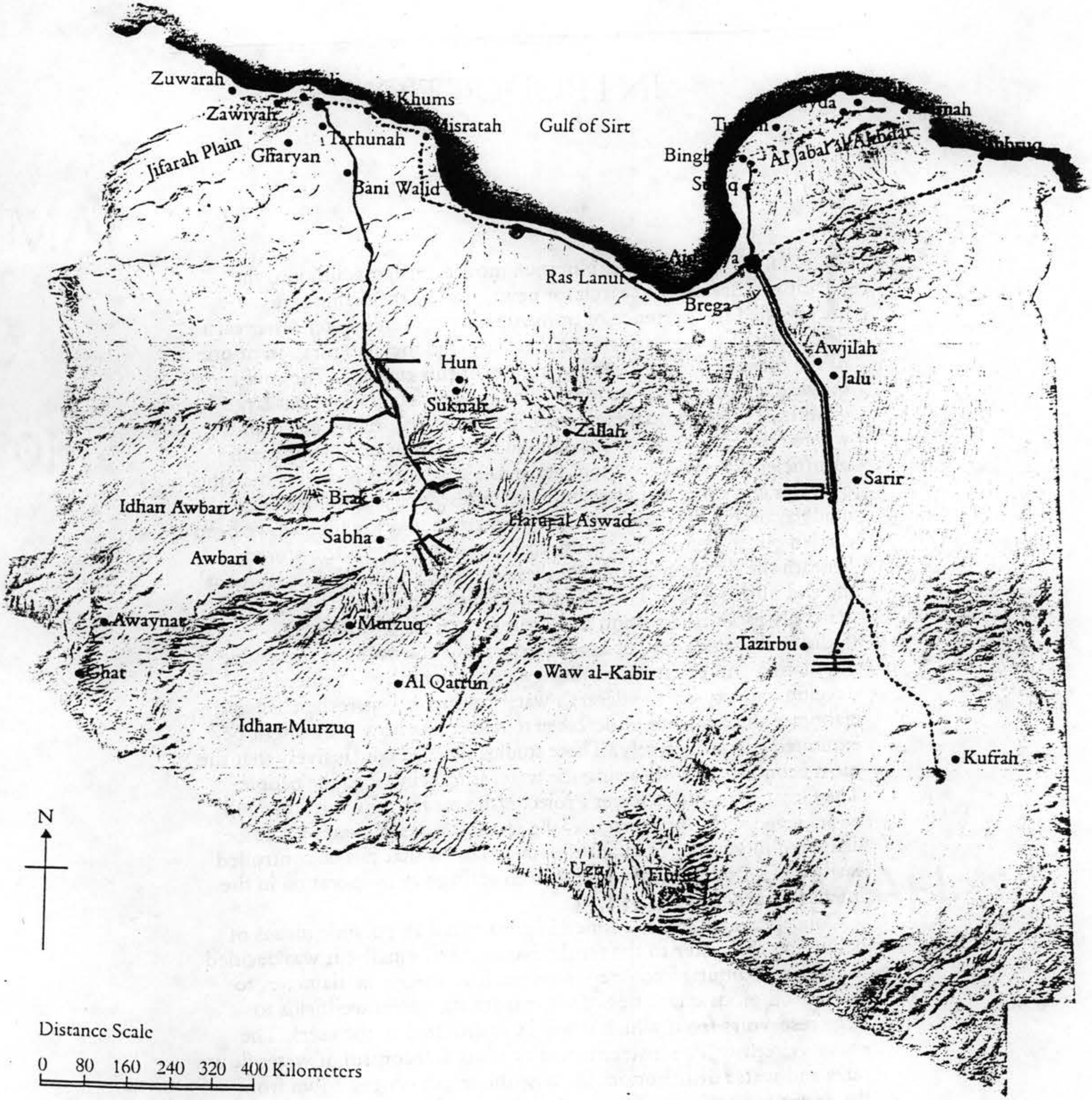

Zuwarah
Zawiyah
Tarhunah
Gulf of Sirt
Jifarah Plain
Gharyan
Bani Walid
Al Jabal al Akhdar
Ras Lanuf
Brega
Awjilah
Jalu
Hun
Suknah
Zallah
Sarir
Brak
Idhan Awbari
Haruj al-Aswad
Sabha
Awbari
Awaynat
Murzuq
Ghat
Al Qatrun
Waw al-Kabir
Tazirbu
Idhan Murzuq
Kufrah
N
Distance Scale
0 80 160 240 320 400 Kilometers

I

INTRODUCTION

IN THE 1960S as oil exploration moved further south into the Libyan desert in a search for new oilfields, the drilling rigs revealed the presence of immense underground water reserves; a discovery of great importance that triggered the inauguration of one of the major civil engineering projects of this century. The country's oil wealth provides its economy with a firm foundation, but large quantities of good quality water offer alternative riches in a country where rainfall is scant or sporadic and the output of existing wells insufficient to meet growing demand. However, this double blessing of water and oil is valueless unless each resource is developed and made available for consumption. Numerous investigations have been carried out to define the quantity and quality of the water stored beneath the desert and some of these are listed in the bibliography at the end of this book. The country's thriving communities are generally established along the fertile coastal strip, where the traditional water supplies are inadequate for the needs of a growing population and expanding industry and agriculture. The need to develop and exploit the desert's water resources was recognised and elaborate studies were undertaken to determine how they might be exploited cost-effectively. These studies showed conclusively that the most economic way of using the water is to bring it to the people. The Great Man-made River Project is the means by which this will be achieved. For optimum use, the country's desert water has to be delivered in very large quantities, in a manner that can be controlled easily and which avoids wastage from spillage or evaporation in the intense summer heat.

Conceptual studies examined in great detail all possible means of delivering the water to the fertile coastal areas. Finally, it was decided to construct a buried concrete pipeline, four metres in diameter, to carry prodigious quantities of water from the desert wellfields to large reservoirs from which it will be distributed to the users. The entire system will be instrumented to allow full control of water flow rates and water distribution. Because the terrain slopes down from the desert to the sea, gravity will supply much of the energy required for operating the entire system, particularly the first part of both Phases I and II. However, upon final completion of the system, erection of pumping stations in certain locations will be necessary to pump additional quantities of water.

In short, the urgent need for a new water supply to supplement and replace the present traditional supply, which is exposed to depletion day by day, has necessitated implementation of a project which is remarkable not so much for its use of advanced technology, but for its sheer size and the complexity of its logistics.

This desert water is a fossil link with rainfall from pre-history and has lain in the rock for millions of years awaiting discovery by man and his technology. The following is the story in words and pictures of the Great Man-made River Project – a modern wonder of the world and a monument to human endeavour in the service of mankind.

II

GEOGRAPHY AND CLIMATE

CHANGES IN CLIMATE over the centuries have shaped the landscape of Libya. Early writers recorded that much of North Africa was a savannah and there are ruins of inland cities and traces of dried-up lakes in the Fezzan. Marshes were known to exist at Kufra 1,700 years ago, but available history of North Africa confirms the gradual formation of desert during the last 7,000 years.

Climatic observations during the last 7,000 years have indicated a gradual world-wide trend towards hotter and drier conditions. Over the past 400 years records have shown an apparent 150-year cycle of minor changes, giving 50 years of hotter weather followed by 50 years of variable or erratic weather and 50 years of colder climatic conditions. It is propounded that the world is currently passing from the variable to the colder climatic condition.

The country covers an area of about 1,800,000 square kilometres spanning three climatic zones: the mediterranean, the semi-desert, and the vast desert zone of the northern Sahara with its sprinkling of oases. The present population of about 3.5 million is growing and lives mainly in the mediterranean coastal zone, with a large proportion in its principal cities of Tripoli and Benghazi. The fertile lands of the Jeffara Plain in the north west of the country, Jabal al Akhdar in the north east, and the coastal plain east of Sirt, all support a flourishing agriculture which is dependent upon rainfall. To the south, separated by a strip of semi-desert, the desert is encroaching ever nearer the Gulf of Sirt.

In the semi-desert, which serves primarily as pasture, rainfall is slight and irregular, and the natural balance of plant life is fragile. As more and more livestock feeds within this diminishing area, the plants disappear or wither under the twin stresses of overgrazing and lack of water; every year the desert claims a few more metres as the sands creep in. Low rainfall and a high evaporation rate characterise the desert zone. Extremes of temperature and lack of vegetation have resulted in erosion of the soil, leaving rock, sand and dust.

Records of rainfall distribution show 500 millimetres falling annually on Jabal al Akhdar reducing to 150 millimetres in the coastal region around Benghazi. 200-250 millimetres fall annually along the Jabal Nefussa and the western coast. Along the coast of the Gulf of Sirt, the annual rainfall decreases rapidly with distance inland, and south of Jabal Nefussa and Jabal al Akhdar it similarly diminishes until only a few millimetres are recorded annually at Sarir in the east and Sabha in the west. Rains usually come between October and March, but occasionally fall in April and May. December and January are the wettest months; in the summer, drought is normal.

The mean annual humidity at the coast is high, between 70% and 80%, and prevailing winds are north-easterly in north west Libya and north-westerly in the north east of the country. In spring and autumn, strong southerly winds – Ghiblis – blow from the desert, filling the air with sand and dust and raising the temperature to about 50°C. These strong winds are a major erosion factor in the desert, transporting sand from one place to another.

High temperatures experienced in the coastal zones reduce with altitude in the hills. In summer, coastal temperatures near sea level can exceed 43°C, but in winter these can fall to below zero. On rare occasions, snow has been recorded on the hills and in the mountains.

Inland, the temperature rises as the rainfall and humidity decrease and maximum shade temperatures of 57°C and 55°C have been recorded at Azizia and Brak respectively. Mean annual humidity inland varies between 30% and 40%. The difference between daytime and night-time temperatures inland is extreme; a variation of up to 37°C has been recorded. The resultant expansion and contraction shatters the exposed rock, which is then eroded and swept away in the wind.

It is over this terrain that the waters from under the desert will be conveyed; traversing 1,200 kilometres of desert plains in the east and 700 kilometres of rocky plateaux, wadis and escarpments in the west.

The Great Man-made River Project is considered a new concept by which the unremitting desert will be exploited for its fresh water resources, allowing vast areas of fertile lands to be cultivated and realising self-sufficiency in local food production.

In the east, the Great Man-made River Project will carry water to Sirt and Benghazi from wellfields which will exploit proven reserves of high quality water at Sarir and Tazerbo, with a future expansion to a wellfield at Kufra. The ground falls steadily along the route of this pipeline, from Tazerbo at an elevation of 270 metres above sea level to a low point in line with Jalu and Maradah, where it is just above sea level. From this low point it rises gently across a limestone plain until it reaches an elevation of 95 metres at a location south of Ajdabiya, where a holding reservoir is sited.

From Ajdabiya one branch of the pipeline continues north, over undulating rocky ground crossed by wadis, to Benghazi; a second line turns west to Sirt over sands, old beach deposits and numerous wadis draining into the sea from the raised coastline. Great care is being taken to minimise disturbance where the pipeline passes through towns and villages. Any agricultural land disturbed by the installation of the pipelines will be carefully reinstated.

In the west of the country, water from beneath the Fezzan region will be conveyed to the Jeffara plain. Wellfields will be developed in the gravel plains of the Sarir Qattusah and in other areas to the north and east of Jabal Fezzan. Extension of the existing wellfield at Wadi Aril is also being considered.

From Sarir Qattusah the pipeline will run to Wadi Aril. North of Wadi Aril the terrain rises steeply to the Hamadah al Hamra plateau, and it will be necessary to pump the water over the Qargaf Arch escarpment, which forms a natural barrier between the Hamadah plateau and the Murzuk basin. From a high point near Jabal Sawda, the pipeline descends as it continues north, and then enters the gently rising Hamadah al Hamra gravel plain, where underlying limestone deposits and volcanic sheets of lava are frequently dissected by wadis draining northeast to the sea.

The pipeline runs through the eastern part of the Hamadah al Hamra plateau for about 300 kilometres. The surface changes slowly from a gravel plain in the south to thin sand cover in the north where the wadis become more pronounced with major wadis at Suf al Jin, Zamzam and Bani Walid. Agriculture and grazing in this semi-desert is limited to the wadi floors. North of Wadi Suf al Jin, the land rises more steeply to Jabal Nefussa with increasing vegetation cover and improved grazing land.

The pipeline route is tortuous as it passes north, crossing ever more deeply incised wadis. These crossings have been specially designed to protect the pipeline from the force of flash floods which are known to sweep down the wadis following intense rain in the hills. Jabal Nefussa rises to 400 metres above the Jeffara plain to the north. To cross this, it is planned to drive a tunnel near Tarhunah with a hydroelectric power plant incorporated at the base of the north escarpment, to generate electricity as the water descends the escarpment to the Jeffara plain. The plain is highly cultivated and the route, which is planned to minimise disturbance to farmland and populated areas, ends near Suq al Ahad.

The task of the Great Man-made River Project is, therefore, to bring water from under the desert, over thousands of kilometres of the harshest desert plains, mountains, sabkhas and wadis to serve the people, their agriculture and industry. The following section outlines the events which led to the formation of huge reserves of high quality water under the desert.

III

FORMATION OF UNDERGROUND WATER

FOR CENTURIES THE vast deserts of southern Libya formed a barrier crossed only by caravan trade routes which followed established tracks from oasis to oasis. From 1953, these vast and largely unknown areas were progressively investigated in the search for new oilfields. This led not only to the discovery of large oil reservoirs but also great quantities of fresh water. The following brief review of the geology of Libya describes the nature and locations of the rock formation and aquifers beneath the desert.

The oldest rocks in Libya lie at its southern boundaries, in certain areas of the Tibesti, Hasawnah and Awenat mountains. The metamorphic rocks are the oldest of all; radiometric dating indicates that they are more than 2,800 million years old.

During the Palaeozoic era, Libya was subjected to strong tectonic movements which, from about 600 million years ago, caused significant igneous activities through the weak zones of the earth's crust, giving rise to the Qargaf Arch. The presence of these igneous rocks and the associated tectonic movements influenced the process of erosion and resulted in the formation, during the Palaeozoic era and the first period of the Mesozoic time, of various marine and continental fluvio-aeolian deposits. A study of the fossils in these rocks shows that the country had been covered by vegetation and by the sea on more than one occasion during this period.

At the end of the Mesozoic era, and as a result of the tectonic movements which probably caused the formation of the Red Sea, the Atlas Mountains and the Alps, uplifts occurred in Libya, giving rise to Jabal Nefussa and Jabal Al Akhdar. Associated downward movements to the Sirt basin during the Tertiary era allowed the Mediterranean Sea water to flow southward to the foot of the Tibesti mountains. During that geological time, the Mediterranean Sea frequently varied in level and as a result various sedimentary deposits were accumulated and formed. However, the sedimentation formed during the Quaternary era was limited to continental fluvio-aeolian deposits.

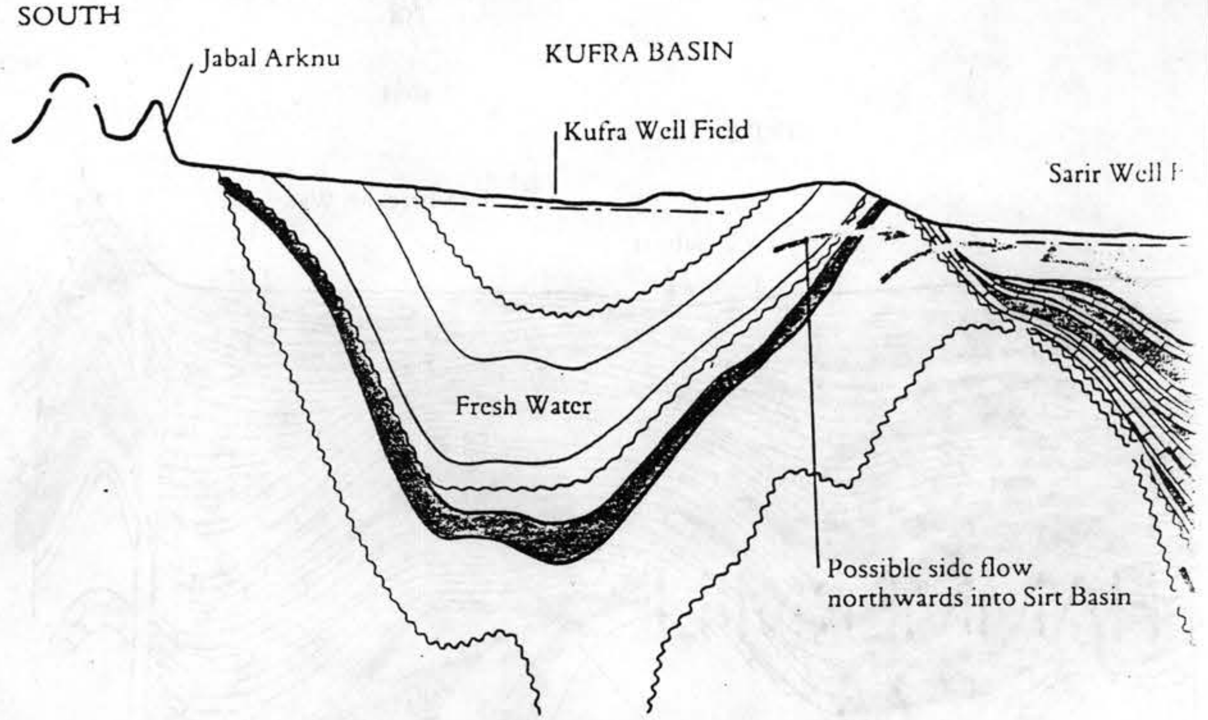
The continental sandstones related to the above geological times represent the most important aquifers and the tectonic movements were the main cause of the topographical uplifts which resulted in the huge underground basins. During the last fifty million years of the process of erosion and sedimentation, other areas located on lines of weakness of the earth's crust, near Jabal Nefussa, Hassawnah, Aghai and Awenat, were subjected to significant volcanic activity.

The Mediterranean Sea established its present boundaries at the end of the Tertiary era. During the ice ages in northern Europe, the climate of North Africa became temperate and there was considerable rainfall. The excess rainfall infiltrated into the ground and was trapped in the porous rocks between impermeable layers, forming reservoirs of underground fresh water, particularly in the thick sandstone sequences. Radio-carbon dating shows that the majority of this fresh water is between 38,000 and 14,000 years old although there are some lenses of water dating from 7,000 years ago. All these ages coincide with known rainy periods.

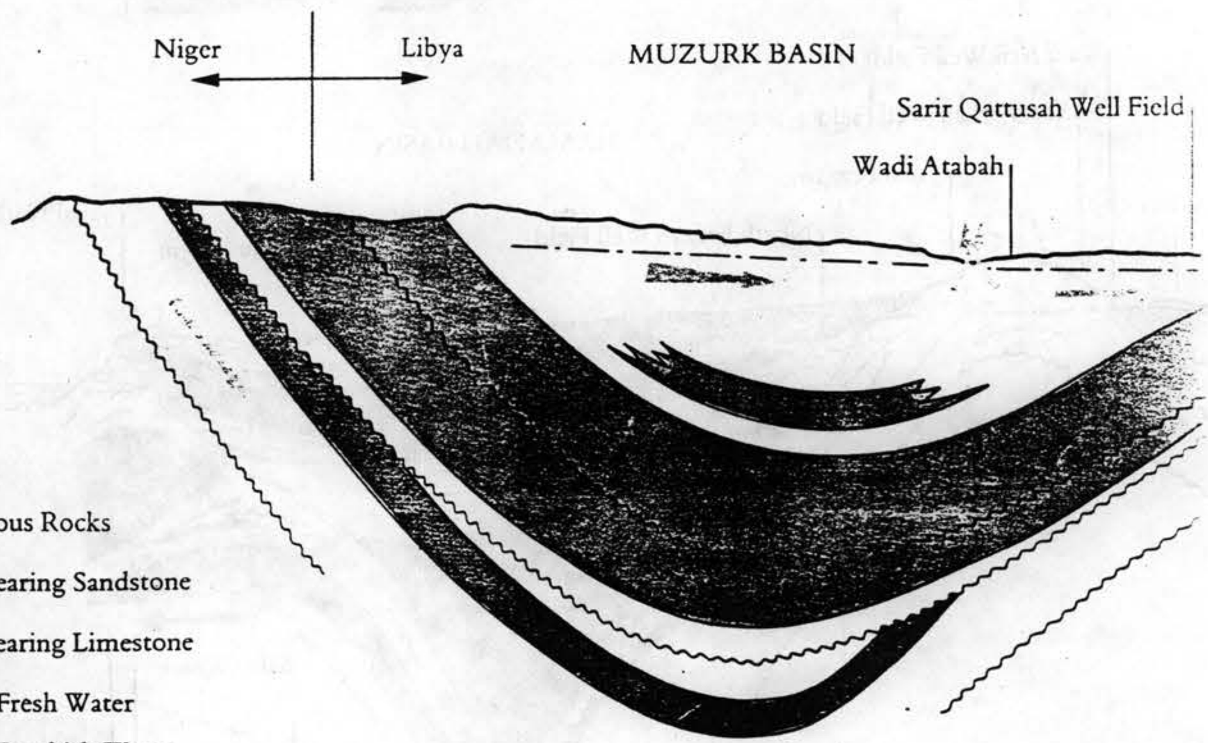
Four major underground basins have been located during exploratory drilling for oil in Libya. In the south east, the Kufra basin covers an area of 350,000 square kilometres and has an estimated groundwater storage capacity of 20,000 cubic kilometres in the Libyan sector, distributed through an aquifer layer over 2,000 metres deep. The basin extends from beyond the southern border of the country to north of Kufra, then swings north-east over the border with Egypt. South of Tazerbo, the basin connects with the Sirt basin which underlies the Sarir Calanscio gravel plain to the Mediterranean. The fresh water aquifer in the Sirt basin is some 600 metres deep and it is estimated to hold over 10,000 cubic kilometres of water.

South of Jabal Fezzan, the Murzuk basin extends from the Qargaf Arch in the north to beyond the south western borders of Libya. The total area of this basin is estimated to be 450,000 square kilometres, with an upper aquifer thickness of around 800 metres and an estimated storage capacity of 4,800 cubic kilometres. North of Jabal Fezzan, the Hamadah and Jufrah basins extend from the Qargaf Arch and Jabal Sawda to the coast. The massive Palaeozoic aquifer underlies both basins.

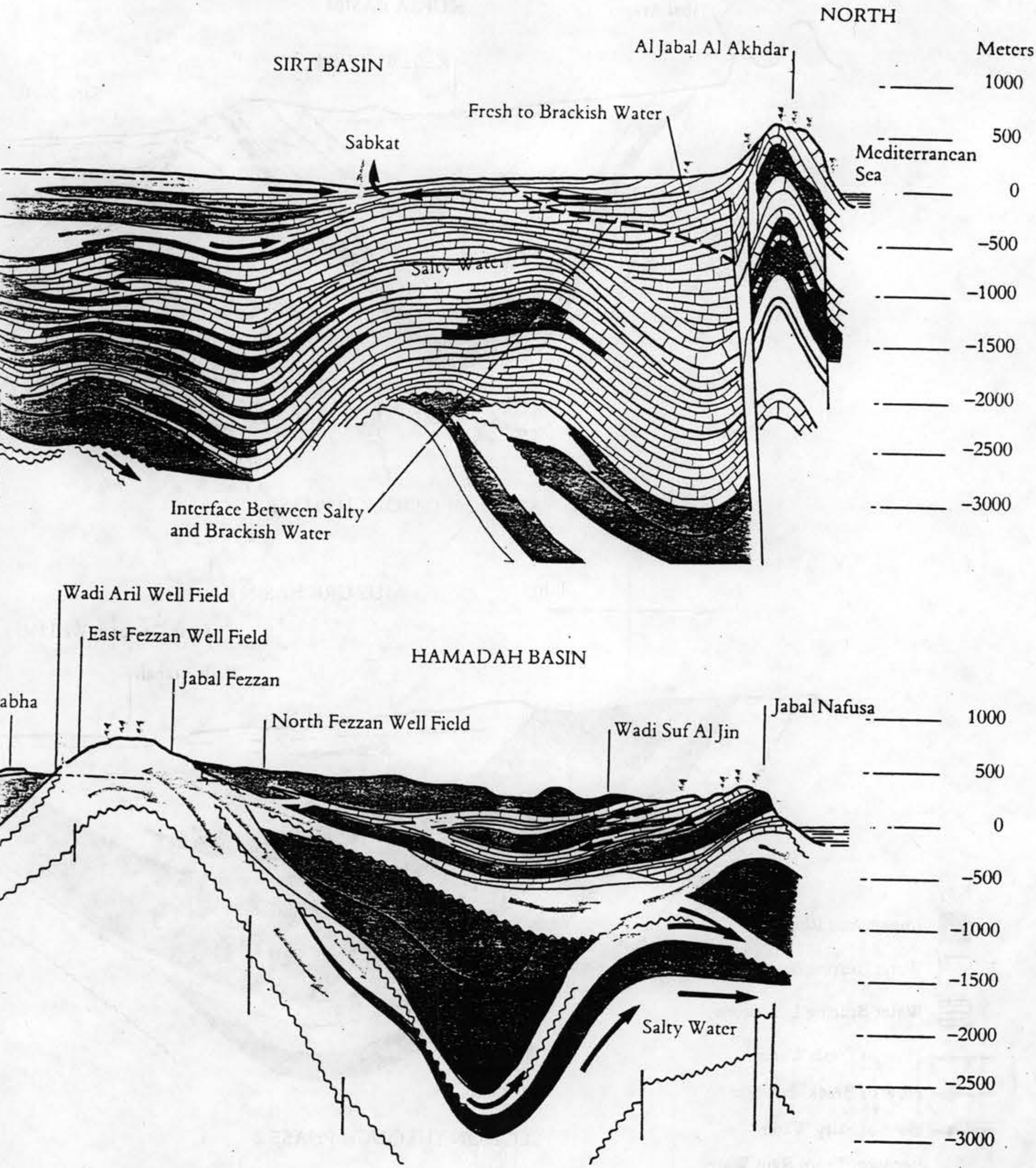
The water that is trapped within these basins is slowly moving from the high mountains in the south, where intermittent rain provides some recharge, towards the coast where it discharges naturally at springs, oases or sabkhas, or, through man's intervention, at wells. The pressure of the water in the basins is sufficient to cause it to rise to within a few metres of the surface if a well is sunk. This artesian condition occurs naturally at springs and oases. In sabkhas, the water reaches ground level over large areas and becomes heavily contaminated with salts through concentration by



SECTION THROUGH PHASE 1



SECTION THROUGH PHASE 2



Hydrogeological cross sections showing the distribution and direction of the flow of groundwater in the major basin aquifers of Eastern (Phase I) and Western (Phase II) Libya.

evaporation. However, the quality of the water located in the Murzuk basin is very good* and in the Kufra basin it is excellent.** In the Sirt and Hamadah basins the water quality reduces as it approaches the coast, mainly because the rock in which it lies changes from continental sandstones to marine limestones which can have a very high salt content.

In some low-lying areas, or sabkhas, the water reaches the surface where it evaporates, leaving the water near the surface brackish and unsuitable for use by man. The philosophy of the Great Man-made River Project is to recover the water from deep wells further inland before it drains to the sabkhas and is lost through evaporation.

The wellfields for the Great Man-made River Project are being constructed 400 to 700 kilometres inland to tap the better quality water available there. They are spread over large areas where the aquifers come close to the surface. The wellfields are designed to extract the water from the rocks at a rate which will not excessively lower the level of the water, so that pumping costs can be kept to a minimum and wellfields will remain productive over a longer period.

The Great Man-made River Project will initially take two million cubic metres of water a day from the eastern wellfields and one million cubic metres a day from the western wellfields. This rate of extraction provides several hundred years of potential production. A small amount of recharge of the basins will occur from the heavy but intermittent rains in the southern uplands.

The development of this project, its engineering design and the major construction work and facilities associated with it are briefly described in the chapter which follows.

* The percentage of soluble salts being approximately 300 ppm

** The percentage of soluble salts being approximately 250 ppm

IV

ENGINEERING

EXTRACTION OF THE water known to lie below the desert has been contemplated for many years. In 1974, Libya took the first steps towards exploitation of this valuable resource when studies were commenced which were to develop into the implementation of the Great Man-made River Project. This, the world's biggest and most far-sighted civil engineering project of its kind, will deliver large quantities of water over immense distances, from deep in the desert to the agricultural coastal areas. It has been demonstrated that its utilisation in the desert areas overlying these water resources would be uneconomical.

The project development is planned in five phases. The first phase, the largest, is already under construction, and consists principally of a system that will extract and carry two million cubic metres of water daily to the coastal region where the majority of the population lives. However, the system is designed to be expanded to carry 3.68 million cubic metres of water daily in the future, utilising a total of about 1,900 kilometres of pre-stressed concrete cylinder pipe, ranging between 1.6 metres in diameter for wellfield networks and 4.0 metres in diameter for the main conveyance pipeline, laid and buried in a seven metre deep trench. (6-7 meter deep trench?)

The wellfield at Tazerbo is the start of the Phase I conveyance system. Here, a field of 108 production wells (and a number of piezometric observation wells) will yield one million cubic metres per day at a flow rate of 120 litres/second per well utilising 98 wells only, the remaining wells being available on stand-by. The wells are connected to three parallel collector pipelines, spaced ten kilometres apart, with each well spaced at about 1.3 kilometres. The wells are connected to the collector pipelines by means of short lateral pipelines equipped with the necessary valves, limit switches, high pressure transmitters, flow meters and other safety devices. The collector pipelines are connected to a larger spine collector pipeline which, in turn, conveys water to an off-line steel header tank at Tazerbo, of 170,000 cubic metres capacity. The function of the header tank is to balance the hydraulic pressures, allowing the system to adjust to variations in water flow and prevent water loss through the overflow facility. From this header tank, the main conveyance system is routed northward to two similar header tanks at Sarir.

At the beginning of the system, near Tazerbo, a chlorination station may be installed to inhibit biological growth on the inside of the pipe. At the end of this system, pressure control valves will be installed to reduce the excess water pressure (an additional head of about 80 metres) arising from the difference in level between the Tazerbo and Sarir wellfields after allowances have been made for friction losses in the 256 kilometre length of the section. Pressure control valves will be installed in the main conveyance pipeline close to the two header tanks at Sarir, each with a capacity of 170,000 cubic metres and having a similar balancing function to the header tank at Tazerbo.

The second wellfield, located at Sarir, 256 kilometres north of Tazerbo, consists of 126 production wells in addition to a number of piezometric observation wells. The production wells are connected to three east-west parallel collector pipelines, spaced ten kilometres apart, with the wells spaced at about 1.3 kilometres on these pipelines. This wellfield will produce one million cubic metres of water per day at a flow rate of 102 litres/second per well, utilising only 90% of the total number of wells, with the remaining 10% available as stand-by. Water will be collected in 1.6 metres' diameter collector pipelines connected at their eastern ends to a larger collector pipeline of 2.8 metres' diameter, running to the two header tanks which are joined to the main Sarir-Sirt conveyance pipeline of 4 metres' diameter. The entire system is cross-connected to allow the output from the two wellfields to flow into both header tanks, or into only one of them when the other header tank needs maintenance. Provision is also made for future connection of the existing Sarir North and South agricultural wellfields to the system if required. From Sarir two parallel pipelines of 4 metres' diameter convey the water to the Ajdabiya holding reservoir, 380 kilometres to the north.

Wellfield modelling studies were used to determine the number of wells, their depth and water level, the type of pumping equipment required and the quantities of water which can be extracted without jeopardising production of the wells. The wells at both Tazerbo and Sarir fields are about 450 metres deep, and submersible pumps will be used within the wells at a depth of about 145 metres. At each wellhead, a control unit will be installed to receive, and respond to, operating signals from the permanent communication and control system. The control unit will start or close down the pump, thereby protecting it against any extraordinary or emergency condition during operation.

From the Sarir area, the daily flow of two million cubic metres of water is conveyed northward through the twin parallel pipelines to

Ajdabiya holding reservoir, which has a capacity of four million cubic metres. Sarir is 150 metres above sea level and the water can therefore flow by gravity to a point near Jalu which is a few metres above sea level and to the higher ground at Ajdabiya holding reservoir, 90 metres above sea level. The minimum pressure rating of the pipe in this sector of the pipeline is 14 bars (140 tonnes/square metre).

The holding reservoir is a circular earth embankment, nine metres high and about 900 metres in diameter. To limit seepage losses, the inside surface of the holding reservoir is provided with an impervious membrane lining, protected by two layers of soft sand and gravel.

From the holding reservoir, the water flows through two pipelines running along the coastal belt, west to Sirt and north to Benghazi respectively. The pipeline leading west to Sirt is four metres in diameter and is designed to convey a water flow of 820,000 cubic metres a day by gravity. A maximum flow of 2.3 million cubic metres a day in the future can be achieved by using three pumping stations. The northern pipeline heading to Benghazi delivers a maximum gravity flow of 1,180,000 cubic metres a day and a maximum flow of 2.5 million cubic metres a day with two pumping stations appropriately located. Turnouts have been located along both pipelines to deliver water to agricultural, municipal and industrial users as defined by studies already carried out. Each pipeline discharges into a circular earth embankment end reservoir, with a storage capacity of 6.8 million cubic metres at Sirt and 4.7 million cubic metres at Benghazi. These reservoirs are designed to balance fluctuations in supply and demand.

The choice of pipe for the conveyance lines involved studies to select the most appropriate material and method of installation. Pre-stressed concrete pipes four metres in diameter were found to be more cost-effective by a significant margin than other alternatives considered, since most of the raw materials required for their production are available in the country. It was also established that pipe buried in trenches seven metres deep was the best method of protecting the pipe from hazards, including temperature variations and other environmental factors.

A pre-stressed concrete cylinder pipe consists of a thin steel cylinder embedded in a concrete core, wrapped with high tensile steel wire, and then coated with a cement mortar to protect it from climatic conditions and normal corrosion. This cement mortar encourages a chemical reaction which limits corrosion by steel oxidation. This is considered an effective remedy in areas where the soil is non-aggressive. The aggressiveness, or otherwise, of a soil depends upon the presence and concentration of chloride and sulphate salts within the soil and on the availability of groundwater to assist their attack.

Where the concentration of chlorides and sulphates is high, and in the potential presence of groundwater, additional protection in the form of a barrier coating applied to the outside of the pipe is necessary to prevent the deterioration of the cement in the concrete from sulphate attack and the corrosion of the high tensile wire wrapping the pipe core from the effects of chloride attack. Cathodic protection may also be provided, if it is shown to be necessary, after the first few years of pipeline operation.

Steel bell and spigot joint rings are welded to the ends of the steel cylinder and embedded in the concrete core to provide a joint with adjacent pipe sections. The joint between pipes is made by forcing the spigot end of a pipe, with a rubber gasket held within a groove, into the bell end of a previously laid pipe, to form a watertight seal with a degree of flexibility.

Purpose-built plants were constructed at Sarir and Brega to manufacture the pipe sections, each of which is seven and a half metres long and weighs up to 80 tonnes. Both pipe plants are self-sufficient, generating their own electricity and provided with other utility services. Cement for the concrete is obtained from the Libyan cement plant at Benghazi; aggregate from quarries near the pipe plants. The water required for mixing the concrete; and for other uses at Brega, was drawn from local wells drilled for this purpose in the Jalu area and pumped to the pipe plant, while the water required for the pipe plant at Sarir was drawn from the existing wells near the plant.

For easy reference the quantities ot materials used for construction of the first phase only are listed below:-

- Total number of pipe sections: 250,000 approximately
- Number of inspection chambers: 3,000
- Air vacuum valves required: 1,500
- Cement: 2.5 million tonnes
- Aggregate: 13 million tonnes
- Pre-stressing wire: 2 million kilometres
- Steel cylinders: 25 million square metres
- Excavation: 85 million cubic metres
- Rubber gaskets: 6 million linear metres

To deal with these huge quantities, the largest concentration of handling and earth-moving equipment in the history of civil engineering has been gathered together including:-

Heavy crawler cranes	64
Bulldozers and tractors	238
Excavators	110

Heavy trucks	367
Truck trailers	226
Tank trucks	50
Buses	40
Forklifts	40
Light trucks	524
Ambulances	19
Light generators	91
Central generators	35
Compactors	115
Heavy backfill equipment	19
Concrete pouring trucks	40

In addition to the civil engineering work described above, many other associated works are required. An example is the permanent communication and control system (PCCS). The PCCS will allow staff in the Benghazi Headquarters control centre to direct the operation of the entire project. Instructions will be issued from Benghazi to personnel at the other control centres to adjust water flow and storage throughout the system and they, in turn, will remotely control the wellfields, reservoirs, and turnout stations from control panels. A computer system will allow operating personnel at Benghazi Headquarters to calculate water flow parameters and process information associated with water use. Computer terminals at the other control rooms will monitor water flow and levels at the wellfields and reservoirs. The same computer system will also monitor control equipment, maintenance efforts and spare parts inventory, and other ancillary activities. The design of the PCCS provides a sufficient number of communication channels to maintain continuous operation even if some components become inoperative.

Electrical power is essential for the operation and control of the project. The total power demand for Phase I, of around 65 megawatts, is provided mainly from a power generation plant constructed at Sarir as part of the project. Power from this plant will be transmitted directly to Sarir wellfield via a 66 kV transmission line, and indirectly to the Tazerbo wellfield via the existing national power supply system, at 220 kV. The power will be transformed down to 66 kV at Tazerbo substation and transmitted to the distribution stations at Tazerbo wellfield via a 66 kV line constructed for this purpose. Sarir power generating plant will consist of six gas turbine generating sets which can operate on diesel fuel if the need arises.

Because of the great distances involved, five operation, support and maintenance centres are required for the efficient operation and maintenance of the project; the five facilities are to be located at Benghazi, Sirt, Ajdabiya, Sarir and Tazerbo respectively. Each centre will include the administrative offices and industrial maintenance buildings required to secure project self-sufficiency, as well as permanent housing and amenities. At each of these five locations, control panels will graphically illustrate the layout of the facility and indicate the operational status of all relevant equipment.

At an average flow rate of 0.95 metres/second, it will take the water over nine days to cover the pipeline distance of 800 kilometres from Sarir to Sirt or the 783 kilometres from Tazerbo to Benghazi. To maintain the flow over these distances, a sufficient number of air relief valves will be installed at high points along the pipeline route to discharge air accumulated inside the pipeline which would otherwise reduce the flow rate. The system is provided with sufficient outlets along the route to discharge water from the pipeline when needed, principally for maintenance which cannot be undertaken without emptying the pipeline. Access points are also provided at reasonable distances, to allow insertion of mobile maintenance equipment as required.

The design of this conveyance system allows it to convey an additional flow of about 1.68 million cubic metres a day from Kufra wellfield. The necessary connections have been provided to allow for the installation of future pumping stations, the locations of which have already been determined. Isolating valves will be installed in the first phase of construction to avoid any suspension of operation when such pumping stations are constructed, to ensure an uninterrupted supply of water to farms, industries and municipal users.

The operating philosophy is based on the continuous delivery of water at constant rates throughout the whole year. For this purpose, large reservoirs have been built to act as strategic storage facilities for summer or drought seasons. Utilisation of water during summer is much greater than in winter, especially when heavy winter rain falls. These large reservoirs, 37 million cubic metres in the Sirt area and 76 million cubic metres in the Benghazi area, will store the surplus water during the wetter winter months for utilisation in the summer when demand is at its peak.

The response of the conveyance system to any changes in the flow rates will be relatively slow, due to the long distance and slow speed at which the water travels. Pre-planning will therefore be necessary before any changes to the flow rates are made. This can only be effected by continuous monitoring of the flow rates, of water levels in reservoirs and of the quantities consumed. For this reason it has been decided that operation of the conveyance system should, in the first years of operation, be undertaken manually, with computer assistance in making decisions relating to any change in the flow rates.

Phase II of the project, which is secondary in importance to Phase I, consists principally of a system that will deliver one million cubic

omitted

2.3 million

metres of water a day from wellfields in the Fezzan region to the Western coastal belt and in particular to the fertile Jeffara plain. It is, however, designed to accommodate a further one million cubic metres a day in the future. The system starts from a wellfield at Sarir Qattusah, from which 550,000 cubic metres a day will be pumped. This wellfield will consist of 127 wells distributed along three east-west collector pipelines; each well will be connected to a collector line equipped with all measurement meters and safety equipment required for the efficient operation of the submersible pumps. The water flow from the three collector pipelines will be combined in a larger spine collector pipeline which will run to the header tank area. From the header tank, the main conveyance pipeline will run northward to Wadi Aril where the output from the existing Wadi Aril wellfield will be added. From this point, the combined flow of one million cubic metres a day will be lifted to a high regulating station on the Jabal Fezzan (Hassawnah) into twin regulating tanks. From here, the flow will be carried by gravity to further twin regulating tanks at Tarhuna. The conveyance pipeline will then fall steeply to the terminal reservoir at Suq El Ahad, which is sized at 28 million cubic metres and provides security against any breakdown of the system or fluctuation in water demand.

This system runs through hills, wadis and plains. At Ash Shwarif, excess pressure will be reduced, using a pressure-reducing station, allowing lower pressure pipes to be used. Precautionary measures will be taken in the areas where the conveyance pipelines cross wadis, especially those at Suf El Jin, Zamzam and Bani Walid, to prevent any erosion which might result from floods.

As in Phase I, the second phase system will utilise pre-stressed concrete cylinder pipe, for the same reasons as previously mentioned. The Phase II system will also be equipped with all protective and safety items such as air relief valves and surge control equipment to avoid any excessive pressures which could result from a failure of the electric power supply to the pumping station or any other similar cause. Arrangements will also be made to reduce the relatively high carbon dioxide content in water delivered from the Fezzan wellfields before this water flows into the system.

This system is designed to accommodate a further one million cubic metres of water a day in future from the east Fezzan and north Fezzan wellfields. East Fezzan wellfield will be connected to the system before the high point regulating station on the Jabal Fezzan, and the north Fezzan wellfield will be connected near the pressure-reducing station at Ash Shwarif. The Phase II system is also provided with outlets along the conveyance pipeline, to allow draw-off of water into the wadis to be used for agriculture or consumers.

The difference between water levels in the regulating tanks and the terminal reservoir at Suq Al Ahad may also be exploited to generate electric power, by the construction of a hydroelectric station capable of generating about 17 megawatts for a flow of one million cubic metres of water a day.

The system will be remotely controlled, using a computer at the main control centre situated at Ben Ghashir. Communication between the various locations will be by microwave radio.

Two main operation and support centres will also be made available, one in Ben Ghashir and the other in Semnu, in addition to satellite operation centres in Wadi Aril, Sarir Qattusah and Suq Al Ahad respectively. These include administration offices, industrial maintenance buildings equipped with all necessary machinery and spare parts, and permanent housing and amenities.

The total power requirement for this phase, estimated to be 65 megawatts, will be provided either from a purpose-built generating station constructed near the wellfields or from the national electricity system, subject to the availability of power and the results of the relevant economic studies.

Plans are also advanced for Phase III of this project, which will increase water flow in the Phase I systems by 1.68 million cubic metres a day. The additional water required will be obtained either from wellfields near Kufra or by utilising both Sarir North and South agricultural production wellfields, connecting them to the main conveyance system of Phase I. Pumping stations will be installed to deliver this additional water to the two end reservoirs at Benghazi and Sirt. For this purpose, a main pumping station will be installed near Jalu, with three pumping stations along the Ajdabiya/Sirt route and two pumping stations along the Ajdabiya/Benghazi route.

Implementation of Phase III is, however, subject to the implementation of Phase V of the project referred to below.

Phase IV will bring the benefits of the Great Man-made River Project to Tobruk. It will provide 200,000 cubic metres of water per day through the construction of a pipeline from Ajdabiya to Tobruk.

The fifth and final phase will have two components. The first connects the Phase I and Phase II systems through a linking conveyance line between Sirt and the Jeffara plain to deliver one million cubic metres of water a day, requiring the installation of two more pumping stations, one near the Sirt end reservoir and the other near Al Khums city. The second expands Phase II by incorporating two additional wellfields to supply one million cubic metres of water a day. Upon completion of this phase, the country will be interconnected with the comprehensive network of this great project, providing a life-giving artery and foreshadowing a prosperous economic future for the country.

V

WATER UTILISATION

THE EXPANDING ECONOMY and growing population along the fertile coastal strip of the Socialist People's Libyan Arab Jamahiriya is creating an increasing demand for water for irrigation, for industry and for domestic and municipal use. At the same time, the traditional water resources are becoming increasingly at risk through intensive use which is resulting in saline intrusion of the coastal aquifer. This phenomenon would, if unchecked, turn agricultural lands into infertile sabkha.

With the realisation of the Great Man-made River Project, an economic and plentiful new source of fresh water will be made available. This will reduce extraction of water from the coastal aquifer, as agriculture ceases to be dependent on existing water wells. The new source of water will, therefore, protect and enhance the fertility of the soil.

Additionally, the Great Man-made River Project will provide water for industrial use, serving established processing and manufacturing industries, particularly the large industrial complexes in Brega and Ras Lanuf. Domestic and municipal users will also benefit from the newly available water, thereby improving the quality of life in the urban areas.

It is planned to utilise more than 86% of the water output for agricultural development, so that the country will become self-sufficient in agricultural products and achieve economic independence. Production of strategic crops such as wheat, barley, sorghum and sheep fodder will be given priority, so that national production of these crops, of beef and mutton, and of milk and dairy products, all vital to human life, can be increased while expensive imports are reduced.

The cost of conveying this underground water from the desert makes it more economical than any other alternative. It is considered that the unit cost of the water delivered by the Great Man-made River Project will be significantly less than the comparative cost of desalinated water.

To secure successful development of as much agricultural land as possible, a water storage and distribution plan has been adopted. The plan aims to maintain a constant extraction of water throughout the year through the construction of large storage reservoirs. Such a storage system allows users to draw water as required. When, in summer, peak demand is higher than the maximum delivery capacity of the pipeline, additional water will be drawn from storage reservoirs which will be re-filled during periods of low water demand. It is planned to construct a number of these storage reservoirs south west of Benghazi, to a total capacity of 76 million cubic metres, with further reservoirs in the Sirt area sized at 37 million cubic metres. It is also planned to construct similar storage reservoirs for the Phase II system, with a total capacity of 28 million cubic metres. Their capacity may be increased if the areas of cultivated lands in the Jeffara plain, and thus the volume of water conveyed, are increased.

Other smaller reservoirs will be constructed in Nuwfaliyah, Bishr and for the existing development projects at certain wadis. Upon completion of the Great Man-made River Project, about 155,000 hectares of fertile land will be cultivated and irrigated by the water from the project. The reclamation and development of some 38,000 hectares south of the Benghazi plain served by the Ajdabiya-Benghazi line, and of some 18,000 hectares on the Ajdabiya-Sirt line, has already started, in addition to preparations for irrigation of the existing wadi developments.

The main crops will be wheat, barley, maize, sorghum, alfalfa and legumes to meet local requirements for these strategic commodities. Provision will also be made for growing fruit and vegetables for local consumption. The ensuing agricultural development will be a mixture of smallholdings, each of 6 hectares, and larger integrated farms and co-operatives of between 1,600-2,000 hectares each, run under the supervision of Agricultural Service Centres in each area. The larger farms will produce cereals, legumes and livestock, and will be equipped with modern machinery and overhead sprinklers for irrigation. The smallholdings will produce fruit and vegetables and will be run by their owners/occupiers under the direction of the Agricultural Service Centre engineers. The area of these smallholdings was determined on the assumption that each can provide an income of not less than five thousand Libyan dinars (LD 5,000) per annum, enough to maintain a comfortable standard of life for a single family. Overhead sprinklers, a drip feed system, or a mixture of both, will be used for irrigation of the smallholdings, as technically appropriate.

Studies and soil surveys have been undertaken to determine the most suitable areas of land to benefit from the water, and recommendations have been prepared. Naturally, some areas of land will need reclamation and treatment, while others will need the construction of drainage systems. It is also contemplated that an Agricultural Service Centre will be established at each large farm or co-operative and a smaller service centre will maintain a group of smallholdings. Such centres will include offices as well as maintenance units and central workshops for the repair of agricultural tools and equipment.

The irrigation system can be divided into two levels of distribution. The primary network takes water from the main conveyance system at the end reservoirs to the agricultural reservoirs, relying on gravity flow where possible but with some pumping stations for the higher level reservoirs.

From the agricultural reservoirs, water will be pumped to the farms at the pressures required for the irrigation equipment. Wherever possible pre-stressed concrete pipes, from the pipe plants, will be used for these distribution systems. For the smaller pipes other materials will be chosen on economic and technical grounds.

The first phase system is scheduled to be commissioned in April 1990 when the first water from this vital project is received. Similar studies will be carried out for the irrigation system for Phase II after the areas of land to be cultivated have been identified, and it is contemplated that the agricultural pattern of Phase I will be applied to Phase II. Implementation of Phase II is scheduled to start during 1989.

The foregoing description of the system relates particularly to agriculture. Water from the project will also provide the large industrial schemes, such as those in Ras Lanuf and Brega, with the quantities they require. This will enable these projects to be developed, since they will be able to obtain water from the Great Man-made River Project easily and more economically than from a desalinated water source. Equally, as most of the Libyan cities and villages suffer from a shortage of, or bad quality, water, a sufficient quantity of this fresh water will be provided for human consumption which will assist in solving these problems. The other alternative would be to use desalinated water, the unit cost of which, as previously indicated, is greater than that of the Great Man-made River Project water, apart from the consideration of the difficult technical problems involved in desalination processes.

In conclusion, the important benefits that this vital project will bring are summarised below:

1. Existing agriculture will cease to be dependent on existing water wells, which, through intensive use, are becoming increasingly at risk from saline intrusion into the coastal aquifer. The new source of water will, therefore, provide a good opportunity for the coastal aquifers to recover a considerable part of the underground water lost during the past years.

2. Cultivation and development of large areas of fertile land which remained idle through lack of sufficient irrigation water.
3. Protection and enhancement of the fertility of agricultural land which has become sterile as a result of saline intrusion into the coastal aquifer.
4. Realisation of a great measure of self-sufficiency in the production of such main foods as cereals, meat and dairy products.
5. Development of the light industries in rural areas which will directly benefit from the Great Man-made River Project water.
6. Support of existing industries, effectively increasing their production.
7. Encouragement of certain cities and villages at risk from water shortages to revive and develop steadily.
8. Agricultural expansion will encourage people in rural areas to stay on their land, which will become rich in agricultural potential, thus relieving the population pressure in big cities such as Tripoli and Benghazi.
9. The creation of new fields of employment which will eliminate, or considerably curtail, unemployment, providing for the time when oil revenues diminish.
10. The Great Man-made River Project will contribute significantly to the development and promotion of the standard of life of the Libyan people in general.

Finally, the Great Man-made River Project represents the fulfilment of a dream long cherished by writers and scientists, a dream of an abundance of water. The benefits of the project will be manifold and far-reaching, reflecting positively on the agricultural, industrial and social fabric of the country. These benefits are not yet tangible, but they will be clearly seen and appreciated in the near future. When the project is completed, the people will judge that the money spent on its implementation, representing but a small part of the oil revenue, has indeed been well invested.

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