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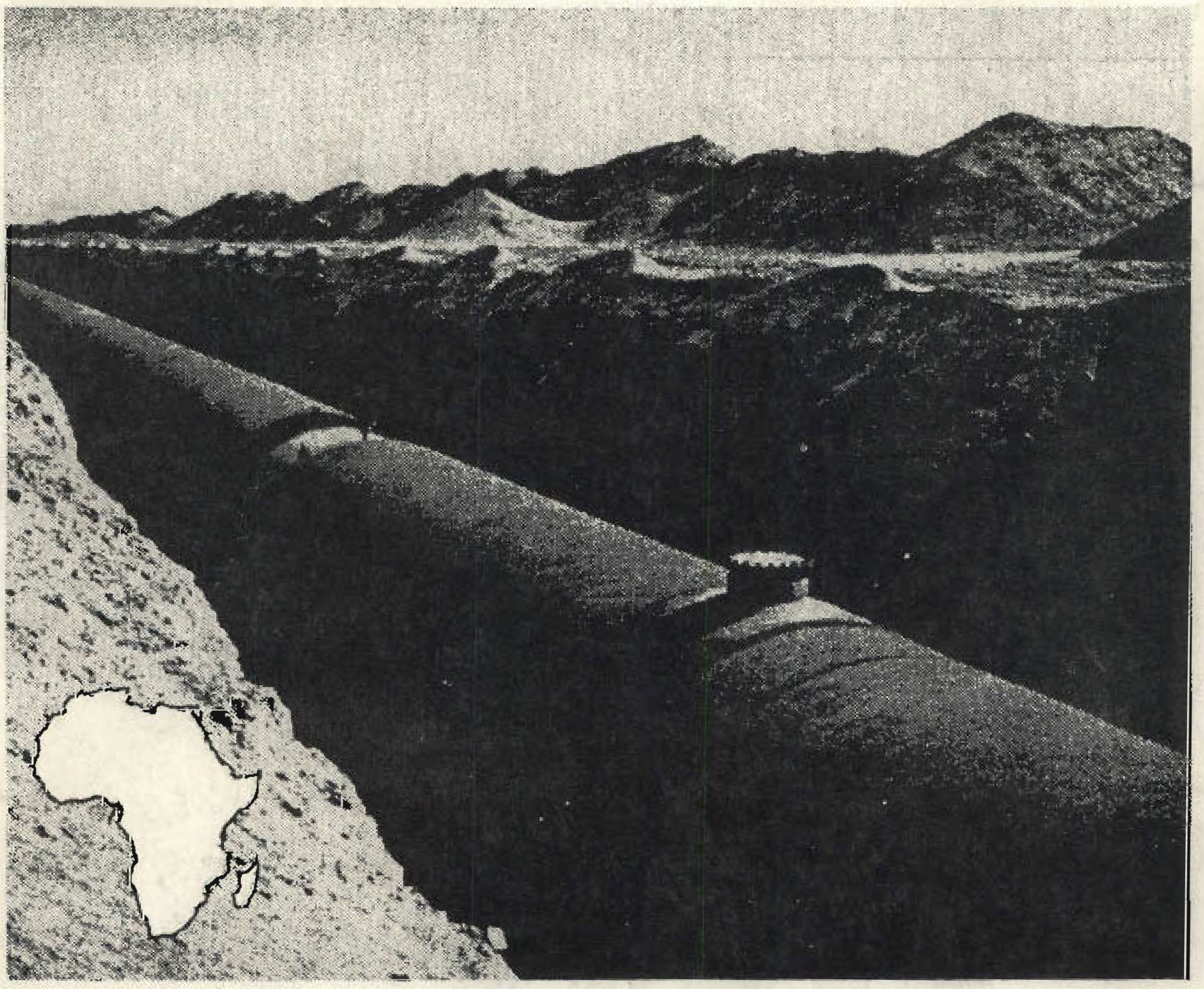
STUDY ON LARGE-SCALE WATER TRANSFER IN AFRICA



STUDY ON LARGE-SCALE WATER TRANSFER IN AFRICA

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FOREWARD

Increasing population pressure, growing need for more food and agricultural products and other development sectors that compete for limited available water resources have set a stress on demand for it. Consequently many countries have been forced to look for new or additional sources that can be developed. In circumstances where solutions are difficult to find, the option was to resort to the application of non-conventional methods of developing new water sources including the use of large-scale water transfer techniques. It is however important to realize that the new generation of water transfer schemes have the associated complexities since more often than not they transcend more than one province, state and even country. Where such schemes span over many administrative or political divisions the sensitivity of the issue in question implies giving away heritage to which deep sentiments and high ascetic values are attached, in addition to exporting economic opportunities whose values increase over time.

Long-distance water transfer has become an attraction to the problems of water shortage that several countries are faced with. Sometimes, the problems of water shortage occur when countries make an exhaustive use of their locally available water resources and at other times they take root in the natural location of the country falling in low-rainfall regimes such that scarcity becomes the most severe problem. Libyan Arab-Jamahiriya suffers from such conditions because large parts of the country receive little or no rainfall throughout the year and 95 percent of its water supply comes from groundwater. Sudan has also a similar condition with most of the country being highly deficient in rainfall. Of necessity countries under such conditions would consider the option of large-scale water transfers from their water-rich and less populated regions to those that are densely populated and resource endowed but water deficient.

There are numerous contemporary experiences of large-scale inter-state and inter-country water transfer schemes in USA, Canada, Mexico, USSR, Hungary, Peoples Republic of China to name a few. In Africa schemes like the Lesotho Highlands Water Project, the Great Man-made River of Libya, and the Jonglei Canal Project in Sudan are some examples from which many lessons can be learnt. While water transfer as an option may provide a solution, it demands careful consideration about the volume of water to be transferred, the physical obstacles along the pipe route, the threats to eco-systems and the political, social and economic consequences thereto.

Large-scale water transfers place major demands on investment capital. They need sophisticated technology and pose political challenges. The series of interacting and interrelated parameters affecting cost-benefit, environment and the life of a population including those post-project impacts and uncertainties require careful consideration. Given that specific problems call for unique solutions that suit a set of circumstances; if the option is for water transfer then the following two considerations need to be satisfied. First, the question of water transfer as an inevitable strategy should be convincing. Secondly, the implications and consequences in terms of eco-systems, political sensitivity, social impacts, cultural and ascetic considerations and technical feasibility and economic viability need to be satisfied to see the trade-off for decision making particularly when other alternatives are available.

Large-scale water transfers often require sophisticated technology in addition to the cost factor. On the other hand it is evident that large towns and industrial and mining enterprises are the ones that can justify the economics of long distance water transfers compared to irrigation which represents high demand for water but only willing to pay cheap prices. It is therefore possible that small urban towns and rural areas which are also a priority for a government might be marginalized when the decision goes in favor of large schemes. Further there are experiences in Africa where some large schemes that involved enormous expenditures, high skills and energy have been criticized as being too complex to manage and far removed from responding to existing needs and problems. Therefore, planning should conform to the immediate and long term needs as well as the skills available to construct and use a scheme. A turnkey project which becomes totally dependent on external skills and consumes huge resources requires much contemplation in view of long sustained operation that yields good dividend to the population at large.

This paper has been prepared with a view to draw attention to contemporary projects in Africa from which some lessons can be learnt. It does not intend to advocate against large schemes because the problem is not on the size and complexity as it is on the sustainability and the attainment of desired objectives. The paper focusses on the need for good planning and management skills such that the undertaking does not induce undue difficulties on the economy of a country and constrain other development activities not to mention the numerous list of apparent problems as has been experienced by many countries elsewhere and in Africa.

THE GREAT MAN-MADE RIVER (GMR) OF LIBYA

I. INTRODUCTION

1. The Libyan Arab Jamahiriya is a vast country in North Africa with an area of 1,760,000 km^2. It has 1600 km. of Mediterranean coastline. It borders Egypt on the east, Tunisia and Algeria in the west and Sudan, Chad and Niger in the south. It falls between longitudes 9° 19' and 25° 00' East, and latitudes 19° 12' and 33° 06' North.

2. The United Nations estimate in 1983 gave a population figure of 3.36 million. The average rate of population growth then was 3.5 % 9/. Eighty percent of this population was considered to live in the coastal areas; with the largest concentration in Tripoli and Benghazi. Other population centers are Zaweyan, Darnah, Misratah. The mid 1988 population was 4.2 million and growth rate was 4.3 % 13/. Industrial, agricultural and housing project activities in recent years have attracted more people to towns situated in the south of the Sahara.

3. There are no perennial rivers in Libya. Torrential streams flow in dry wadis* following storm rainfall which is sporadic and may not occur every year in some regions. The unpredictable nature of storms and subsequent torrents yield a high ratio of potential storage to mean annual runoff volume that requires some control work. This however demands structures for impoundment. Against the high rate of evaporation of stored water which tends to make over-year storage uneconomic, and the high incidence of sedimentation that shortens the life-span of reservoirs, big structures are not technically and economically feasible. In order to meet the need and strong demand for water resources, the country has however, ventured to construct several dams across wadis to harness its water for agricultural and other purposes.

4. In general, a very small amount of the runoff reaches the sea. Most of the water is either evaporated or infiltrates in the wadi beds and recharges the underlying aquifers. The total average annual runoff has been roughly estimated to be 200 million cubic meters and this amount constitutes about 5 percent of the available water resources of the country.

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* Wadis are intermitent rivers which flow only during the rainy season.

II. BACKGROUND AND SUMMARY OF THE GREAT MAN-MADE RIVER PROJECT

5. The extreme aridity in 95 percent of the area of Libya is a cause for concern and naturally the country attaches great importance to development of water resources. The arid and semi-arid conditions and the unevenness of incidence of rainfall even in the Mediterranean coastal regions poses severe limitation on water-oriented development programmes. In the past few decades there has been a growing stress on water demand from various use sectors particularly from agriculture.

6. Rapid build-up of irrigated farming has virtually induced an unregulated expansion of wells. The intensity of the problem increased with the decision to diversify the economic base of the country on its natural resources other than non-replenishable oil resources, notably land reclamation and water resources. This outlook had also the objective of achieving the goal of food and agricultural self-sufficiency through intensification of agriculture especially irrigated farming based on ground water. In line with the stated objectives, massive irrigation programmes were launched in the 1970s by using oil revenue for such development. The combination of rapid urban development and the drive for a more accelerated agricultural development" were imposing unusually high demands on limited available water resources. This necessitated an intensified exploitation and uncontrolled tapping of groundwater that gave way to serious drawdown of wells. Consequently the water tables were falling 1 - 3 meters/year by mid-1970s and discharge was four times recharge 10/. The impact was immediately felt since development came to be constrained by lack of water resources.

7. Libya has been searching for new water sources and a series of exploration and study was going on since 1950s. The growing demand on water for agriculture, domestic and industrial uses has been a major factor to add to the launching of a concerted and vigorous effort for the exploration of deep ground water sources. Numerous investigations have been carried out in many parts of the country by various expert groups. These exploratory works have been integrated and co-ordinated in a framework to prepare a synthesis on a national basis to take stock of the available water resources.

8. The project of the Great Man-made River (GMR) is a result of the series of ground water investigations that led to determine the extent of the availability of this reserve. The GMR is a huge project both in terms of technical complexity and capital outlay. It is a project in which internationally recognized firms are participating. The project envisages developing well fields, construction of reservoirs, and conveyance or transportation of some 2 million cubic meters of groundwater a day by constructing about 1900 km of concrete pipeline from wells deep below the Sahara to the coastal regions. Allied activities constitute the establishment of pipe manufacturing industries and construction of power stations and transmission lines.

9. The project also includes development of irrigation, livestock, and food processing industries. The GMR scheme is expected to be completed in 25 years and the total scheme is valued at US$ 25,000 million 5/. It is intended to lay the basic foundation for the country's economic and social development well into the 21st century.

III. PHYSIOGRAPHIC, CLIMATIC, AND HYDROGRAPHIC FEATURES OF LIBYA

A. Physiography 11/

10. Libya is predominantly represented by vast plains with some mountains in the north, central and southern parts. The main mountains are Jabal Nafusah (600-800m) and Jabal Akhdar (500-600m) in the north along the Mediterranean costs, Jabal Sawda (803m) and Jabal Haruj (l200m) in the center, and Toammu (l022m), Tibesti (2300m at Kainet) and Archenu (l,460m) in the south 1/.

According to FAO statistics, arable land is estimated at 2,400 ha, permanent crops 1,400 ha, permanent pastures 6,750 ha, and forest and woodland 534 ha. Recent estimates of irrigated area is 133,000 ha out of a total of 388,000 ha 12/.

11. The country is divided into the following four physiographic units.

a) The coastal plains:

12. These are located along the entire Libyan coast. They vary in their economic importance and areal extent. The most important ones are Al Marji, Benghazi, Sedra, and Al Jafara.

13. The triangular plain of Al Jafara which is dominated by the heights of Jabal Nafusah, is located in the north western tip of Libya. This plain has a very good climate as well as soil and water resources. It is known for being the main producer of the country's farm products. It is also the region where the capital Tripoli and other major urban centers are located. The good climatic conditions and its endowment with natural resources have made it the most densely populated part of the country. Another important plain in the north eastern tip and with a lesser significance than the Al Jafara is the Benghazi plain where the town of that name is located. The Jabal Akhdar mountain is a dominating feature in this area. Beside these two plains, there are also others whose economic importance is comparatively less significant.

b) The Northern Heights:

14. These are mountains running close to the coastal plains. They include the Green Mountain peninsula and Jabal Nafusah reaching 800 meters in height. South of the Jabal Nafusah lies the vast desert plateau of Hamata Al Hamra. At its peak this mountain range attains heights of 500 to 600 meters.

c) The Central lowlands:

15. These lowlands generally occupy the region from east to west. In this region there are a number of oasis like Ojlah, Jalou, Jaghboub, Al-Jadaf, Fazun depression and Al Kufrah. In this part appear the heights of Al Haruj and Al-Aswad. The Al Kurah is an immense basin stretching to the Egyptian frontier and rising to an altitude of l00m in the north and 800m in the south. In the north are expanses of gravel and sand dunes and in the south are gravel, stones and rocks with many small areas of sand dunes. There are other flat and desert areas such as the Sirt, Jabal Haruj and Sarir Tibesti in this physiographic region.

d) The Southern and Western Heights:

16. The southern and western heights run near the borders with Algeria, Chad and Sudan. They slope in the direction of east and north and include the Red Hill of Al-Hamada in the north, the heights of Dahan Marzuq in the middle and the mountains of Tibesti, Al-Awaynat and Archenu in the south. The Marzuq basin (Edeyin) which is covered with sand dunes is found in this south-western part.

17. Sedimentary rocks commonly occur over most of the country. These generally consist of limestone and sandstone. Sand dunes are found in parts of the central and the southern region. On the coast and internal lowlands there are quaternary deposits.

B. Climate

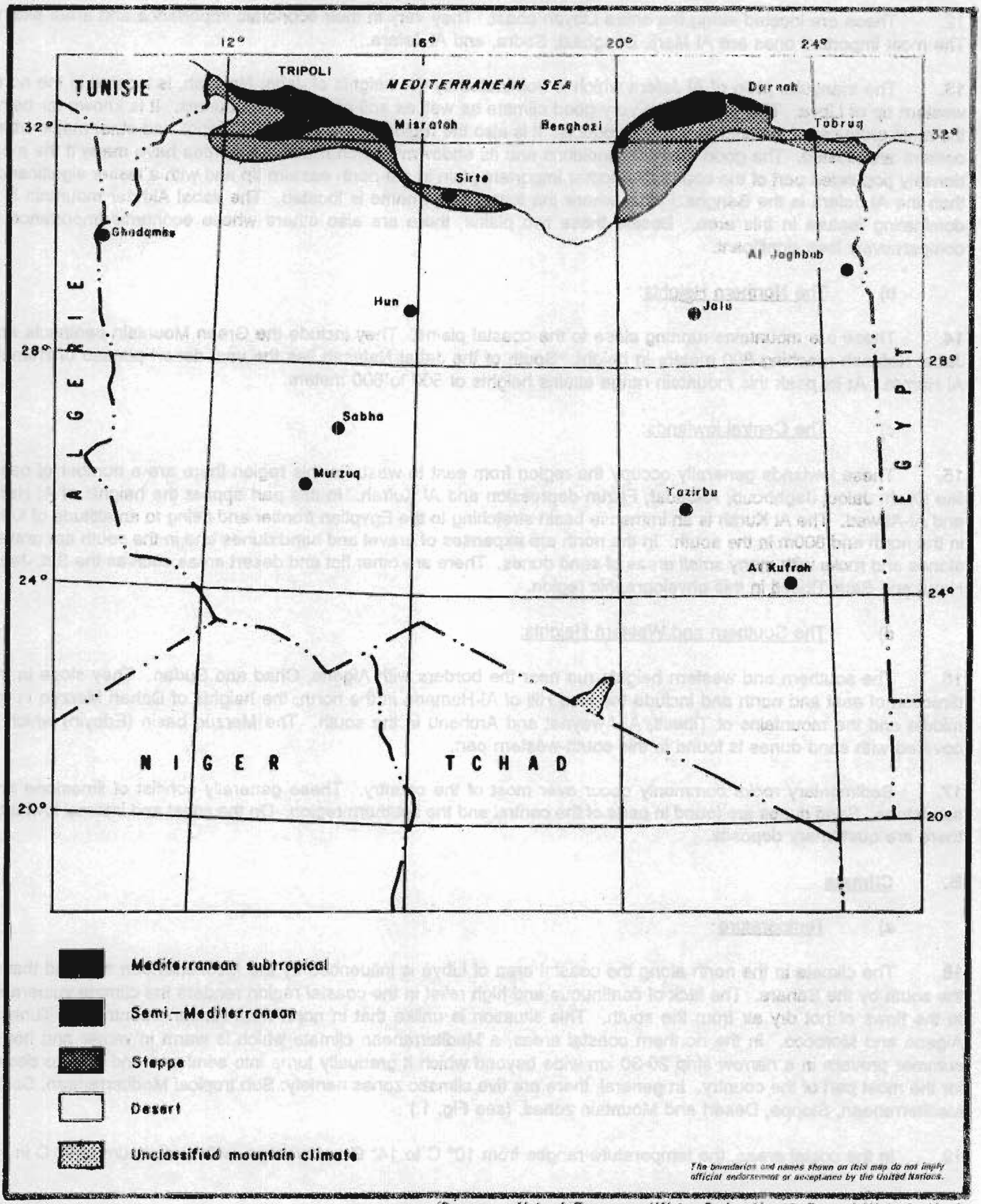
a) Temperature

18. The climate in the north along the coastal area of Libya is influenced by the Mediterranean sea and that in the south by the Sahara. The lack of continuous and high relief in the coastal region renders the climate vulnerable to the flows of hot dry air from the south. This situation is unlike that in north-west African countries of Tunisia, Algeria and Morocco. In the northern coastal areas, a Mediterranean climate which is warm in winter and hot in summer prevails in a narrow strip 20-30 km wide beyond which it gradually turns into semi-arid and then to desert for the most part of the country. In general, there are five climatic zones namely: Sub tropical Mediterranean, Semi-Mediterranean, Steppe, Desert and Mountain zones. (see Fig. 1.)

19. In the costal areas, the temperature ranges from 10° C to 14° C on average, with a minimum of 0° C in

LIBYAN ARAB JAMAHIRIYA
CLIMATE ZONES

Fig. 1



CART-91-II

Sources : Natural Resources / Water Series No. 18 Ground Water in North and West Africa United Nations 1988

winter. During summer temperature reaches as high as 40° C. Further down in the steppe zone temperature variations are wider. At Al-Aziziyah the world's highest temperature of 58° C was recorded in September I922. The average for July is 24° C to 28° C and that for January is 10° C to 14° C. Temperatures of -3° C have been recorded in winter and snowfalls on the Jabal Nefusah and Jabal Akhdar mountains have been recorded.

20. In the desert zone, there are marked variations of the daily temperature. The average range goes from 26° C to 4l° C in July and from 8° C to 16° C in January. At Ghadamis the recorded absolute minimum is -2° C in November, -5° C in December, -6° C in January and -8° C in February. The absolute maximum varies between 45.2° C and 50.6° C.

b) Humidity

21. The relative humidity in the country as a whole decreases from the coastal northern regions to the south. The humidity ranges from 70 to 80 per cent along the coast in the months of December to February to as low as 50 per cent in June/July. For Sabha in the mid-west of Libya the range is 40 to 50 per cent in winter and declines to 20 per cent in summer.

c) Wind

22. The force and direction of wind varies from day to day throughout the seasons. The wind velocity ranges from 5 to 15 knots.

d) Evaporation

23. The evaporation rates are high, with the maximum being in June/July and the minimum in December /January. The average annual values measured in piche evaporometer increase steadily from north to south with the climatic zones. The values range from 1700 to 2500 mm on the coast and from 4000 to 5000 mm towards the interior with the average amount for Kufrah being 6100 mm.

e) Rainfall

24. Rainfall is received in winter, mainly from October to March. The average annual rainfall ranges from 250mm in Tripoli in the North to 500mm in Shabat and Al-Baida in the Green mountain. The maximum annual rainfall of 400 to 600 mm is received along the Jabal Akhdar; and this amount diminishes to 200-400mm towards Misurata in the west and Ajdabiya-Darnah in the east. Southwards rainfall declines rapidly and it reaches 5mm in the middle of the country. The I00 mm isohyet is parallel to I50 km to coast which it follows for almost the whole length of the Gulf of Sirt. South of the 30th parallel N, rainfall is vestigial and is often less than 25 mm. The amount is below I00 mm for about 95 percent of the country(see fig 2).

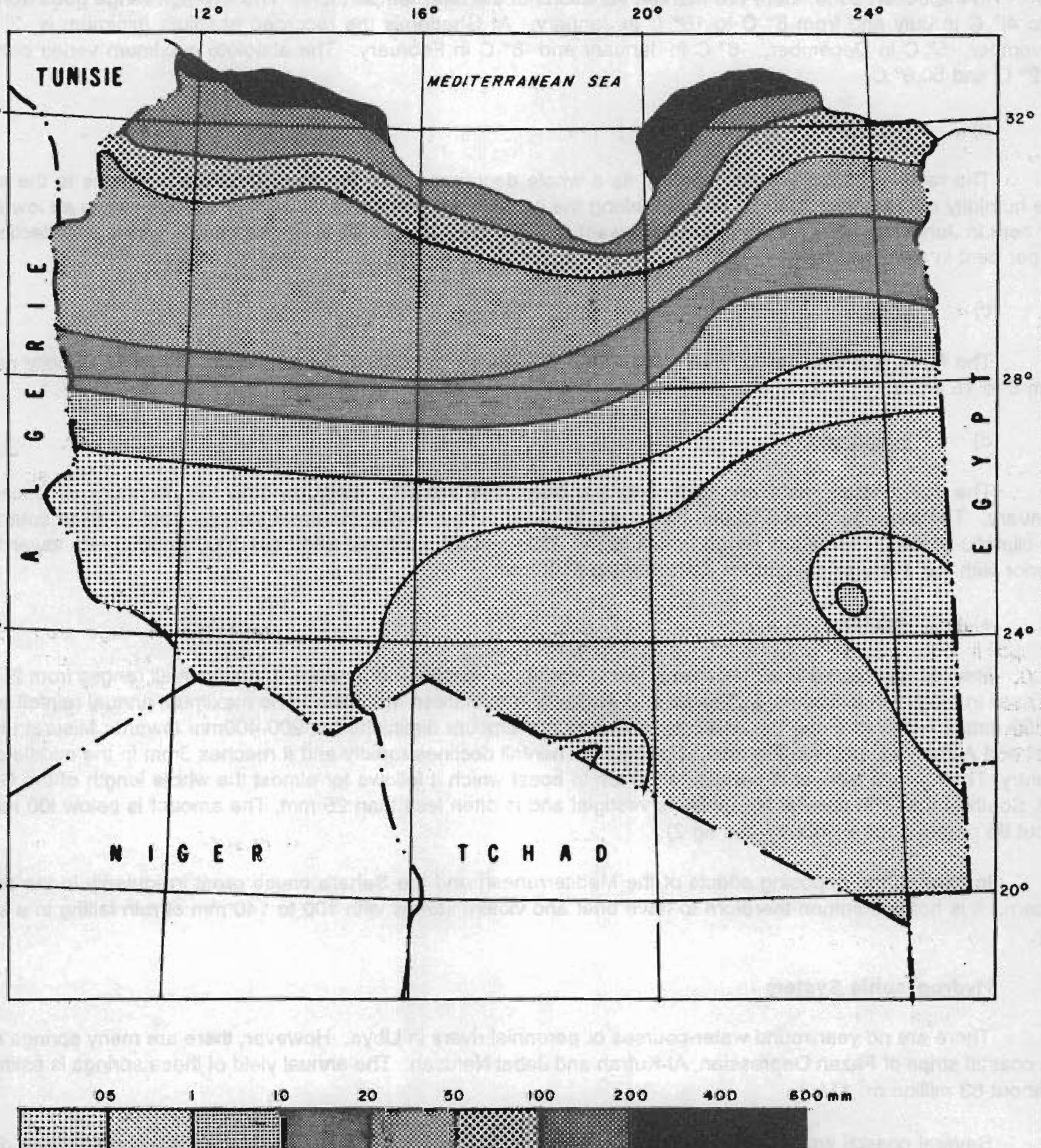
25. In general the opposing effects of the Mediterranean and the Sahara cause great irregularity in the rainfall pattern. It is not uncommon therefore to have brief and violent storms with 100 to 140 mm of rain falling in a single day.

C. Hydrographic System

26. There are no year-round water-courses or perennial rivers in Libya. However, there are many springs along the coastal strips of Fazan Depression, Al-Kufrah and Jabal Nefusah. The annual yield of these springs is estimated at about 63 million m^3 11/.

27. Several coastal wadis (intermitent rivers) like Sawajjin, Bay Kabir and Zamzam flow for short periods during winter months. Some of these are large in terms of length and basin size. They have their sources at the eastern end of the Hamata plateau and reach the coast between Misratah and Sirt.

LIBYAN ARAB JAMAHIRIYA
AVERAGE ANNUAL PRECIPITATION



Sources : Natural Resources / Water Series No. 18 Ground Water in North and West Africa United Nations 1988

The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

CART – 91 – 10

Fig. 2

28. Jabal Nafusa has 30 hydrographic basins with a total area of 7,500 km^2 which collectively receive 1,700 million m^3 a year. The flow of runoff in the streams varies depending upon the condition in each basin. The coefficients of runoff in the basins are in the order of 2 to 20 per cent and the maximum flow in the wadis range between 10 to 250 m/s in a period of a few hours. Their annual yield is estimated at 50 - 100 million m^3 1/. This volume of surface water represents 5 per cent of the water resources of the country.

D. Conservation of surface water resources

29. The scarcity of water has been recognized and possible conservation and development measures are being taken. Towards this end, construction of cisterns with capacities of 50 to 500 m^3 in the western mountain of Al Jaffara plain, Central valleys and Green Mountain regions have been undertaken. Storage dam construction across streams for irrigation and domestic purposes are also carried out extensively. The capacities of these dams range from 0.25 to 11 million m^3. At present there are 17 dams in the country 11/. Many check dams are also constructed on the southern slopes of Jabal Nafusah and the Green Mountain. These serve for harvesting rain water and for controlling surface runoff in small and large streams for use in orchard tree-growing and for agronomic crops. It is noted that such dams are in need of extensive maintenance programmes. They have an important role in soil and water conservation and in combating drought.

IV GEOLOGY AND HYDROGEOLOGY

A. Geology

30. The geological formations in Libya are wide ranging in age falling between precambrian to quaternary.

31. The precambrian metamorphic basement rock of quartzite, phyllites, marbles, schists, gneiss and intrusive rocks have major outcrops in the south, south east and centre. Small outcrops are along Algerian-Libyan frontier and in Bergaf area. Elsewhere in the country the basement rock lies at depths between 500 to 5000 meters.

32. The cambrian - Ordovician formation is represented by sandstones of mainly continental origin. They rest in discontinuity on the basement rock with thicknesses of 500 to l500 m 1/. They outcrop in the south-west and center of the country attaining maximum thickness in the middle of Ghadamis - Hamata basin.

33. Silurian formations occupy a vast area of the Jabal Tadrart on the western edge of the Marzuq basin and a narrow strip of land east of the Jabal Biu Ghunaymah on the eastern edge of the Marzuq basin.

34. Overlying the Silurian formation in the western basins of Marzuq and Ghadamis is found the Devonian sandstone and schist. The Upper Devonian contains more schist but in Kufrah the formations are more sandy and less in thickness 1/.

35. A thick carboniferous strata overlies the Devonian formation. It includes schists and fine sandstones interbedded with sandstone and limestone layers. In the middle of Ghadamis basin the formation attains a thickness of 1200 m.

36. In the Marzuq and Ghadamis basins there is a sequence of continental sediment of Poleozoic - Mesozoic age covering in discontinuity the Paleozoic marine sediments. This fine grained sandstone has variable thickness of up to 600m. The coarse continental sandstone in this region known as "Nubian Sandstone" equivalent to continental intercalcaire overlies these formations in discontinuity in the Marzuq and Kufrah basins -it outcrops extensively in the south of the country. It is more than 1000 m thick in the middle of the two Mesozoic - Cenozoic basins. In the north-west are found sedimentary formations containing shallow water, ranging in age from Middle Triassic to Paleocene. The Triassic formation consisting of Kufrah sandstone, Aziziyah limestone and Abu Shayeah sandstone provide important aquifers.

37. Basaltic volcanic rocks are found extensively south of Ghargan and Jabal Sawda, Haruj and Tibesti.

38. There are quaternary deposits which include immense expanses of sand dunes in Marzuq, Kufrah and Sarir basins, as well as loess and alluviums in other regions and along the coastal mountains (see fig. 3)

B. Hydrogeology

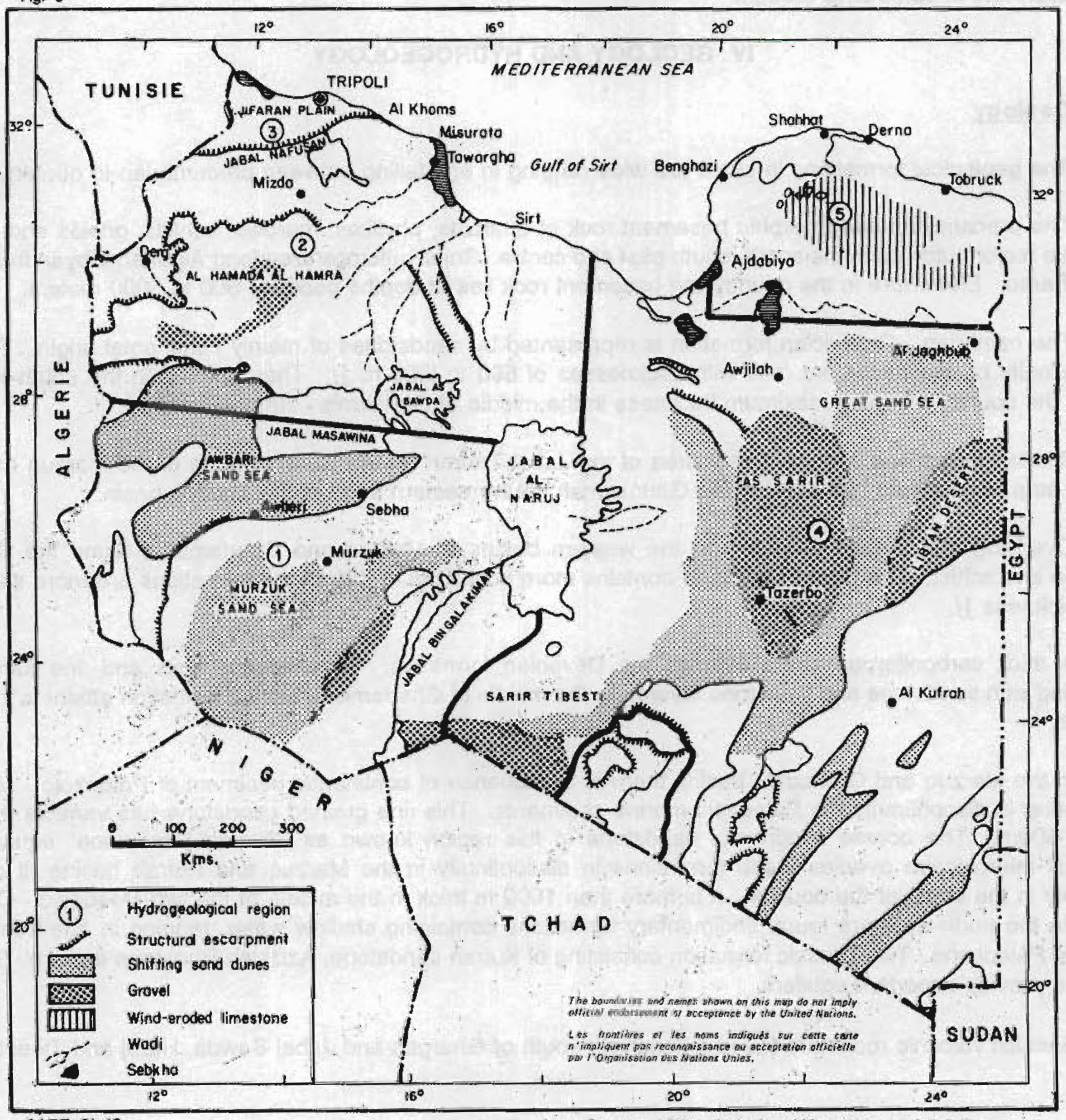
39. The largest source of water in Libya is groundwater. This is concentrated in five identified and largely independant aquifer systems shown in fig 3, namely:

- The Marzuq basin system of the south-west situated between 28° N latitude and approximately l9° longitude.

- The Jabal-Nfusah - Sawf el Jin - Western Sirt and Hamata basin system lying north of Marzuq basin and the 18° E longitude.

LIBYAN ARAB JAMAHIRIYA
MORPHOLOGY

Fig. 3



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Source ; Libyan Arab Jamahiriya, Water and Soil Department

- The Jefara plain system in the north west corner of the country surrounding Tripoli.
- The Kufrah Sarir basin system to the east and approximately south of the 31° N latitude.
- The Jabal Akhdar system to the north east corner, lying east of Benghazi.

40. These are all deep aquifers, with some regions having artisan condition. The outstanding characteristics of the aquifers in the country can be classified into two major groups, namely:

(i) **the outcroping connection of coastal aquifers, the Jefara plain and the Jabal Akhdar system that have connection with the sea and have possibilities of annual recharge from rainfall.**

(ii) **the comparatively large storage capacity aquifers in the south-western and eastern areas with negligible annual recharge except infrequent rainfall events that occur in frequencies ranging from 10 to 20 years.**

41. The aquifers in (I) are affected by sea water intrusion consequent to prolonged pumping and over exploitation because of their connection with the sea. It has been observed that during pumping, piezometric heights remain stable but a gradual deterioration of water quality takes place. Given the low rainfall over the country as a whole, and the high potential evaporation it is natural that the existence of shallow aquifers is generally represented by their small and scattered presence. There has been intensive exploitation of the coastal aquifers in Tripoli region between the Tunisian border and Misurata, particularly in the Jefara plain. Rational use of groundwater in these areas is an imperative need such that extraction by pumping is limited to recharge rates.

42. The main aquifers along the coast have storage that can be reached at depths of up to 100 meters. The deeper aquifers with 700 - 1000 meters that lie to the south of the Jefara plain are used for growth in grazing fields, since the soil and the climate in this area are not suitable for agriculture.

43. In the aquifers to the south western and eastern parts of the country, large storage capacity aquifers have been identified through a series of detailed studies and through investigations carried out over the years for purposes of large-scale irrigation development.

C. Hydraulic characteristics 1/ of the Five Independent Groundwater Basins in Libya: A Leap towards GMR project

44. From the climatic and physiographic conditions it can be seen that Libya has very limited surface water resources. At the same time, the demand for water by all sectors such as agriculture, industry and domestic supplies etc. has been continuously growing. For a long time these demands were for the most part met from ground water sources. Over the years the extraction and mining of ground water was constrained by a series of set backs ranging from decline in water tables to salt water intrusion from the sea along coastal regions to occurrence of land subsidence in areas like Sarir. These problems have not been without negative economic and environmental impacts. The gravity of the problem was intensified as the water crisis worsened. To avert this situation there has been a persistent pursuit and search for new ground water source which could be developed to respond to the growing needs set by the various use sectors. To concertize this effort the Libyan Arab Jamahiriya allocated large amounts of money to promote studies and investigations which have ultimately enabled the classification of the country into five ground water basins according to their hydraulic characteristics. This classification which was based on consolidated studies was fundamental to concentrate and intensify efforts for the realization of the Great Man-made River Project (GMR). Some water quality aspects and hydrogeologic characteristic features of the five identified basins are given below:

(i) Marzuq basin - Area : 300,000 km^2

45. The Marzuq basin consists of (a) the lower Paleozoic (b) the Carboniferous and the Upper "Nubian" aquifers.

(a) Lower paleozoic aquifer

46. The lower Paleozoic aquifer consists of Cambrian-Ordovician, Silurian, and Devonian formation. The lower Silurian formation known as the "Tanezzufts Schist" is not water bearing and it extends towards Algeria, Niger and Chad. The strata which are water bearing in the Lower Paleozoic aquifer are:

Hazawinah, Hauaz, Melezz and Memouniat (Cambrian-Ordovician, with thickness of 200 - 1 400 meters) and;

- Tadrart, Ouan Kasa, Uwaynat, Wannin (Devonian, with thickness of 40 - 600 meters).

47. The piezometric level of the aquifers decline from 700 meters in the south-west to 250 meters in the north-east. Recharge is practically non-existant due to lack of rainfall. Carbon-14 dating of the water bearing aquifers indicates an age range of 6000 to 14 000 years. Natural depletion of 0.1 meters/year occurs through evaporation and exploitation along Wadi Ash Shati. Transmissivity for artisan aquifers is 10^{-5} m^2/s. The quality of water is good, however, it deteriorates towards the north west. The similarity in the properties of water of the Cambrian - Ordovician and Devonian aquifers suggests that they have interconnections. The water in these aquifers is corrosive and warm with temperatures ranging from 35° C to 40° C.

(b) Carboniferous aquifer

48. The Carboniferous aquifer of Marzuk basin consists of thick impermeable stratum of argillaceous schist.

(c) Upper "Nubian" aquifer

49. The Upper "Nubian" aquifer is found in the centre of the basin covered with deposits in forms of sand dunes and a "sand sea". Its thickness declines from 1000 meters in the middle to 200 - 300 meters at the edges. Because of lack of rainfall and high evaporation, the aquifer is not recharging. Carbon - 14 dating indicates the water to be 21,000 years old. Flow direction is towards the north-east. The transmissivity ranges from 1.3×10^{-2} to 2.8×10^{-3} m^2/s. The storage coefficient is in the order of 2×10^{-4}, porosity between 20 to 40 percent. The quality of water in shallow wells is affected by evaporation and recycling of irrigation water, such that it ultimately becomes saline.

(ii) Jabal Nafusah - Sawf el Jin - Western Sirt and Hamada basins

50. This is a group of hydraulically interconnected sub-basins. The main water bearing strata consist of: (a) the Cambrian - Ordovician (b) the Lower Cretaceous or Kiklah (c) Upper Cretaceous or Mizdah, and (d) Cenozoic aquifer systems.

(a) Cambrian - Ordovician aquifer

51. The Cambrian-Ordovician aquifer is an extension of the Marzuq basin and is found in the central part of Hamadah. Its significance lies in the capability to recharge the lower cretaceous sandstone and the upper cretaceous limestone aquifers. The transmissivity ranges from 10^{-2} to 10^{-3} m^2/s, the storage coefficient is 10^{-1} for the unconfined conditions and 10^{-3} to 10^{-5} for the recharge zone. The water quality is exceptionally good in the south but deteriorates towards the north with the decline in the hydraulic gradient.

(b) Lower Cretaceous or Kiklah aquifer

52. The Lower Cretaceous or Kiklah is the most important aquifer in the north-west of the country. It is recharged by the Lower Cretaceous outcrops and the Cambrian-Ordovician aquifers. Part of this recharge is thought to come from the Algerian Atlas. Water from this aquifer is extracted from boreholes at depths of 700 to 1 000 meters which are artisian or sub-artisian. The quality of water is generally good.

(c) Upper Cretaceous or Mizdah Aquifer

53. The Upper cretaceous or Mizdah is a well developed aquifer. It consists of limestone interbedded with marl and has thicknesses varying from 100 to 300 meters. In Al Jufrah area water is exploited for irrigation by means of artisian boreholes. The flow direction is towards north-east, the transmissivity is 3.6 to 10^{-3} m^2/s, and the storage coefficient is around 10^{-3}. The aquifer is recharged by direct infiltration from rainwater and surface runoff, and by underground contact with the paleozoic and lower cretaceous aquifers. The water quality varies greatly throughout the area with its dry residue ranging from 1.3 g/l at Jufrah to 4.4 g 1/l at Hamada. The water has a low PH, and is corrosive and warm.

(d) Cenozoic aquifer

54. The Çenozoic aquifer (Eocene, Oligocene, Miocene) has thick deposits of limestone and dolomite separated by thick layers of clay, marl and argillaceous schist. It has dry residue greater than 5 g 1/l. Along coastal zones between Misratah and Khums a better quality of water exists and is used for agriculture and drinking purposes. The aquifer is recharged by rainwater and from bilateral contact with Nalut aquifer. Excessive pumping of this system has led to quality deterioration that induced sea-water intrusion.

55. In this region there are two important springs known as the Tawargha and Ka'am that discharge 63 and 11 million cubic meters a year respectively from the aquifer 1/.

(iii) Jefara Plain - area : 15,000 km^2

56. This triangular plain occupies the north-west part of the country between Jabal Nafusah in the south and the Mediterranean sea in the north. The region is of great economic importance. About forty percent of the country's population live in this region and most of the urban centers are located here including the capital Tripoli. Much of the plain is irrigated and more than half of the country's farm supplies are produced in this part. The main aquifers are: (a) The Upper Miocene, Pliocene and Quaternary (b) the Middle and Lower Miocene and (c) Triassic formation.

(a) Upper Miocene, Pliocene and Quaternary

57. The quaternary consists of the "phreatic" aquifer and formations of Upper Miocene, Pliocene and Quaternary age. These have thicknesses of 30 to 150 meters and they are hydraulically interconnected. The saturated layer of these formations is 10 to 90 meters thick. Near coastal areas transmissivity is in the order of 2×10^{-3} to 10^{-2} m^2/s and in the interior it ranges from 2×10^{-2} to 10^{-1} m^2/s. Its storage coefficient ranges from is 6×10^{-2} to 10^{-1}. In the Quaternary aquifer, the wells yield 20 to 60 m^3/h. In areas where there is a heavy abstraction of water for irrigation purposes a steady decline of 5 m/year is occurring with consequent sea water intrusion taking place along the coastal strip 20 kilometers east of Tripoli between Sabratan and Tajura.

58. The dry residue in the central part is 1 - 2 g/l and the concentration increases towards the west due to the influence of gypsum and limestone intercalations at the base of the aquifer. Nitrate concentration is in excess of 45mg/l and the salinity between Sobratah and the Tunisian frontier is over 5g/l.

59. In the western Jefara plain, the Quaternary aquifer is fairly small and has a saturated layer of 10 to 30 meters. Towards the west, the aquifer is confined and has good quality water with a dry residue below 1g/l. Recharge is by rainwater and surface runoff from the wadis. The lateral contact in the south and the vertical drainage from the Middle and Lower Miocene formations are also considered to contribute to the recharge.

(b) Miocene aquifer

60. The Miocene aquifer consists of the Middle and Lower Miocene formations of central and northern Jefara.

61. The Middle Miocene lies between two clay strata. It has a thickness of 125 to 200 meters. Average transmissivity is 5×10^{-2} m^2/s and the storage coefficient is 1×10^{-3}. Recharge is from lateral contact to the south and the water quality is poor with dry residue being 3 to 4 g/l.

62. The Lower Miocene aquifer constituting of sand or dolomitic limestone is found in the western and central Jefara. It lies at depths of 250 to 485 meters. At Sobratah it is 90 meters thick and has transmissivity of 5×10^{-4} m^2/s. The dry residue is 2 to 4 g/l and exceeds 6g/l towards the west. Though the aquifer is artisian, it is not exploited because of its high salinity. Recharge is obtained from lateral Triassic limestone. In eastern and central Jefara, the aquifer lies at depths of 150 to 200 meters and the dry residue ranges from 2,5 to 4.5 g/l. Further east, where the aquifer thickness declines the water quality improves.

(c) Triassic aquifer

63. The Triassic system constitutes of two separate formations known as the Sandstone and the Aziziyah aquifers. The Sandstone aquifer at Abu Shayba is of Upper Triassic age and has a maximum thickness of 350 meters. Its transmissivity is 5×10^{-3} m^2/s, and the storage coefficient is 10^{-2}. Water quality is generally good with a dry residue of less than 2g/l.

64. The Aziziyah aquifer belonging to the Middle and Upper Triassic ages is exploited in the southern part of Central Jefara. It has transmissivity values ranging from 2×10^{-2} to 5×10^{-2} m^2/s and a storage coefficient of 5×10^{-2}. The average yield of the wells is 70 - 110 m^3/h for the unconfined aquifers and 30 - 50 m^3/h for the artisan ones. The residue amount varies between 2 g/l in the south to 4 g/l in the north. North of the Aziziyah fault the aquifer slopes down towards the north through a series of ladder faults and reaches a depth of 900m meters near Tripoli. In eastern Jefara, the aquifer is found at depth of 200 to 500 meters and has transmissivity of 1 to 5×10^{-3} m^2/s and dry residue of 1.7 to 2.5 g/l.

(iv) Kufrah and Sarir basins

65. These basins cover a very large expanse of eastern Libya and extend towards Chad and Egypt. They are limited in the north by the 30th parallel and in the east by the 18th meridian. Hydrogeologically the region is divided into Kufrah and Sarir or Sirt sub-basins.

Kufrah sub-Basin :

66. The hydrogeology of this sub-basin was first studied in detail in a small area around Kufrah. Lithological data collected during oil-drilling are available for the rest of the region. The whole sub-basin is formed of Cambrian Cretaceous aquifer with a maximum thickness at the centre reaching 3000 meters. The structure consists of sandstone interbedded with clay and silt. A Continental Mesozoic aquifer of Nubian sandstone constituted of Triassic - Lower Cretaceous formations supplies water to two irrigated areas and to inhabitants in Kufrah. The aquifer is saturated to a depth of 1000 meters and the wells are generally 300 to 400 meters deep. In the Nubian sandstone aquifer the static water level is only a few meters below the surface.

67. The direction of ground water flow is along the north and north-east and the static water level falls by 400 meters for some unknown reasons. Boreholes discharges range from 135 to 300 m^3/h specific yields are 10 to 50 $m^3/h/l/m$, transmissivity ranges are 300 to 500 m^2/day and the storage coefficient is 1.1×10^{-4} to 1.5×10^{-2}. The regional drawdown due to pumping is closely monitored by means of a network of observation wells located close to or within the pumping zones. A maximum drop of 25 meters was observed in the central part of these zones up to April 1985. The drop declines rapidly away from the center and is only 20 to 25 centimeters at a distance of 30 kilometers. The fall in water level is induced by the drawoff of ground water which amounts to 90 to 120 million cubic meters a year. Although pumping began in 1968 the drawoff did not reach the above amounts until 1975. The phreatic aquifer, which is about 60 meters in depth, is sometimes considered as a separate unit because of its hydrochemical properties. This aquifer has long been exploited by farmers and a water level decline of nine meters was observed up to April 1985. The quality of water is excellent. The mineral content for wells of 137 meters is in the range of 180 and 300 mg/l. In the phreatic aquifer depending on the location and depth of the wells a maximum figure of 8 g/l is observed. Wells located close to sebkhas or lagoons are often found to be more saline. The water of deep aquifers has a low PH value and a high CO_2 content and is consequently corrosive. The amount of free CO_2 near Kufrah goes up to 34 to 57 mg/l. This gives rise to increased construction and maintenance cost of wells.

Sarir or Sirt Sub-Basin

68. This sub-basin is situated north and west of Kufrah sub-basin. The Sarir Tibesti part of this region has not been researched; but the northern Sarir Calancio area has been studied since the end of 1960s with a view to developing two well fields for irrigation purposes. In addition to existing well fields others were developed in 1985 for supplying water to coastal zones. This basin is younger than Kufrah which is a Paleocene-Miocene formation, but the aquifers are limited to post-Eocene formations; of which two, namely (a) the Post-Middle Miocene and (b) the Lower and Middle Miocene aquifers contain fresh water.

(a) Post-Middle Miocene aquifer

69. The Post-Middle Miocene aquifer which has a thickness of up to 200 meters consists of medium to coarse grained sand merging into calcarious sandstone with fine intercalations of clay.

(b) Lower and Middle Miocene aquifer

70. The Lower and Middle Miocene aquifer in the Maradah formation has thicknesses of 150 to 880 meters. In the north it consists of marine limestones, clays and evaporites; and in the centre it has alternate formations of clay, limestone, sand and coastal sandstone. Fluvial sands and thin strata of sandstone and clay predominate in the south and south-east. In the South and South west is found the Oligocene aquifer with thicknesses varying from 240 to 730 meters. This formation consists of coarse sands and sandstone interbedded with clay (non-marine facies). Further north, calcareous sandstone, limestone, dolomite rocks and clay with some evaporates (marine facies), make up the bulk of the series. This aquifer is normally in hydraulic continuity with the Lower Middle Miocene in the exploitation zone in the south and south-west.

71. The Post-Eocene reservoir is therefore a multi-layered system. The vertical gradient between the Post-Middle Miocene (PMM) and the Lower Middle Miocene (LMM) is less marked in the south but it increases towards the north owing to larger amounts of schists and carbonates. In both aquifers ground water flows towards the north or north-east. Piezometric maps indicate a drop of 200 meters from south to north over a distance of 500 kilometers. The hydraulic gradient is in the order of 4×10^{-4}. The discharge of the Post-Eocene reservoir is affected by sebkhas (lagoons) and pumping. Recharge comes from underground migration from Kufrah basin of Nubian sandstone and Cambrian-Ordovician aquifer. There are large variations in transmissivity coefficients. In the south coefficients of transmissivity of about 1300 m^2/day and in the north in wells drilled in the LMM values ranging between 750-1000 m^2/day with a maximum of 10,000 m^2/day are observed. The storage coefficient for artisian aquifers is 5×10^{-4}. The quality of water in the Past-Eocene aquifer varies greatly. The Salinity increases from south to north in the direction of flow. North of the 28th parallel N there is a high concentration of gypsum and anhydride and the dry residue increases to 5g/l. South of the 28th parallel N the water is sweet with a salinity value of 2 g/l.

(v) Jabal Akhdar aquifer system

72. The Jabal Akhdar system is located in the north-east of the country, north of the Sarir basin. It is an east-west anticline and its formations are of the Upper Cretaceous and Tertiary periods. The main aquifers are found in the fractured limestone rocks of the Eocene and Miocene eras which are heterogeneous, anisotropic, karstified and hydraulically interconnected at the regional level. Water levels fall by more than 400 meters over a fairly short distance north and south of the Jabal's axis. The crest of the range forms a watershed for both surface and ground water. The flow direction in the central part is toward north and south and becomes radial with an easier gradient in the east and west. The aquifers are recharged exclusively by direct infiltration of rain-water and surface runoff.

73. The Miocene aquifer is unconfined. It consists of limestone and dolomites covered by Otolithic limestones and calcarenites. East of Benghazi the transmissivity ranges from 10^{-2} to 10^{-4} m^2/s with higher values in the karstified areas.

74. The dry residue is in the order of 1.3 to 2.5 g/l and it tends to increase as a result of more intensive pumping in Benghazi plain which has led to sea-water intrusion along the coast.

75. Elsewhere the Eocene aquifer consists of chalky and marly limestone. It is unconfined in the area of the Jabal and partly artisan or semi-artisan elsewhere. Generally speaking, the aquifer has low transmissivity values ranging between 10^{-3} to 10^{-5} m^2/s, except in the heavily fractured zones.

76. The water of the Eocene aquifer is of good quality with a dry residue of between 0.6 and 1.32 g/l. Higher concentrations are found in Benghazi plain. South of Jabal Akhdar the water quality deteriorates quickly and the dry residue increases to 5-10 g/l. Salt contents in excess of 10 g/l are not uncommon in the vicinity of the coastal and interior sebkhas (lagoons). These sebhas act as natural outlets for the groundwater.

V. INSTITUTIONAL SET UP FOR WATER RESOURCES DEVELOPMENT

77. The government body responsible for research, development and management of ground water resources is the Department of Water and Soil (DWS). This office comes under the Secretariat of Agricultural Reclamation and Land Development. The department has four sections - namely: section for dams, section for soils, section for irrigation and drainage, and section for water resources. The section for water resources is the one responsible for hydrology, hydrogeology, geophysics and drilling activities.

78. Urban water supplies are the responsibility of the secretariat of utilities while coastal towns getting supplies from desalination plants fall under the Secretariat of State for Electricity.

79. The General Water Authority established in 1972, is responsible for the whole country for water resources. It has regional offices at Benghazi, Sabha and other parts. According to hydrographic conditions, the country has been divided into five water regions each of which has sections for drilling and geophysics. These regions have each a team of geologists and hydrogeologists and they carry out prospecting and drilling activities.

80. Institutional changes have been made in the course of time. In 1977 the General Water Authority was elevated to a ministry and became the Ministry of Dams and Water Resources. The Department of Water and Soil was established later and dams and soil have been brought under the Water Authority.

81. The Agricultural Development Council has been given the responsibility for water use legislation and issuance of drilling licenses. It also controls ground water pollution, and sets limits to extraction or abstraction of groundwater in coastal regions to prevent sea water intrusion.

VI. DRILLING DEVELOPMENT AND MONITORING OF WELLS, AND USE AND MANAGEMENT OF WATER RESOURCES

A. Drilling Development and Monitoring of Wells

82. For ground water production wells, rigs with lifting capacities of 20 to 180 tons are used. These rigs are able to drill to depths of many hundred meters. The deepest hole goes up to 2000 meters. the methods used for drilling are mud, clean water, air lift with normal or inverse circulation, and foam. **Table 1** gives figures on drilling works carried out in northern Libya from 1980 to 1984 by various enterprises under the supervision of the Department of Water and Soils. The figures are considered as representing 50 percent of the operation in the whole country.

83. Deep drilling techniques similar to those used in oil wells are employed in the drilling and furnishing of the wells in Libya. Wells over 800 meters deep are equipped with telescopic tubing. Artisan wells are fitted with a special design cap to control the wellhead discharge and to combat corrosion. Diagraphy is used to determine the calibre, the spontaneous potential, the resistivity and the neutron-ray and gamma-ray logs. On completion, boreholes are fitted out and are made to undergo test pumping to determine the hydrological characteristics of the aquifer. The final test lasts 72 hours and this includes the time for pumping to increase depths and for measurement of the recovery. Water samples are taken for analysis and a final report, including all the hydrogeological lithological and drilling data, is prepared and submitted for inventories.

84. A network of observation wells are established in all areas of groundwater exploitation in order to monitor the fluctuation in the static water level either manually or by means of automatic recorders. The data are collected periodically and used in the preparation of hydrograms and piezometric maps.

85. Mathematical models have also been used to estimate the water resources and simulate the future withdrawals and its quantitative and qualitative changes.

Table 1

Drilling operations in North Libya (western & central) 1980-1984*

Enterprise	No. of rigs	1980		1981		1982		1983		1984	
		Wells	Metrage	Wells	Metrage	Wells	Metrage	Wells	Metrage	Wells	Metrage
Local firms (Libya)	20	4	1,439	13	2,672	10	2,325	4	1,827	5	2,640
Bulgarocomin (Bulgaria)	14	2	943	14	2,672	18	8,916	16	11,045	21	15,987
Stojexport (Czechoslo.)	5	9	4,994	20	10,222	20	9,805	13	5,771	13	5,305
Others		15	4,290	105	17,616	38	14,378	28	6,533	7	1,854
Total**		30	11,668	152	33,182	86	15,444	61	25,176	46	25,786

Average well depth 389 218.3 412 412.7 560.6

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* Only sites supervised by DWS.

** These figures represent about 50 per cent of the operations in the whole country.

Source: Ground Water in North and West Africa (ST/TCD/5)
Natural Resources / Water Series No.18
United Nations, New York 1988

B. Use and Management of Water Resources

86. Whereas surface water resources availability is limited, its role in development is quite significant. However, it is obvious that the major part of Libya's water resources comes from groundwater. As regards use, there have been studies made to determine and quatify consumptive and other sectoral uses. For this purpose both direct and indirect approaches have been separately and collectively used. The techniques consisted of field surveys, water metering, mathematical calculations of water drawoff and energy consumption for pumping, deduction on the basis of irrigated areas, interpretation of aerial photogrammetry and satellite imageries. The studies have subsequently yielded a general indication regarding water consumption and use patterns as shown on **tables 2, 3 and 4**.

87. The per capita domestic consumption of water is found to be around 250 to 3200 liters a day in the towns and 100 to 150 liters a day in rural areas. The present drawoff is in the order of 278 million cubic meters.

88. The per hectare consumption of irrigation water is 5,000 to 15,000 cubic meters a year and it can be as high as 20,000 cubic meters a year in the southern regions. In the Murzuq basin, for example, the agricultural projects launched in 1974-1976 entailed water consumption which reached 230 million cubic meters in 1983-1984 as shown on **table 2**. The figures given do not include the water drawn off for small private farms, and the requirements of towns and industries.

Table 2
Drawoff of ground water for irrigation projects in the Murzuq basin (hm^3)

(P.Illy, 1984)

Zone	Initial estimate	1979/80	1983/84	Forecast
Murzuq	115.55	76.40	83.50	222.30
Awbari	132.42	36.10	63.17	135.40
Sabha	17.40	14.20	19.20	20.00
Birak	145.81	41.20	68.30	151.20
Total	451.18	167.90	234.17	528.90

Almost everywhere the biggest consumers are private farmers and this has continued to grow at a very high rate, as can be seen from **table 3**.

Table 3
Drawoff of ground water in the Sabha zone

(P.Illy, 1985)

Agriculture (private)	25	55	115
Sabha farm project			
Livestock project	-	3	8
Urban and industrial supply	5	12	27
Total	30	70	150

Source : Natural Resources/Water Series No. 18. Ground Water in North and West Africa, United Nations 1988.

89. According to Idrotecnico, in 1978 the use of water (hm3) in the Wadi Ash Shati and Jufrah zones was as follows:

	Wadi Ash Shati	Jufrah	Total
Domestic	2.5	1.8	4.3
Private agriculture	90.0	2.9	92.9
Farm projects	40.5	26.1	66.6
Total	133.0	30.8	163.8

90. In a recent study for the Department of Water and Soil (DWS) on various possibilities of supplying water to the Jefara plain, FAO cited the data used in estimates of the amounts of water consumed in the plain, during several periods from 1948 to 1978 as shown on **table 4**.

Table 4

Use of water in the Jefara plain from 1948 to 1978 (hm^3/year)

Year	Pumping for agriculture	Pumping for urban consumption	Total pumping
1948	12	12	24
1953	16	23	39
1958	80	25	105
1973	343	75	418
1978	463	95	558

Source : Same as tables 1, 2 and 3.

91. **Table 5 gives an estimate of the drawoff of groundwater based on earlier studies, on extrapolation of population growth, on farm and industry forecasts, and on plans for new tapping areas to supply water to the coastal zone from the Kufrah-Sarir and Murzuq basins.**

<u>Table 5</u>

<u>Ground-water drawoff in Libya</u>

Hydraulic region	1985 drawoff (hm³/year)		Forecast drawoff in 2000 (hm³/year)		Comments
Murzuq	465	45	1,150	95	Including water delivery project
Jabal Nafusah, Hamada, Saw-fajjin, W. Sirt	210	60	270	130	
Gefara	600	120	700	220	
Kufrah & Sarir	370	40	1,280	75	Including water injected for oil extraction Including water delivery project
Jabal Akhdar	100	105	190	210	
Total	1,745	370	3,590	730	
	2,115		4,320		

<u>Source</u> : Same as tables 1, 2, 3 and 4.

VII. GROUNDWATER DEVELOPMENT CONSTRAINTS

92. It is estimated from the foregoing that the demand projection, in the year 2000 will double that of 1985. The problems were therefore expected to grow more acute, especially in the coastal and other areas where fresh-water aquifers are either limited or rest on salt water if other sources were not to be developed. The Jefarah plain has currently a huge deficit in its water balance, which was already in excess of 350 million cubic meters in 1980 and continued pumping to meet requirements has caused a considerable decline in the water table with consequent sea-water intrusion in the coastal aquifers. The penetration is already in the order of 3 to 5 km inland from the coast 1/.

93. At Bin Ghashir, 30 km south of Tripoli, the old wells tapping the first aquifer have dried up and have been abandoned. It has been necessary to drill to depths of 250 to 300 meters to exploit the second aquifer.

94. Elsewhere, when the upper aquifer is in hydraulic contact with an underlying saline aquifer, as is the case in the coast from Misurata to Ajdabiya, intensive pumping from shallow wells dug along the wadis to tap the lenses of groundwater recharged by rainfall have caused the level of the salt water to rise. In many oases close to sebkhas excessive pumping has caused intrusion of saline continental water into fresh-water aquifers.

95. The implementation of new agricultural projects particularly those involving pumping water for irrigation from deep fresh-water aquifers have caused a disturbance to the hydrodynamic conditions due to heavy extraction of water with significant decline in the water levels of the aquifers and a consequent impact preventing their recharge capability to phreatic aquifers that receive their supply under normal circumstances. This is the case in particular at Ghadamis and Jufrah and in many other locations. At Jufrah, a place known for the quality of its palm trees, farmers are compelled to drill to considerable depths to find water and save their already endangered trees, which used to grow naturally by drawing water they needed from shallow ground sources.

96. Several natural springs in Jabal Nafusah and Jabal Akhdar basins have dried up. Until very recently these springs were playing an important role in supplying water for small settlements and livestock.

• Modified, according to WSD, FAO, Idrotécnico, Pallas, Illy and others, with extrapolations based on the projects planned, the water delivery plans, and the population growth.

97. Subsidence has taken place as a result of extraction of groundwater in Sarir basin. Over-exploitation of ground water has imposed heavy economic burdens on both private and public sectors. The drilling of very deep wells which produce water of average to poor quality and at high temperature have entailed the installation of corrosion-resistant materials and powerful submersible pumps which consume large amounts of energy and call for advanced technologies. They also demand very high investment capital and entail high operation and maintenance costs in addition to costs required for cooling and treatment of water where these deem necessary. Moreover, the groundwater resources which were in use so far have proved insufficient to meet the requirements of the population along coastal regions calling for recourse to the desalination of sea water, treatment of waste water, construction of dams to store water from the wadis before they are lost to the sea.

VIII. GROUNDWATER STUDIES FOR THE REALIZATION OF THE GMR PROJECT

98. It was becoming evident that the problem of water scarcity in Libya was reaching a very acute stage as time passed by. At the same time there have been relentless efforts to avert the worsening situation by taking measures that seemed to be timely. These measures included limiting drilling operations, limiting the expansion of irrigated farms, prohibition of crops which consume large amounts of water, effecting control measures on the pattern and use of water in order to minimize evaporation and wastage, introducing new tariff policies to discourage and limit the amount of water use, and promulgating new laws on groundwater use and on safeguarding its quality. These efforts that were meant to combat the crises tended to squeeze and impede development progress. They did not serve to answer the fundamental question for more water.

99. To solve the problems of water needs of Libya, a major focus was directed to developing deep groundwater sources. This desire was upheld since the first discovery in the 1950s of huge water reserves beneath the Sahara by geologists searching for oil. The indications on the existence of immense volumes of deep groundwater in the interior of the country were further confirmed by subsequent studies following its independence in 1951. In time the venture to persistently continue by focussing on the investigation was picking up stronger momentum.

100. Along side the investigation for new groundwater sources, much research was also being carried out into the possibility of using water of inferior quality for irrigation and employing non-conventional techniques of desalination to get additional water and relieve the stress on demand which kept growing at a considerably fast rate. At the same time, overall water resources surveys were made in Benghazi, Derna, Agedabia, Wadi Soffejin, Misurata, Wadi Coam, Wadi Gatara and Wadi Meganin.

101. Geophysical reconnaissance was carried out at Al May (Berce), Ras Jadu and Jardas-el-Abiol. Several wadis have also been surveyed hydrogeologically.

102. In the investigation, and evaluation of ground water resources of the various basin aquifers modern equipment, methods and techniques were employed. Mostly boreholes penetrated to depths of 1000 meters and more. In certain aquifers up to 2000 meters have been drilled. Complete diagraphic studies were made of the majority of deep boreholes. Pumping tests on drawndown and recovery, chemical analysis, paleontological dating were also conducted to determine the properties of the aquifers and to establish and develop correlations with other wells in the vicinity. Isotopic analysis was made of the recharge; flow characteristics and age of the groundwater and of the losses through evaporation were also studied. Good results have been achieved by studies of the intrusion of sea water in coastal zones and on reducing evaporation losses from sebkhas (lagoons).

103. Numerous hydrogeological studies and investigations were conducted by late 1970s and particularly before 1977 under the aegis of the Agriculture Development Council. The large-scale in-depth study campaigns were launched by allocating a huge sum of money derived from oil revenue for employing recognized firms and expertise from various countries. The study on the Western part which was carried out by the French group (GEFLY) was one among many that produced much data from its investigations. Other extensive studies were also carried out by other firms including the British Geological Institute, Tipton and Calback Company, a group of German companies, the Flemen Company of Finland and a group of Egyptian consultants.

104. The studies by the different companies varied in scope and depth according to the desired objectives. They consisted of hydrogeological, topographical, geological mapping activities, exploratory and productive drilling and preparation of mathematical models to identify the water resources potential for development and use. These studies

were conducted in different groundwater basins such as Al-Kufrah, Al-Sarir and Tazerbo covering 250,000 square kilometers, and Marzuk, Al-Hasauna mountains and Coastal Valley with an area of 720,000 square kilometers which in all constitute the most important regions where volumes of good quality groundwater are found. In the coastal plains around Tripoli and Benghazi where most of the population is concentrated studies have been conducted on the yield and recharge of aquifers.

105. The synthesis of years of studies and investigation work have been compiled to build up a mosaic of information and produce a composite national picture on groundwater resources availability and distribution in terms of both quantity and quality for large-scale exploitation and use. These findings were the basis out of which the GMR project was born and following which a set of contracts were signed between 1979 and 1981.

IX.THE GREAT MAN-MADE RIVER PROJECT (GMRP)

A. General

106. The potential for exploiting the deep-aquifer-water on a large-scale, which for a long time was a concept or a dream, was transformed to the exploration stage in 1980 under the nomenclature of the Great Man-made River Project. It was initiated and resolutely taken up as a project after a technical confirmation of the feasibility that the water in the deep aquifers below the Sahara could be drawn to the surface and then piped long distances bringing the water to where people live according to the newly adopted policy of Libya. The elaboration of the project was greatly encouraged by the views of experts confirming that there was enough fresh water available in the aquifers to meet the needs of Libya for at least a century and possibly for much longer. The complete project of the water transfer scheme is designed in five stages or phases as shown on **table 6.**

Table 6

The Five Stages of GMRP

Projet stage (phase)	Project Component	Approximate Volume of water at full development Million cubic meters per day (MCm/d)
I.	Sarir to Sirt (SS) and Tazerbo to Benghazi (TB) (2 wellfields and 2 pipelines)	3
II.	Fezzan to Gafara and Tripoli	2
III.	2 fields to supplement stage I will require major pumping effort	3 - 5
IV.	1 field and pipeline extension to Tubruk area	2
V.	1 field in Fezzan region to supplement stage II supplies also along Coast to east to SS line near Sirt	2 (?)
	Total	12 - 14 (estimate)

Source : Libya's Great Man-made River Project
Peter F.M. Mehoughlin (unpublished).

107. The GMR is a mammoth scheme which entails technical complexity of great magnitude and requires a long-time dimension for its full realization. It is a project that demands massive resources in all respects. Thus the technical feasibility, economic viability and long-sustenance have been questions that engaged the minds of many concerned people. Some of these questions might have been answered but it is to be expected that there are some others that remain unanswered.

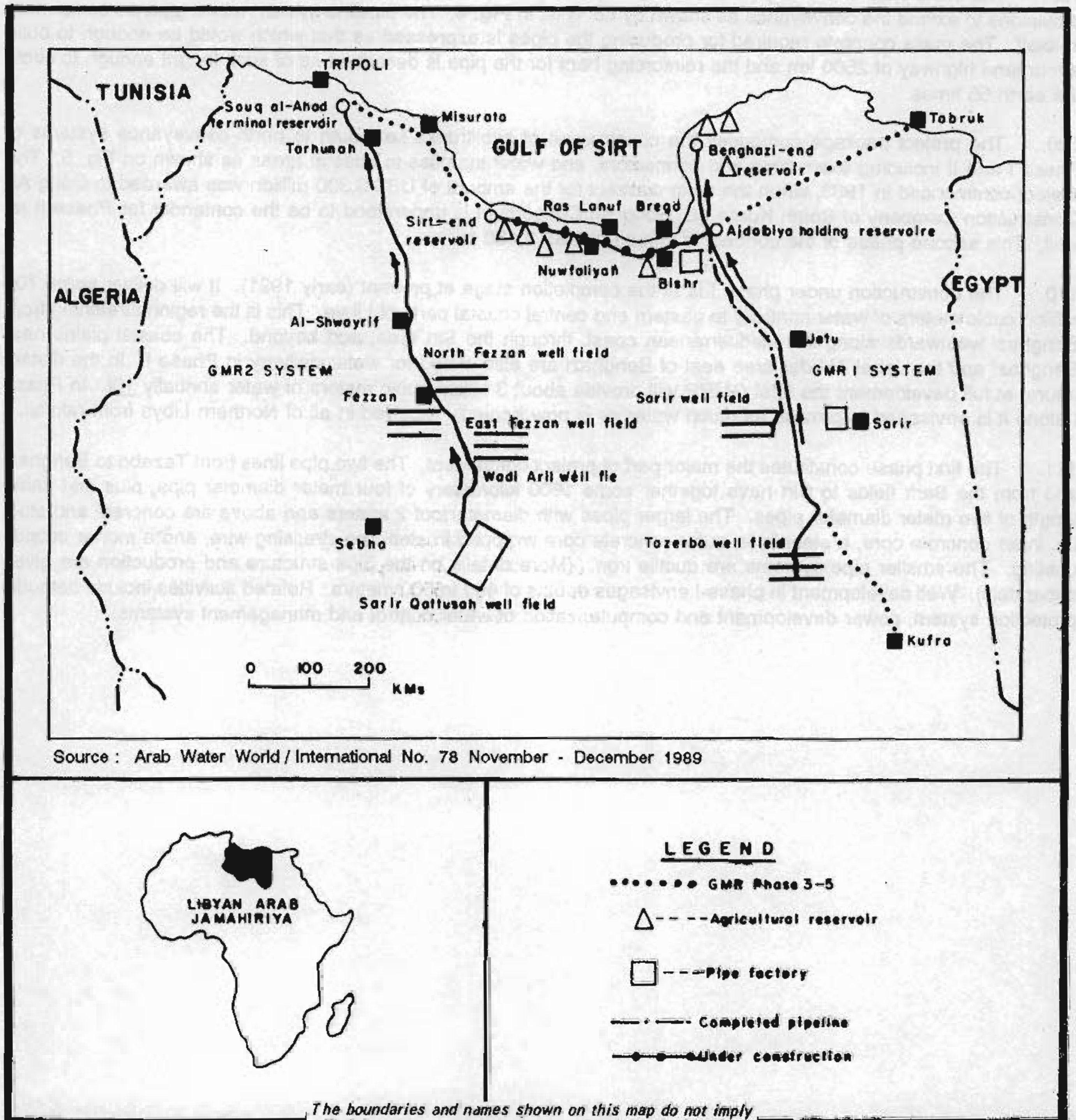
108. The initial plan is to transport 2 million cubic meters of water a day through 1900 km conduit. The plan has provisions to extend the conveyance as shown by dot lines in **Fig. 4**. The pipeline system was a gigantic component in itself. The mass concrete required for producing the pipes is expressed as that which would be enough to build a four lane highway of 2500 km and the reinforcing bars for the pipe is described as of such lenght enough to circle the earth 55 times.

109. The project package comprises the construction of two trunks i.e. south to north conveyance systems of Phase I and II including extensions and connectors, and water supplies to coastal areas as shown on Fig. 5. The project commenced in 1983, when the main contract for the amount of US$ 3,300 million was awarded to Dong Ah Construction Company of South Korea 5/. Dong Ah Consortium is understood to be the contender for Phase II as well. This second phase of the contract is valued at US$ 3,460 million.

110. The construction under phase I is at the completion stage at present (early 1991). It will deliver some 700 million cubic meters of water annually to eastern and central coastal parts of Libya. This is the region stretching from Benghazi westwards along the Mediterranean coast, through the Sirt area, and beyond. The coastal plains near Benghazi and the Jabal Akhdar area east of Benghazi are also slated for water delivery in Phase I. In the distant future, at full development the total GMRP will provide about 3 billion cubic meters of water annually 10/. In Phase I alone it is envisaged to provide as much water as is now annually received in all of Northern Libya from rainfall.

111. The first phase constitutes the major part of project component. The two pipe lines from Tazabo to Benghazi and from the Sarir fields to Sirt have together some 1900 kilometers of four meter diameter pipe, plus that same length of two meter diameter pipes. The larger pipes with diameters of 2 meters and above are concrete and steel i.e. inner concrete core, a steel liner, outer concrete core wrapped in steel pre-stressing wire, and a mortar outside coating. The smaller pipe systems are ductile iron. (More details on the pipe structure and production are given separately). Well development in phase-I envisages depths of 400 to 500 meters. Related activities include cathodic protection system, power development and computerization of water control and management systems.

THE GREAT MAN-MADE RIVER PROJECT



Source : Arab Water World / International No. 78 November - December 1989

The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

CART-91-9 (03/91/250)

Fig. 4

B. Purpose of the project package

112. The main purpose of the GMR project is:

- to achieve food self-sufficiency in cereals/grains and meat and to provide surplus for export and thereby generate income;

- to provide drinking water for population in cities and villages along the coast and also to satisfy industrial water requirements;

- to create employment opportunities through the development and expansion of agricultural and industrial schemes and thereby bring about considerable transformation in the social and economic sectors.

113. Towards this end there are projects for sheep raising and cultivation of 185,000 hectares of land with grain in winter and 100,000 hectares with grain and crops in summer. It is estimated that the grain crops will amount to one million tons annually.

C. Water Well Drilling

114. Basically, drilling for the whole package consists of 800 wells in different aquifers:

- 340 wells in Al Sarir well field
- 130 wells in Tazerbo well field
- 130 wells in Al-Kufra well field
- 200 wells in Al-Hasouna Coast Valley well field.

D. Phase-I Contract Elements, Major Works, and Some Features of the GMR Project

(a) Phase-I Contract Elements

115. The prime contractor for the first phase of the project, the Dong Ah consortium was to perform the following 7/. Complete details are shown on **table 7**.

- build two large concrete pipe manufacturing plants;

- produce more than 250,000 pieces of large-diameter (i.e. 4 meters) pipes;

- construct a pipeline to a length of 1900 km; including two operating water well fields in Tazelbo and Sarir, and a reservoir for four million cubic meters of water at Ajdabiya;

- install pumps where necessary;

- operate the entire system for one year prior to turning it over to the Governments Authority for the Great Man-made River Scheme;

- build more than 1500 km of road.

Table 7

Great Man-Made River 1 - Contracts

Contract	Contractor	Date	Value
Construction of nearly 1,900 kilometers of pipeline to take 2 million cubic meters of fresh water a day to coastal regions from the southeast Sahara, and two pipe fabrication plants	Dong Ah Construction Company (South Korea), and its subsidiaries, Dong Ah Concrete and Korea Express Company	November 1983	$ 3,300 million
Subcontracts			
Geotechnical investigations	Woodward Cycle Consultants (US), Temel Investigation (Turkey) and Geos Ingenieur (Geneva-based)	1985	$ 536,010
Aggregate source investigation	Raymond International (UK)	1983	$ 1.5 million
Ajdabiya holding reservoir and review of hydraulic technology	Alexander Gibb & Partners (UK)	1985	n.a.
Supply of pipeline manufacturing equipment and technology	Price Brothers (US)	1983	$ 150.5 million
Development of wells to supply water for the pipe manufacturing process	Condrill (Sweden)	1984	$ 2.5 million
Drilling 120 wells at Tazerbo and 126 wells Sarir	Braspetro (Brazil)	1985	n.a.
Construction of a power station for well fields	C Itoh & Company (Japan) and Dong Ah Construction Company	1986	$ 59.5 million
Gas turbines for power stations	Westinghouse Canada, a subsidiary of Westinghouse Electric Coporation (US)	1986	n.a.
Transmission lines	Toyo Menka Kaisha (Japan)	1986	n.a.
Six 66/33-kV well field substations	ABB Asea Brown Boveri (Zurich-based)	1986	n.a.
Construction of a 4.7 million-cubic-meter reservoir at Benghazi	Enka (Turkey)	1988	$ 120 million for the two projects
Construction of a 6.8 million-cubic-meter reservoir in Sirte	Sezai Turkes-Feyzi Akkaya (Turkey)	1988	see above
Supply of seven electrically operate sluice gates for the Ajdabiya holding reservoir	Boving Newton Chamber (UK)	1988	n.a.
Supply of end-control valves for the Tazerbo to Sarir pipeline, to regulate the flow from the reservoirs	Mokveld Valves (Netherlands)	1988	n.a.
Supply of various pipeline equipment	Kubotal (Japan)	1988	n.a.
Supply of transformers	Westinghouse Canada (letter of intent)	1988	n.a.
Supply and installation of submersible pumps for the well fields, site installation and commissioning	Marubeni UK, a subsidiary of Marubeni Corporation (Japan)	n.a.	n.a.
Supply of 254 submersible pumps for 234 wells	Weir Pumps, a subsidiary of the Weir Group (UK)	1988	$ 14 million
Construction of a 24 million-cubic-meter agricultural reservoir at Benghazi	Award expected in early 1990	-	-
Construction of 15 million-cubic-meter agricultural reservoir at Sirte	Award expected in early 1990	-	-
n.a. = not available			

Dong Ah has full responsibility to apoint GMR2 subcontractors. Sanctions prevent US firms from bidding. Trade and construction agreements with Belgium, Sweden, Turkey, India and Yugoslavia means firms from these countries are likely to bid. French, UK and Far East interest has been strong.

Technical and tender details still have to be clarified, but subcontracts similar to those on GMR1 will be on offer. These include reservoir construction, and supply and installation of pumping equipment, water control equipment, sluice gates and valves holding tanks and power equipment. Unlike with GMR1, Dong Ah's contract for GMR2 includes well drilling.

Source : No. 78, November-December 1989.

116. Price Brothers company was entrusted with engineering services for:

- designing of two pipe manufacturing plants;
- designing and supplying required pipe production machinery, and technology;
- training of Dong Ah technical staff to operate the plants and produce the pipes; and
- providing on-site support.

b) <u>Major Works and Some Features of the GMR Project</u>

117. It has been noted that each piece of the prestressed concrete cylinder pipe comes in lengths of 7 1/2 meters, diameter of 4 meters, weighs 70 metric tons, and that 250,000 pieces are required for the full length of the pipeline in the first phase of the project. The size and weight dimensions together with the number of pieces for the project indicate that transporting the pieces by road to the installation sites along the 1500km newly constructed road is no small job despite the cranes, fork-lift, trucks and extra heavy tractor trailers to handle the job.

118. The other engineering work concerns the installation of water pumps. The first phase of the pipeline uses gravity flow system as the route from the desert to the seacoast is downhill. However, when the wells at Kufra shown in figure 4 are developed, the volume of water to be transported is stipulated to increase from 2 million cubic meters per day to 3.75 million cubic meters per day 7/. For this purpose four pumping stations will have to be installed between Sarir and Ajdabiya reservoirs. Booster pumping stations are planned for the future expansion of the flow.

119. The second phase crosses the Jebel Fezzan hilly region where water will have to be pumped 600 meters above sea level. From two tanks at Fezzan, the water will flow by gravity to a regulation tank in Tarhunah, and from there to a 28 million cubic meter terminal reservoir in Souq al Ahad 5/. Power sources for pumping stations will have to come from an electric plant to be built although there may be a consideration to see into the possibility of existing lines near the coast.

120. The project <u>per se</u> will encompass in the package other infrastructural and allied constructions such as roads, electric networks, control systems, communications facilities, digging and earth moving works, development of quarries and such related activities.

121. The project constitutes a number of water reservoirs with a cumulative storage capacity amounting to 300 million cubic meters of water 8/. This quantity is envisaged to accommodate the agricultural needs during the various seasons of the year.

E. <u>The Pipe Plant Manufacturing Process and Quality Control</u>

122. The establishment of two manufacturing plants one at Brega and another at Sarir have been looked as beneficial from the point of view that the material for production is locally available and would create jobs for 2500 employees. These aspects have to be seen against the fact that both plants are five times the size of any other plant in the world and each is a self contained industrial complex. In other words the plants are able to generate their own power, maintain their own communication systems, treat their own manufacturing water in order to reduce the salt and sulphate contents of the concrete. These plants include 110 buildings and permanent houses to accommodate 2500 workers and support staff. The ease in mobility of the plants to be set up in any convenient location and be operated by local work force using locally available material is considered a highly positive feature. Another merit relates to the fact that the expected years of productive life of the plants will be at least 25 years even under harsh climatic and environmental conditions.

123. It is estimated that it will take five years to produce all the pipes needed. Giant locomotive cranes of the plant will move pipe sections through each step in the process of production. The plant works in an assembly line fashion that is automated. The total of five production lines include two at Brega and three at Sarir plants.

124. Manufacture of prestressed concrete cylinder starts by welding steel sheets to form cylinders and then welding into each end of these cylinders steel joint rings that are used to join the pipe during installation. The cylinder assembly is a watertight steel sleeve that will be encased in the wall of the concrete pipe. The cylinder assembly is hydrostatically tested before being cast. The next step in the assembly line is placing the cylinder in a vertical casting mold surrounded by a thick wall of high-strength concrete. On removing the mold, a combination of the steel cylinder embedded within a concrete wall known as the core of the pipe is obtained.

125. The pipe core is prestressed by wrapping under tension a continuous high-strength steel wire around its exterior wall from one end to the other with each end of the wire anchored to the pipe such that a permanent inward compression on the pipe core is imposed. The desired compression on the pipe core can be altered according to the water pressure and the external load the pipe will be subjected to by controlling the spacing between the wire wraps. The prestressing with high tensile-wire is important to give strength and reliability to the pipe. Depending on the pressure the pipe is to withstand, upto 18 km of wire are wrapped on each core, either in one or two layers. After the prestressing, the pipe core is given a protective coating to shield the steel components of the pipe and also to provide a rugged physical protection for the pipe's exterior. Curing of the coating takes place in a humid and temperature controlled enclosure. The finished product undergoes inspection for quality control before shipment.

F. <u>Why Prestressed Concrete Pipes?</u>

126. Once the decision was made to transport water from the well fields to the north, the next issue was to see the criteria and substantiate the justifications for preference for prestressed concrete pipes to others like steel, ductile iron, fiberglass and plastic pipes.

127. The choice for prestressed concrete pipe for the GMR project was made on the basis of technical and economic grounds affording the natural flow by gravity that reduces costs of energy consumption and avoid the need for use of complicated equipment. Important quality features of prestressed concrete pipes are enumerated as follows:

- the pipes combine a rugged concrete core with a watertight steel cylinder such that it acquires maximum durability due to the inherent characteristics of concrete attaining strength and hardness over time. There is also an added advantage of the concrete lining which stays smooth and thereby minimizes surface friction facilitating the flow of water and contributing to reduction of pumping costs;

- prestressed concrete withstands internal water pressure and external forces of the surrounding earth. The high strength prestressing wire is wrapped around the concrete core and steel cylinder at a stress 13 times higher than the design stress of mild steel in steel pipe. With only about one-third as much steel being used in the prestressed concrete cylinder pipe, it becomes a very economical choice in terms of initial investment;

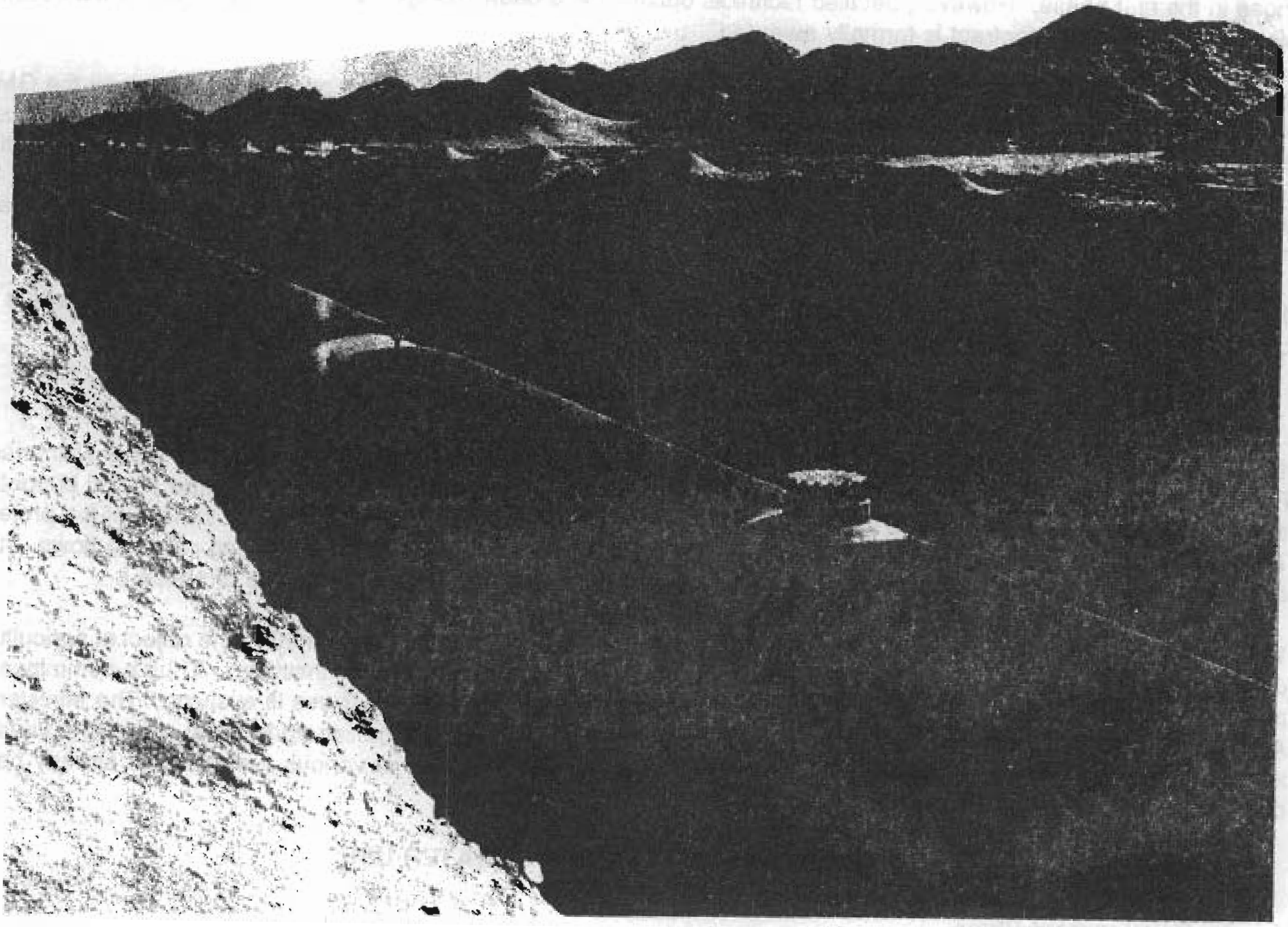
- prestressed concrete cylinder pipe has considerable rigidity and supports external earth loads with little deflection, whereas flexible pipe designs of steel, ductile iron, fiberglass and plastic pipes deflect under earth loads. These later ones must therefore, rely heavily on the soil on each side to prevent collapse. Often, a mild deflection could cause cracking or flaking of the protective mortar lining and coating that is necessary for flexible steel and ductile iron pipes;

- a major reason for choosing prestressed concrete pipe lies in its quality to withstand all but the most corrosive ground conditions. Under normal corrosive ground conditions, the steel wire, end rings and cylinder embedded in the concrete are well protected by the high alkaline of the free lime in the concrete. This helps avoid the costly external corrosion control measures and maintenance needs that are often associated with other pipes. The high alkalinity of the concrete pipe also protects its inner surface from developing friction against flow that is often caused by internal corrosion and tuberculation which happens to be a common occurrence with unlined ferrous pipes;

- another advantage of prestressed concrete pipe is the ease with which installation is performed. Most notably, this is attributed to the pipe's precise, self-centering joint rings that hold and compress the O-ring gasket to form a watertight pressure seal even when there may be minor deflections along

the line. Fig. 5 shows a picture of a small section of the installed prestressed concrete pipe under the GMR Project. Once installed, each joint is free to move slightly with temperature changes and earth movements, without losing its seal.

128. In addition to cost saving, the manufacture of pipes in the country itself is seen to combine the advantage of using locally available materials and creating employment opportunities as well as providing a framework for development of national skills.



Installation of the 250,000 pieces of pipe for the Great Man-made River Project is done at the rate of one piece of pipe every 15 minutes with the help of giant cranes and bulldozers. It is expected to take five installation crews more than four years to install the pipeline.

Photo credit: Price Brothers

Source:WWI/August 1989

X. WORK PROGRESS OF GMRP AS AT JANUARY 1990

129. In the first phase, that part of work for the system to supply Benghazi with water from aquifers of about 270 wells at Sarir and Tazerbo, some 1000 kilometers south of the coastal city will see completion in 1991. Development of the distribution network, however, will extend the project for a number of years. Dong Ah, the contracting firm had as of January 1990 US$ 1,840 million worth of work left from its first phase contract, awarded in 1983. The work in that first phase included two parts and it was contemplated that water would start to flow to Sirt from the Sarir well fields by the end of 1990 and construction of the second part - the Tazerbo to Benghazi link, would begin in 1991.

130. In the second phase, it is stipulated to link the aquifers in the Fezzan region of the Sahara with the capital Tripoli. An announcement for the second phase has been released and the contract was expected to be finalized with the South Korean Dong Ah Company in October of 1990. The second phase requirements will be similar to those in the first phase. However, detailed technical options have been changed several times and this will become clearer only when the contract is formally awarded.

131. There has been an increasing demand for water in Tripoli and the western coastal regions since the GMR scheme was planned. Consequently, it is now intended to bring 2 million cubic meters of water a day on stream through phase II all at once instead of in two stages, as originally envisaged. Subsequently, the Authority for the GMR is now concentrating initially on developing the Fezzan well fields, rather than fields further south (see Fig. 4). It is also likely that Dong Ah will continue to use the Brega factory for producing pipes rather than erect a new plant as planned initially.

132. The financing for phase two will stay the same as for phase one; that is using domestic taxes on letters of credit. For the time being oil barter has been ruled out.

XI. INSTITUTIONAL SET UP FOR THE GMR PROJECT

133. The Government body responsible for overseeing and controlling the GMR project is the Great Man-made River Authority (GMRA). It's offices are in Benghazi and Tripoli. The authority has utilized a large capital budget of the country, revenues from oil exports, and taxes levied from the population to pay for the construction of the project. The GMRA discharges the functions of a public utility such as delivering water and managing revenue flows. It is concerned to see that the project pays at least for the operation and maintenance activities of phase I.

134. A second agency for the post-construction water distribution activities (that are mainly the object of agriculture development in Phase II) with a different set of responsibilities was necessary to be instituted. Thus a committee to plan for water use across the board - with a distinct emphasis on agricultural water use is evolving. The Minister of Agriculture supported by senior agricultural executives is taking initiatives to establish agricultural projects of various kinds keeping in perspective that the location and volumes of water needed at various turnouts had already been considered.

XII. DEVELOPMENT PLANS AND WATER USE

A. <u>Development Plans</u>

135. A newly revitalized Agriculture Secretariat is taking charge of agricultural development. The plans for Sirt are well advanced. A net irrigated area of 10,230 hectares is envisaged with one large farm producing grain and fodder, and 2 smaller farms growing fruit and vegetables as well as fodder. The plans include dairy farming, milk processing plant, a beef fattening unit, sheep farms, an abattoir and support services.

136. Plans for Benghazi are apparently not going to be different although they are not discretely set out. It is however known that it will have a net irrigated area, of 32,000 hectares with one large and many small farms, livestock production, and agricultural processing plant and a central support service.

137. It is stipulated that the five phases of the GMR project package and allied programmes will get fully implemented over a period of 25 years. Therefore by early next century, the plans for bringing 185,000 hectares of land under irrigation will become fully operational for production of crops and cereals both for domestic consumption

and for export purposes. It is also expected that all people living along the Mediterranean coast, from Tobruk in the east to Tripoli in the west shall be supplied with safe and adequate drinking water.

B. Water Use

138. It is estimated that 80 percent of water from the GMR Project will go to agriculture. Of the remaining, 16 percent will be for domestic supplies and 3 percent will be for industrial purposes.

139. The water use situations in phase - I from Sarir-Sirt (SS) and Tazerbo - Benghazi (TB) well-fields present the following picture: once the water from deep aquifers is brought to the surface, it is transported to a "mixing" reservoir at Adjdabya in the north near the coast. The SS line then branches-off west to Sirt and the TB flank turns off east to Benghazi as shown in Fig. 4, for distribution to municipal, industrial and agricultural areas listed on table 8.

Table 8
GMRP : Planned Water Utilization SS/TB by Main Type 10/

Sarir-Sirt Line (SS)	No. of Turnouts	Water Needed (Mm^3)	Notes
Municipal Supplies	7	23.89	Connections needed
Industrial Supplies	4	23.22	Mainly Ras Lanuf and Brega pipe plant
Agricultural Supplies			
Wadis-Abjdabiya-Sirt Western Wadis	8 6	44.88 15.00	Orchards and sheep west of Sirt; require storage and pumping ex-settlement
Designated Small Farms in Sirt Area Balance available for new large and small farms a/	1	36.61 143.40	Project farms Total SS before losses=287.00Mm^3/day
Tazerbo-Benghazi Line (TB)			
Municipal supplies b/	5	80.82	Benghazi majority, connections needed
Industrial supplies c/			
Agricultural supplies Planned Large Farms d/	2	137.14	South and east of Benghazi; with pumps
Planned Small Farms d/	2	13.17	Into Alkhadra Hills
Balance available for designated large and small farms	4	166.80	Total before losses=413.00 Mm^3/day

a/ Farms "scoped"; in desert areas generally.
b/ After Benghazi, Adjdabiya second largest consumer.
c/ A "core" development programme included new farms plus the provision of additional water to existing but moribund settlement/farming projects.

Source: Libya's Great Man-made River Project
Peter F.M. Meloughlin (unpublished).

140. Because of its dominant need; Benghazi will receive 70 million cubic meters a day from a reservoir unit. This amount is expected to increase to 105 million cubic meters a day at full development. The cities at Brega and Wadi

Ahmer are also included in the plan for supply. In all, the plan foresees the installation or enhancement of twelve urban water systems.

141. The industrial plants at Ras Lanuf and Brega as well as the refineries and cement-steel manufacturing plants are getting their water supplies from self contained units. When the GMRP plan for the provision of all industrial and municipal units takes effect, it will have a consequent outcome of releasing other sources like desalinization. There will also occur freshening and replenishment of groundwater systems in the long-run since some amount will go towards infiltration and thereby recharge the aquifers.

142. The decision on water delivery for private agriculture has not been made since it hinges upon a number of undetermined elements such as size, type, location and institutional set up of small private farms. However, commercial farms in units of 4000 to 6000 ha near Sirt and Benghazi on the coastal plains which are under one management are contemplated for water delivery. This package embraces such farms that are ready to go through prefeasibility and feasibility studies and be tabled for bid to private sector farm management agencies. The water needs of such farms are estimated to be 60 - 85 million cubic meters per day, on average. It is anticipated that such farms are likely to need reservoirs to supplement their peak season requirements.

143. According to current estimates, it is foreseen that large commercial farms would consume about two-thirds of the water produced by the GMRP. Whatever amount of water left would be used to supply towns, industries and a wide range of small farms as well as livestock enterprises. These latter ones are grouped into the following five types.

144. The first type of enterprise to receive "new water"* is livestock and or treecrop farms located along wadis running north to the Mediterranean coast, and towards the eastern and western flanks of Sirt. There are about twelve wadis with upto 1000 to 1500 family farm units. Rainfall amounts in these areas range from 200 to 350 millimeters annually. Farming largely consists of barley and cash crops. Fodder is also grown widely and the area is extensively used for sheep grazing. Each farmer along the wadis will be allocated some 20,000 cubic meters of water annually from the GMR project mainly to improve orchard farms and sheep raising 10/.

145. The second category of enterprises to receive "new water" are the 1000 or more farms between 5 to 10 hectares sizes. These farms which were mainly depending on wells, except for some Wadi catchments, were suffering from salinity problems in their well sources. As an incentive to add impetus and support the efforts of these farms, encouragement will be given by providing inputs and facilities and allocating each farmer an amount of 50,000 to 65,000 cubic meters of water annually so that they will be able to improve their irrigation and cropping methods and patterns.

146. The third category constitutes those found at high altitudes, in the Green Mountains, east of Benghazi. These comprise of several hundreds of 5 to 20 hectare farms at Rajmad and Got Sultan areas. Some of these schemes which were established many years ago deteriorated or became inoperational. However, since the facilities such as water delivery, housing and equipment of most of these projects are still intact, they are slated for supply by GMRA.

147. Under the fourth category for "new water" delivery are the small, unsettled farmers/livestock enterprises which are yet to be developed en-bloc in identified areas. This package has remained a subject of controversy and of long discussions. Some of the issues being contested relate to the difficulties of finding qualified settlers and project authorities to undertake the task of settling the people. The question of soil suitability for irrigation in these regions is another problem still awaiting resolution. Therefore the decision for water delivery shall yet remain pending the fulfillment of the above conditions.

148. In the fifth category for "new water" supply are the very great number of small farmers who use urban water systems to supplement their peri-urban horticulture and farming enterprises. This group of farmers will receive their water supply from the GMRA. It is foreseen that the water received will give an additional benefit for recharging their depleted aquifers as well.

New Water refers to water obtained from GMR scheme.

149. Given that the set of assumptions like cropping, rotation and consistency of water delivery and operations, and storage will be met, about 50,000 to 60,000 ha of crop land can be irrigated with the 400 million cubic meters of water that will be made available per day. While there are problems in several small-scale farms attendant to their number and sizes, it is foreseen that these could in time be integrated to evolve into large commercial farms such that the apparent problems will be resolved in the transformation and evolution process.

XIII. DEVELOPMENT IMPACTS

A. Socio-Economic Aspects

150. The population of Libya (4.2 million in 1988) has a growth rate of 4.3 percent which is the highest in North Africa. Most of the population i.e. about 68 percent live in urban areas. The largest majority representing 80% are concentrated in the two principal towns of Benghazi and Tripoli, and along the fertile coastal belt of Cyrenia in the east and Tripolitania in the west where most farming takes place. There has been a significant improvement in the social and health conditions of the population during 1965-1988. During this period, infant morality per 1000 births dropped from 138 to 80. In 1987, the average adult literacy rate was 75 percent. The GNP for Libya is the highest in North Africa being US$ 5,420, followed by Algeria US$ 2,360, Tunisia US$ 1,230, Morocco US$ 830, Egypt US$ 660 and Sudan US$ 480 13/.

151. Since ancient times Libya has been an agricultural country. Agriculture is the occupation that offers employment to the large majority of the population. In this sector, the average annual rate of growth during 1965 to 1980 was 10.7 percent. Despite this increase however, food imports in 1988 were representing 15 percent of total imports. Since most of the country is of desert condition the only way that agriculture and food production can thrive is under irrigation. The recent strategy is accordingly focused at revolutionarizing the sector by expanding the area under irrigated farming and increasing the agricultural crops and livestock production to a level of achieving self-sufficiency and reducing dependency on imports. Concurrently steps are planned to be taken to increase the production capabilities of the labor force, to increase the capital investment for the sector and to make adequate provisions of production inputs for food industries. To translate the new thinking into action, during 1970-1988 an investment amount of 7,560 million L.D. (Libyan Dinars) representing 25 percent of the aggregate investment has been made 8/. As a result, remarkable strides have been achieved in development in this field. The emphasis and efforts being accorded are foreseen to continue in the future with even greater momentum.

152. The new focus to agricultural self-sufficiency and the outlook to diversify the country's economy and liberate it from being oil revenue dependent is being pursued by throwing full weight in support of developments of agriculture and agro-based industries. This implies also that farming and food production will take-off at an accelerated pace to make this sector the central avenue for improving the socio-economic conditions of the majority of the population.

153. The coastal area in Libya is the region where agricultural activities are intended to be intensified. Situations reveal that even with critical water scarcity prevailing, its economic importance and the expansion of agriculture has been steadily increasing in this region. With most of the nation's agricultural potential being limited within this geographical area, it is anticipated that the region will significantly flourish and prosper with the GMR project in place.

154. The exploitation and use of fresh water reserve in the Sahara is considered a vital input to all development programmes. The GMR project is perceived to relieve the critical situation on drinking water that has a very important bearing on the quality of life of the people and in improving the state of health of communities. It is viewed to be instrumental to provide leverage and invoke a major thrust to the expansion of irrigated farming and increase production of crops, to expand livestock development projects and to facilitate the establishment of agro-based industries mainly in the coastal areas. In essence the scheme is regarded as one opening up new avenues and development opportunities that will broaden Libya's economic base and provide impetus to enable it not only to acquire self-sufficiency in food and agricultural products but also to increase its capacity to export surplus and generate additional revenue.

155. Needless to say that the oil industry is currently the most significant and it is the major source of revenue. It plays a key role in generating the most needed development capital for the food production sector. There are in addition other small industries for manufacturing chemicals, building materials, shoes and such items as are necessary to meet the basic needs of the people.

B. Environmental Impacts

156. Development forces including rapid urbanization, agricultural expansion and industrial development have set a crucial stress on the demand for water. On the other hand pumping from local aquifers which are major sources has been constrained by problems such as lowering of ground-water tables, drying of wells, salt water intrusion in coastal aquifers, a decrease of pressure in aquifers and land subsidence which all have economic and local environmental consequences. These constraints on the one hand, and the new outlook to diversify the country's economy essentially in the agricultural sector on the other, have compelled Libya to opt for the bold solution of a water transfer scheme and use its sub-Saharan fresh water reserve for the coastal regions where it is most needed and where a developed infrastructure exists. To avert the possible negative consequences that could damage the environment originating from availability of ample water that facilitates accelerated development and naturally create a suitable environment for a greater influx of population to these coastal areas, it is imperative to rigorously monitor and control the changes taking place.

157. The studies so far although not conclusive in themselves, suggest that the GMR project is not only of economic significance but also of ecological and environmental value provided that development is guided and supported by proper management skills. As regards water resources use, given that except the share of annual volumes moving to various users which may be evaporated, consumed by plants or consumed by humans and animals, a large amount of that generated by the GMRP is expected to enter the ground water system or enter the sea in those areas nearest to the sea to yield positive results in recharging depleted aquifers and in dispelling salt wedges thereby contributing towards the improvement of localities.

158. The transportation of fresh water in the heart of Libya and its use for development along the coast is seen to counter desertification, ameliorate social conditions, and offer good possibilities to control and protect the environment.

159. As the water is extracted from deep aquifers, brought to the surface, and transported by means of a closed conduit to the northern coastal region there is no significant consequence to the local environment and ecology. However, fears were expressed that the project would induce negative environmental impacts. A particular problem foreseen was the "draining away" of aquifers in the Nubian and Tassilian sandstones in the northern and north central regions of countries like Chad and others. Because of this concern, studies were conducted and these confirmed that the groundwater reserves of the aquifers in the south of Libya are of such immense volumes to dispel the worry. If for example one considers the Marzuq basin; lowering its water table by only 1 meter per year in the upper reservoir would mean releasing 15 to 20 billion cubic meters of water annually 10/. Figures twice this volume could be anticipated from Sarir and Kufrah basins that are being developed in phase - I. This provides a firm technical evidence of the extent that even "without" the modest replenishment coming from southern seepages from the Jabal Akhdar and other areas and from rain, there is still ample water for hundreds of years without getting to worry about "draining away" effects. This however does not rule out the possibility of specific spots in the limestone and sandstone becoming saline or there being need to incur increased pumping costs as a result of local depletion. It should also be borne in mind that the longer term implications of drawdowns such as settling are unknown although these may not be important.

160. The absence of people dwelling around the well fields in the Sahara, removes the question of interference to affect the lifestyle of the people. Hence, the impact of the project can briefly be summarized as one contributing to developmental needs of Libya and to the overall improvement of social, economic, environmental and ecologic conditions including the fight against drought and desertification.

C. Financial and Económic Considerations

161. The GMR is considered as a very costly project. It is described as the single largest turnkey civil construction ever awarded to a single contractor. The cost for construction of phase - I is US$ 3.3 billion. The second phase is valued at US$ 3.46 billion.

162. There have not been enough data available to make a study of costs and benefits. Even if data were available, the benefits would be elusive and subjective representing different things to different people. Because,

aside from economic benefits there are inherent in the GMR project social aspects which are difficult to translate in pure economic or monetary terms.

163. The policy of the Libyan Government and the GMR Authority is that the project should pay for itself. This implies that GMRA will in the main cover operational/recurrent expenditures. What this involves is financing some degree of repair and maintenance costs as well as paying for supplies and payroll. It is also stipulated to put against capital some surplus over and above operating requirement. GMRA is then planning to bill its expenditures to the users and customers.

164: The question however, remains as to where the net increase in value will come from (in the economy) to cover net increases in investment and recurrent costs. A reasonable assumption may be to consider that the fund will be generated by the intensive use of large volumes of better quality water by the manufacturing and industrial sectors and processing enterprises. However, it can be seen that the added value obtained from these sources are limited. The balance, should nonetheless be obtained from the agriculture sector. This requires some detail study to see the extent of net increases in value added from existing farms, including herds and orchards and from new farms to be developed if these produce adequate funds to off-set the unpaid portion of the costs of water. In order to do this, efforts are now underway to assess the operating budgets of GMRA based on realistic estimates of costs of operation and maintenance; repair and replacement. Again the question remains as to whether the unaccustomed Libyan farmers are prepared to pay for government supplied services. Added to this is also the improbable question to assume if high productivity can be acquired for the unit cubic meter of GMR water used. Under the circumstances it may be necessary to account any thing paid to second-level distributing agencies to constitute as a transfer fund from elsewhere. Acceptance of this condition does not provide a simple answer since it will set a precedent for meeting costs of subsequent phases of development which becomes a major predicament. It therefore, remains a question to be further examined and resolved by the Government.

D. <u>Transboundary Aquifers and Regional Cooperation</u>

165. Once a significant proportion of groundwater reserve starts to be exploited, the question of its conservation and proper management are likely to arise. The issue becomes critical where transboundary aquifers are involved. In all cases caution should be exercised to limit the amount of water being extracted instead of drawing water to purely satisfy demand requirements. The repercussion of responding to demand elasticity or otherwise to continue providing water in proportion to population growth and allied factors without restraint, could have irreversible measures to arrest apparent problems, because whatever limited success could be achieved would not be without incurring severe economic and environmental damages.

166. Even in areas of adequate rainfall, where ground water is regarded as a renewable resource, the total amount available for use is finite being limited to the storage in an aquifer. Ultimately, if the resource is not carefully managed, the cost penalty of falling water levels, the deterioration in water and soil quality and other environmental consequences could be very disappointing. In the case where an aquifer is shared by more than one country, the concern will be a preoccupation of all the countries sharing the aquifer. The Nubian sandstone is a good example for this.

167. The Nabian sandstone aquifer underlies Libya, much of Sudan, Egypt, and Chad. It forms an extensive ground water basin with considerable storage, offering a great potential for irrigation, combating desertification, for the establishment of oasis along desert routes and for augmenting domestic and urban water supplies. Since the aquifer is sub-divided into hydraulically inter-connected sub-basins, regional cooperation is deemed necessary for its proper planning and management. In acknowledgement of this fact and of the potentials the aquifer possesses, there have been efforts to launch a study by UNDP on development problems related to the exploitation and use of water resources for different purposes. The project which was scheduled for 1990 had been intended to establish a regional mechanism for exchange of experiences and information pertaining to the development of the aquifer and the land overlying it.

168. So far the Nubian Sandstone aquifer has largely been exploited in Libya and to a lesser extent in Egypt and Sudan, while no use of it has been made in Chad. The study of the hydrogeologic conditions and ground water resource potential of the aquifer indicate that development in one part of the aquifer is not likely to affect other parts adversely or pose environmental repercussions 9/.

169. However, regional cooperation to promote standardization and correlation of hydrogeological data of adjacent countries is obviously considered indispensable. This will ensure better understanding of the hydraulic properties and the lateral extent of the different units comprising the aquifer system which form the basis for regional development planning. In view of this, the countries sharing the Nubian Sandstone aquifer have agreed to cooperate concerning hydrogeological data procurement and compatibility.

XIV. MANAGEMENT, MONITORING AND EVALUATION

170. One of the primary steps to success lies in the planning and management machinery for the GMR scheme. The planning for water resources development should fall within the technical competence of the responsible organization and within its financial means. The project should as far as possible not perpetuate excessive dependence on expatriates.

171. During the construction stage of the GMR, adequate efforts have been demonstrated right from the outset by the various Libyan government agencies and contractors to see through the accelerated construction programme. The result has been very encouraging. All problems have been surmounted with great success. The questions of "how much water" "at which place" and " for what purpose" had to be answered to carry on with the design and construction of the project. The GMR Authority had to make, in many cases, decisions on outlet locations and sizes some years in advance of procuring information on water use. Under the circumstances, the decisions made for municipal and industrial supplies were satisfactory whereas the needs of growing urban populations have been left to be provided in subsequent stages.

172. Monitoring and evaluation as a management tool should be an integral part of GMR project. The proper use and management of water resources stands out crucial for the realization of the desired objectives to procure maximum benefits by means of resource regulations oriented to both quantity and quality aspects in a unified system and to be in dynamic equilibrium with socio-economic and environmental aspects with due regard to future projections. This requires developing a plan which integrates primary water utilization programmes to the continuous cycle of re-use of the water. Establishing such linkages is necessary because most of the water which is not consumed should be available for re-use in an accessible location of a groundwater aquifer.

173. There are still uncertainties and challenges since some users are not yet prepared and ready with their plans for "new water" supplies. Situations reveal that the industrial sector is ready for the most part, whereas urban and municipal towns including Benghazi are not fully prepared with their treatment and distribution units. Of all users, agriculture has fallen far behind schedule in its preparation. The gap between the speed at which construction is advancing ahead of the user sector gives an indication that engineering and management problems are becoming apparent. The need to strengthen the institutional capacity with skilled and qualified staff, and provide adequate financial resources so that the institutions are capable to discharge their responsibilities in the planning, operation and maintenance of the scheme efficiently and effectively remains a crucial question requiring urgent attention.

174. It is evident that the GMR Authority could have difficulty to train adequate numbers of qualified people in a reasonably short period of time to operate, maintain and manage the project. There is already awareness of this problem and the contractors are asked to train counterparts in the GMRA, in reservoir systems, in pipeline construction and establishment in cathodic protection system and in computerized management and control system. Given the size and diversity of the project, it is anticipated that hundreds of people with varied skills would be needed. While scores are being somewhat trained, the dearth of qualified candidates moving through, from the higher education system remains a far cry to satisfy even a fraction of the needs. At the same time since the complete GMRP system is much larger than just stage I, the demand will correspondingly be much greater leaving a wider gap in the trained and skilled staff requirement. In making efforts to meet the need in the time ahead the alternative now leaves the continued dependence on expatriates. It is however, imperative that all preparations and efforts should urgently be taken up in the planning and preparation for making adequate number of trainee candidates available and thereby minimize excessive and prolonged dependence on external skills which are very costly.

175. Decisions about management policies regarding the most appropriate use of water can only be made if adequate data on all water resources demands in the country are known and the priorities are established. It would therefore be essential to have all necessary information on resources. The benefit of observation wells are also essential in the management and long-term surveillance of aquifers exploited by the GMR scheme.

176. To monitor major groundwater development schemes such as the GMR, observation wells are necessary. Monitoring the impact is an important aspect which has to be incorporated in the development scheme. This involves a cost component which may be high but would pay-off in the long-run. The importance and benefits of observation networks is highly valuable in regional evaluation of aquifer properties such as the Nubian Sandstone and in monitoring its impact on the aquifer system.

XV. CONCLUSIONS AND RECOMMENDATIONS

177. The Libyan Arab Jamahiriya is implementing the largest long-distance water-transfer scheme. The project is perceived to avert the current problem of water resources which has constrained development. It is also envisaged that when the scheme along with allied developments in agriculture and agro-based industries are realized, a significant socio-economic progress for the majority of the population will be attained.

178. The experience in Libya would be a good example to learn from its intensive development scheme for mining deep aquifer and transporting the water across the country to the developed but water short coastal regions. A detailed post-project study would provide a useful experience for the future.

179. Libya has already acquired some experience on exploitation and use of groundwater from the Nubian Sand Stone aquifer. There exist many useful data to suggest the importance for rational use and protection of groundwater so that development follows a coherent and sustainable course to benefit present and future generations. It is also necessary to see that these developments are responsive to changing demand patterns and should be consistent with the nation's economic and social development programmes. This requires formulation of strategies and proper planning regarding use of resources in the short, medium and long-term perspectives. The rational use and conservation should be guided by well formulated policies, legal and administrative procedures and economic instruments so as to integrate groundwater management into the overall water resources development programme. Because, groundwater is a vital commodity with economic and ecological values and is an exhaustible, finite resource it has to be used with great caution.

180. Water quality and corrosion are two problems that call for urgent and continuing action. Skill development and training will be outstanding issues for a very long time. The question of working out a plan for the staged development of the GMR project needs close scrutiny because, this has to be seen and synchronized with an accelerated programme of agricultural development for water use. In the light of unfoldments in the early years of the first stage of development, the possibility should be examined to see the use of water for replenishing depleted aquifers. Another important preoccupation would be the need to develop a system whereby water will be paid for at all levels.

181. The proceedings of the workshop on major regional aquifer in North-East Africa that was held in Khartoum from 12 to 14 December 1987 state that locally intensive exploitation of the fossil groundwater has occurred since World War II. It reveals that groundwater levels have declined in some of the development areas with serious consequences as for instance in Egypt where at least 50% of the 350 deep wells drilled in the New Valley project area (Kherga and Dakhla) have stopped flowing and pumping has become necessary. This is said to have posed a major management problem. It is therefore to be noted that water transfers or availabilities are not ends in themselves but rather means of providing a critical resource to meet perceived needs. It remains crucial that the rational use, conservation and protection of this resource be administered by proper management and skilled administrators.

182. The impact of exploitation of aquifers on regional consequences need to be observed to enable dealing in time with any changes should these become apparent. The understanding and cooperation between Libya, Egypt and Sudan over the Nubian Sandstone Aquifer is a good example to follow regarding transboundary aquifers. Collation of data with interested neighboring countries should be promoted so that the knowledge about groundwater may not stop at the frontiers thus becoming a barrier that precludes the possibility to understand the extent and limitations of aquifers and their hydraulic characteristics. In this regard, future investigations notably geological correlations, and other aquifer characteristics such as specific yield and hydro-chemistry need to be undertaken by interested group of countries.

REFERENCES

1.	Groundwater in North and West Africa Natural Resources/Water Series No. 18, United Nations	ST/TCD/5 - 1986
2.	Transnational Project on the major regional aquifer in North-East Africa	DP/UN/RAB - 82 013/
3.	Proceedings of Project Workshop held in Khartoum, Sudan 12 - 14 December 1987	United Nations New York, February, 1988
4.	Some aspects of the economics of groundwater conservation and protection	R.A. Downing British Geological Survey
5.	Arab Water World	November/December 1989 ISCN 0255-8580
6.	Water and Wastewater International	Volume 4, issue 4, August 1989
7.	National Development - Middle East/Africa	May 1989
8.	1969 - 1989 - 20 years of revolution	Al. ARAB
9.	Mission to Libya Arab Jamahiriya, April 6-12, 1982	By S.A. Acheampong
10.	Libya's Great Man-Made River Project	Peter F.M. McLoughlin (unpublished)
11.	The Major Regional Project on Rational Utilization of Water Resources in the Rural Areas of the Arab States with emphasis on the traditional water systems	UNESCO/ACSAD 1986
12.	Land and Water Resources Survey for Irrigation in Africa	Volume II Part A UNECA
13.	Conservation and Rational Use of Water Resources in some North African countries	UNECA, 1991

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THE JONGLEI CANAL PROJECT IN SUDAN

A WATER CONSERVATION AND MANAGEMENT SCHEME

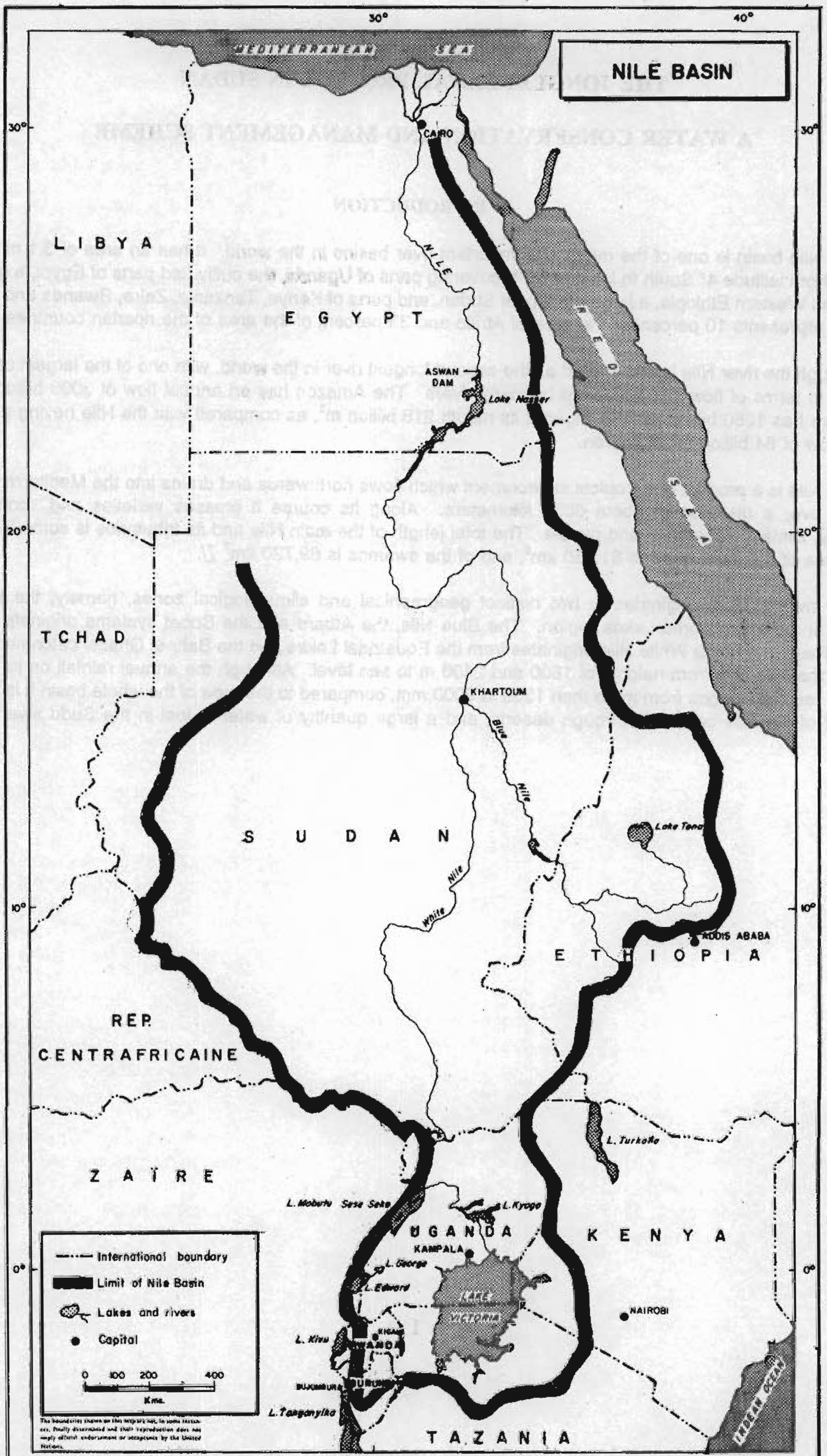
I. INTRODUCTION

1. The Nile basin is one of the major and important river basins in the world. It has an area of 3.1 million km^2 extending from latitude 4° South to latitude 31°N covering parts of Uganda, the cultivated parts of Egypt, a good part of North and Western Ethiopia, a large portion of Sudan, and parts of Kenya, Tanzania, Zaïre, Rwanda and Burundi. The basin represents 10 percent of the area of Africa and 33 percent of the area of the riparian countries. (Fig.1)

2. Though the river Nile is considered as the second longest river in the world, with one of the largest catchment areas, yet in terms of flow it is exceeded by many rivers. The Amazon has an annual flow of 3000 billion m^3, the Congo/Zaire has 1250 billion m^3, the Niger at its mouth 218 billion m^3, as compared with the Nile having an annual average flow of 84 billion m^3 at Aswan.

3. The Nile is a product of a tropical environment which flows northwards and drains into the Mediterranean sea stretching over a distance of about 6650 kilometers. Along its course it crosses varieties and contrasts in topography, climate, vegetation and people. The total length of the main Nile and its tributaries is some 37,200 km and the area of the main lakes is 81,550 km^2, and of the swamps is 69,720 km^2 7/.

4. The river system originates in two distinct geographical and climatological zones, namely; the Ethiopian highlands and the Equatorial Lakes region. The Blue Nile, the Atbara and the Sobat systems originate from the Ethiopian Plateau and the White Nile originates from the Equatorial Lakes and the Bahr el Ghazel catchment. Along its course the Nile falls from heights of 1600 and 2400 m to sea level. Although the annual rainfall on its plateaus and upper reaches ranges from more than 1300 to 3000 mm, compared to the area of the whole basin it is very low. About half of the Nile course is through deserts, and a large quantity of water is lost in the Sudd swamp in the Sudan.



NILE BASIN
MEDITERRANEAN SEA
30°
40°
20°
10°
0°
CAIRO
LIBYA
EGYPT
NILE
RED SEA
ASWAN DAM
Lake Nasser
KHARTOUM
Blue Nile
SUDAN
Lake Tana
White Nile
ADDIS ABABA
ETHIOPIA
TCHAD
REP. CENTRAFRICAINE
L. Turkana
ZAÏRE
L. Mobutu Sese Seko
L. Kyoga
UGANDA
KENYA
KAMPALA
L. George
L. Edward
LAKE VICTORIA
NAIROBI
L. Kivu
RWANDA
BUJUMBURA
BURUNDI
L. Tanganyika
TAZANIA
INDIAN OCEAN
International boundary
Limit of Nile Basin
Lakes and rivers
Capital
0 100 200 400
Kms.

II.SOME MAIN ASPECTS OF THE NILE RIVER SYSTEM

A. Social and Economic Features of Nile Countries

5. Of the nine states sharing the water resources of the basin, six are least developed countries. The proportion of the Nile basin area falling within each territory is given in Table 1. It can be seen that the countries in the Nile basin are among the poorest in the developing world with six having a per capita income of US$ 236 or less 4/.

6. In order to promote social and economic development, apart from the essential utilization of the water resources of the Nile for irrigated agriculture, there is potential for multisectoral development in such fields as hydroelectricity, fisheries, transport, livestock and water management. Some of the possible development activities could affect both upstream and downstream users and consultation and cooperation among riparian countries is essential.

7. With population growth, food deficit, and drought there has been a growing demand in the water use of the Nile river. Correspondingly the need for proper management has also grown in response to the critical need of promoting the social and economic development of the population. However, with few exceptions, the water resources in the upper reaches of the Nile system are not yet much developed. The major development that has so far taken place is in Sudan and Egypt. The upstream countries are also contemplating development of the Nile water resources in their territories.

B. Hydrographic Features

8. Over much of the Nile basin, evaporation exceeds rainfall. The hydrographic and hydrologic characteristics of the Nile vary greatly. Rainfall in the head water areas is abundant but seasonal. In the lowland region, from about 14° N, the river runs through arid country.

9. The two main water sources for the Nile come from the Ethiopian highlands of the Blue Nile trunk and the equatorial region around lake Victoria of the White Nile (see fig.2). The Blue Nile rises from Lake Tana in Ethiopia (which is 1800 meters above sea level) and supplies one-seventh of its total annual discharge. The rivers Didessa, Dabus and Beles are the main sources of water to the Blue Nile. There are also many other tributaries joining it along its journey from lake Tana to Khartoum where the White Nile and Blue Nile meet.

10. At Khartoum, the annual discharge is estimated at 51 billion m^3, of which the bulk (85 percent) comes during summer. The annual contribution of the Blue Nile at Aswan dam in Egypt constitutes 60 percent of the total Nile flow.

11. The most distant source of the White Nile is the Luvironza river which is a tributary of the Kagera river, the main supplier to Lake Victoria. Out of Lake Victoria emerges Victoria Nile at Jinja and enters into Lake Kioga after passing a series of falls. Along its course from Kioga to Lake Mobutu Sese Seko it crosses another series of rapids and falls. From Lake Mobutu Sese Seko the river known as Bahr-el-Jebel enters the Sudan at Nimuli with a normal annual discharge of 23 billion m^3, and reaches Mongalla with a discharge of 27 billion m^3 ---- after receiving further discharges from the Torrents between Lake Mobutu Sese Seko and Mongalla. North of Mongalla the river enters the swamps of southern Sudan and after passing the Aliab valley it enters the Sudd Region. The Sudd Region can be considered as starting at Bor 138 kilometers north of Mongalla. It continues for over 600 kilometers to Lake No and is characterized by an extremely flat slope. The river flows across a clay plain bounded on either side by interminable marshes. Formerly, when there was no regular navigation to keep the main channel open, it was liable to be blocked by floating vegetation masses. Thus the name "Sudd" which is Arabic means "block". Because the natural channel is too narrow to contain the discharge, water spills over the banks and spreads in the swamp area which is about 8000 km^2. Practically none of this water returns to the main stream.

Least Developed Countries of Nile riparian countries are: Uganda, Ethiopia, Sudan, Tanzania, Rwanda, Burundi.

FIGURE - 2

NILE BASIN AND JONGLEI CANAL

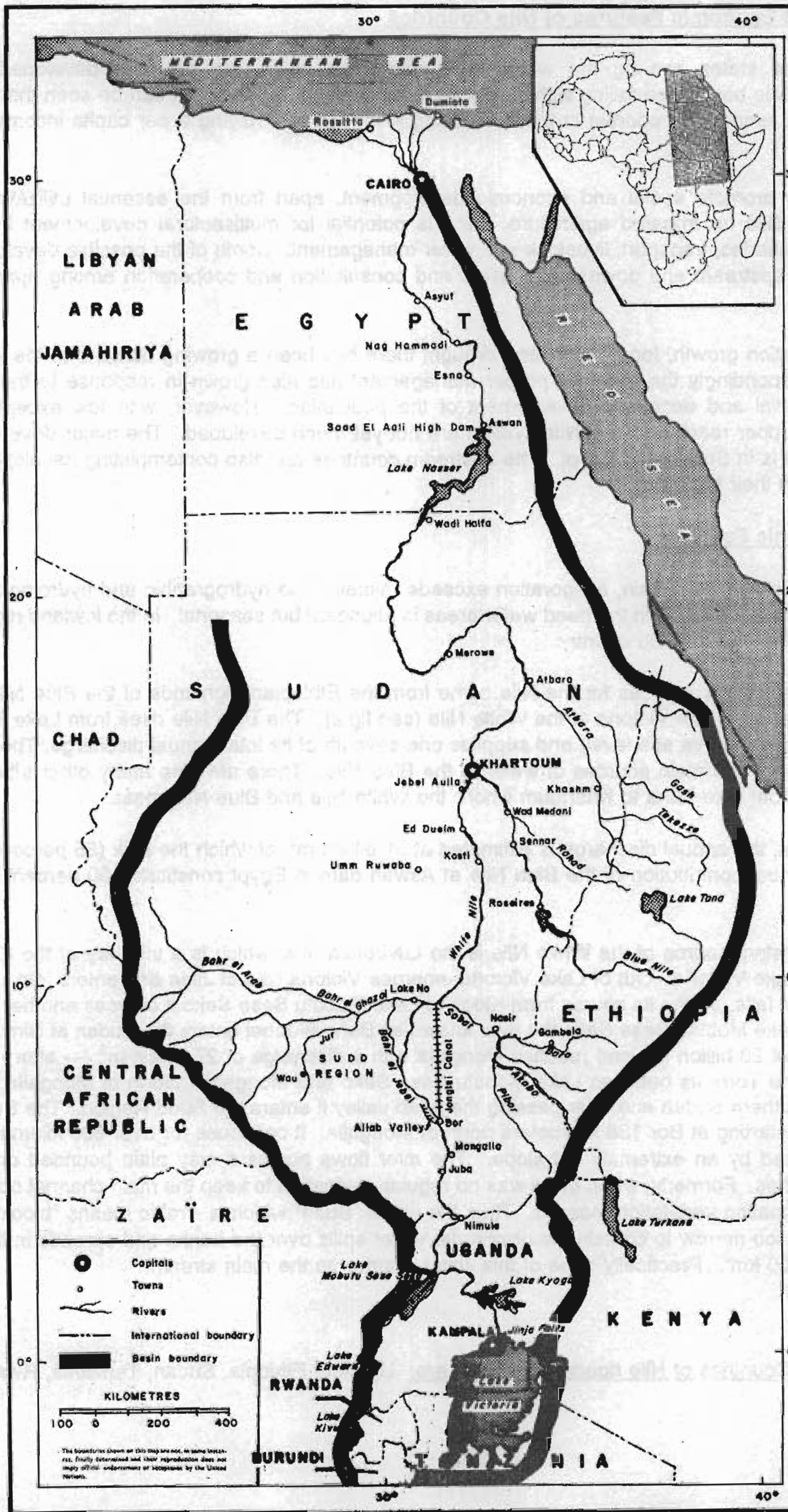


Table 1

Basic Facts Sheet - Nile Basin

COUNTRY '(PCI PER CAPITA GDP for 1988 at 1980 constant market prices)	SUB-BASIN	AREA km² (after FAO approximate figures)	RAINFALL mm	TOTAL AREA km²	% of total Basin Area
BURUNDI	L. VICTORIA	4599	963		
(PCI - US$ 235)				4599	0.15
RWANDA	L. VICTORIA	8531	863		
	L. ALBERT	457	967		
(PCI - US$ 234)				8988	0.29
KENYA	L. VICTORIA	48542	1147		
(PC - US$ 376)				48542	1.56
TANZANIA	L. VICTORIA	115376	1097		
(PCI - US$ 171)				115376	3.71
UGANDA	L. VICTORIA	154199	1197		
	L. ABLERT	45522	1196		
	UPPER WHITE NILE	27956	1164		
	SOBAT	3881	874		
(PCI - US$ 203)				231558	7.46
SUDAN	L. ALBERT	332	1268		
	UPPER WHITE NILE	397664	699		
	SOBAT	165997	893		
	BAHR EL ARAB	614724	779		
	BLUE NILE	109603	526		
	ATBARA	130737	235		
	WADI EL MILK	116197	111		
	ASWAN	364776	48		
	WADI AMUR	32470	42		
	WADI GABGABA	48750	25		
(PCI - US$ 395)				1981250	63.80
ZAIRE	L. ALBERT	19209	1400		
	UPPER WHITE NILE	240	1752		
	BAHR EL ARAB	15	1750		
(PCI - US$ 212)				19464	0.63
ETHIOPIA	UPPER WHITE NILE	4155	1217		
	SOBAT	67696	1542		
	BLUE NILE	190488	1461		
	ATBARA	107785	885		
(PCI - US$ 109)				370124	11.92
EGYPT	ASWAN	46878	25		
	WADI GABGABA	26409	25		
	LOWER NILE	252357	31		
(PCI - US$ 792)				325644	10.48
		GRAND TOTAL		3105545 km2	

12. The Bahr-el Ghazal, catchment of the White Nile which receives its waters from the watershed to the west of Bahr-el Jebel meets the river at Lake No.. The estimated discharge of 14 billion m³ is lost in the (Bahr-el- Ghazal) swamps before it reaches the Nile at Lake No. Beyond Lake No the river is known as the White Nile. South of Malakal at about latitude 9°30' the river Sobat which derives its waters from the Baro-Akobo and Pibor rivers originating from the Ethiopian foothills joins the White Nile. The Machar march receives almost 20 billion m³ from the spilling of Sobat, the Eastern torrents and the direct rainfall; about 15 million m³ is lost in the swamp.

13. The White Nile at Malakal receives only 27 billion m³, out of the total estimated volume of 75 billion m³ generated by the system. Thus in the swamps of Bahr-el-Jebel, Bahr-el-Ghazal and Machar marshes over 45 billion m³ are lost. Table 2 gives data on the areal extent, rainfall, total water supply and potential water recovery from the Sudd, Marchar, Bahr-el-Ghazal and Kioga swamps.

Source: ECA Secretariat

Table 2

Potential recovery of water losses from the four major swamps within the Nile basin

Swamp	Area in km^2	Rainfall[a] in mm	Total water supply in billion m^3	Potential water recovery[b] in billion m^3
Sudd region	8,290	1000	8.29	6.62[c]
Machar Marsh	6,480	800	5.18	4.14
Bahr el Ghazal	14,500	1000	14.50[d]	11.60
Kioga Swamps	4,500	1400	6.30	5.04[e]

14. The Atbara which originates from the Ethiopian highlands is a third major tributary of the main Nile. The Setite and other Atbara branches are its feeders. The river Atbara contributes an average discharge of 12 billion m^3 annually. This river has a similar discharge cycle like the Blue Nile with about 90 percent of its flow occurring from July to October. Between the months of January to May it is completely dry.

C. Prominent Hydrometeorological Parameters of the Jonglei Area

15. The precipitation and evaporation in different locations in the Nile basin are given in Table 3. The Jonglei project area falls in the Savannah belt south of Malakal and receives rainfall of 800 mm in the Machar swamps and 1000 mm in Malakal and Sudd swamps. This is received from April to November and is highly variable from year to year and from month to month. In these areas, evaporation exceeds rainfall. For example in Malakal and the South, the evaporation is 1240 mm, in Sudd swamps it is 1860 mm and in Machar swamps it is 2660 mm. Precipitation in the Lakes Tana and Mobutu Sese Seko area is above 1000 mm, and it keeps equilibrium with evaporation particularly in lakes Edward and Victoria which receive 1400 mm of rainfall. Northwards from central Sudan to Aswan, rainfall decreases from 600 mm to nil and evaporation is 2300 mm in Central Sudan, 2840 in Khartoum, 2,780 mm in Northern Sudan and 1,640 mm at Aswan.

16. Average temperature in the jonglei area ranges from 20°C to 35°C. The extreme temperatures vary from 11°C to 43°C and the potential evapotranspiration is about two to three times the annual rainfall. As seen from Table 3, evaporation amounts exceed precipitation.

17. The jonglei region is flat with the average topographical slope being in the order of 10 cm/Km. The general soil mass consists mainly of heavy, cracking clays having no definite pattern of drainage. In the wet season the appearance of inundation of the surroundings of the Sudd is enhanced by extensive flooding characterized by erupting flow phenomenon. Ofen the average annual rainfall of (800-1000 mm) causes wide spread inundations and locally a sheet of flow develops to a depth of 0.30 - 0.50 m, with a velocity in the order of 0.05 m per second 9/. In such circumstances it is difficult to distinguish between inundations caused by the river and those resulting from direct rainfall.

D. Water Yield of the Nile System 6/

18. Khartoum is the confluence of the Blue Nile and White Nile. The Atabara river joins this combined river course 330 kilometers north of Khartoum. At Aswan the normal total annual discharge is 84 billion m^3. Between Khartoum and Aswan, the river is characterized by a series of rapids and cataracts.

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[a] Based on Hurst (1952)

[b] 80% of water supply

[c] Report by Dekker (1972) as 7.82 billion m^3

[d] Close to the total loss given by Dekker (1972)

[e] Estimated as 7 billion m3 (at Malakal) by Waterbury (1979)

Table 3

Precipitation and evaporation in mm/year at selected locations along the Nile [1]

Location	Evaporation in mm	Precipitation in mm	Location	Evaporation in mm	Precipitation in mm
Mediterranean coast	1,100	200	Southern Sudan (Malakal and South)	1,240	1000
Nile delta	840	25 - 200	Sudd swamps[2]	1,860	1000
Cairo	1,020	25	Machar swamps[2]	2,660	800
Aswan	1,640	0 - 5	Lake Tana	-	1000
Northern Sudan (Wadi Halfa to Atbara)	2,780	0 -25	Lake Mobutu Sese Seko	1,420	1000
Khartoum	2,840	200	Lake Edward	1,420	1400
Central Sudan (up to Roseires)	2,300	600	Lake Victoria	1,400	1400

19. The Nile system is known for its marked seasonal and annual flow variations. The fluctuation in discharge is observed from the hydrologic characteristics which show that more than 80% of the annual flow occurs from July to October and only 20% occurs during the remaining months of the year. It is also interesting to note that the annual discharge of the Nile for the year 1913-1914 was 41 billion m^3 as compared to 151 billion m^3 in 1878-1879 while the average annual flow at Aswan for this century is estimated at 84 billion m^3 distributed as 48 billion m^3 from Blue Nile, 24 billion m^3 from White Nile, and 12 billion m^3 from Atbara. The percentage contribution of the main tributaries of the Nile is as follows:

- Blue Nile 59%
- Sobat 14%
- Atbara 13%
- Bahr-el-Jebel 14%

20. It can clearly be seen from the above that on the average 86 percent of the flow of the Nile comes from the Ethiopian plateau and only 14 percent comes from East Africa. During the rainy season, the percentage contribution of the river system is as follows:

- Blue Nile 68%
- Atbara 22%
- Sobat 5%
- Bahr-el-Jebel 5%

21. Hence, during the flood period 95 percent of the water comes from the Ethiopian highlands and only 5 percent comes from East Africa. During low periods the picture is quite different. About 60 percent of the water comes from the Ethiopian plateaus and 40 percent comes from East Africa.

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[1] Based on Hurst (1952) and other sources.

[2] Swamp evaporation rates are taken as 1.5 times the evaporation rates of open-water surfaces in the same location due to the existence of tropical plants (especially the Nile hyacinth).

22. The low contribution of the White Nile to the Main Nile is attributed to the large quantity of water which is lost by evaporation in the swamps while the Ethiopian plateau acts efficiently for draining the water of the Nile .

III. DEVELOPMENT AND CONTROL WORKS

A. The Historical Development and Control of the Nile River System

23. The Nile has dominating topographic and hydrologic features in shaping the development of the region since early times. It is a basin where many political events and foreign influences have been experienced since many centuries and most recently during the scramble for Africa. To date, the Nile politics remain very strong in the sub-region.

24. For Egypt, the Nile is the only source of surface water. The study of Nile flow records and flood irrigation along its banks date back many thousand years. Modern river control works started in the middle of the 19th century when barrage constructions were made to divert water to the fertile areas of the Delta. However over the years, there was a continuous problem of water shortage for irrigation during summer seasons, and the problem of floods causing serious damages to life and property during wet season.

25. By 1980, the cropped area in Egypt under perennial irrigation reached about 3 million acres in addition to 2 million acres cropped area under basin irrigation, and the whole of the natural flow of the Nile during the low flow period was consumed. It was naturally felt that it was no more possible to expand irrigated agriculture without the construction of control works across the Nile to store the excess flood to supplement the water requirement for crops during period of shortage. For this purpose, the Aswan Dam was constructed in 1902 to store 1.0 billion m^3. Later in 1912 it was heightened to increase the storage capacity to 2.4 billion m^3 to meet the increasing demands.

26. From the turn of the century up to 1919, the Sudan developed 83,040 acres of basin (flood) irrigation in the northern province and 39,960 acres of pump irrigation.

27. Surveys and studies by the Egyptian Irrigation Service were underway in the upper reaches of the river to provide Egypt with more water and to serve as a measure for flood control as well as to meet the increasing demands of Sudan, especially for the Gezira Irrigation Project. Plans were prepared after the low flow of 1913-1914 for further annual storage at Sennar in the Blue Nile and Jebel Aulia in the White Nile to meet the needs of the two countries. The plans included diversion of the Sudd region to reduce evaporation loses, and increase the storage of water in the Equatorial Lakes while the plans for storage works in lake Tana were to provide additional water during low flow period and protect against floods during high flow seasons.

28. The annual storage reservoirs at Sennar and Jebel Aulia were constructed in 1925 after the First World War, but the plans for over-year storage and the Sudd project encountered difficulties since these were outside Egypt. A number of study groups and a Commission were established by Egypt to examine the situation and to resolve the problem possibly through a frame work of co-operative arrangements. In 1920 the Egyptian Government appointed the Nile Project Commission, instituting an international body of three engineers to give it an opinion in the planning and allocation of water between Egypt and Sudan. The Commission endorsed the construction of Sennar and Jebel Aulia reservoir and recommended further studies to be made on the over-year storage in the Equatorial Lakes, Lake Tana and the Sudd Diversion projects. This recommendation formed the basis for the 1929 agreement between Egypt, Sudan and the East African countries in a form of an exchange of notes between the Government of Egypt and the Administrations of Sudan and of East Africa through the Government of Great Britain.

29. In 1946 the Egyptian Government published a document titled the "Future conservation of the Nile Basin" in which a proposal for a comprehensive scheme of development of the Nile, based on the principles of over-year storage for the benefit of Egypt and the Sudan was put forward. The main features of the plan were:

(i) A new Main Nile reservoir near Marawi for flood protection and summer storage

(ii) A reservoir for over-year storage in Lake Mobutu Sese Seko combined with regulations in Lake Victoria.

(iii) A diversion canal in the Sudd Region to carry about half the discharge from Lake Mobutu Sese Seko with natural losses - at the same time the remainder of the flow to go down the Bahr-el-Jebel with diminished losses.

(iv) A reservoir on Lake Tana for storage for irrigation and flood control.

30. In 1949 Britain and Egypt agreed to construct Owen Falls Dam in Uganda for hydropower and over-year storage of 200 billion m^3. The dam was completed in 1952. In 1951 Egypt completed the Edfina Barrage on the Roseta branch of the Nile to replace the earth embankment which was built in 1890; and in 1952 it agreed to the proposal made by Sudan to raise Sennar Dam by one meter and Jebel Aulia reservoir by 10 cm to provide additional storage to meet Sudan's water requirement for agricultural expansion. At the same time Egypt proposed the construction of High Aswan Dam and Sudan proposed the construction of the Roseires Dam. These proposals were the bases for the 1959 agreement between Egypt and Sudan.

B. **The Equatorial Nile Project**

31. The idea of reducing losses by river spill and subsequent evaporation and transpiration in the Sudd Region was first conceived in 1904 and since then with the accumulation of hydrological data, various plans have been developed, such as the Vevenor-Pibor scheme (1932) and the Bahr-el-Jebel Banking Scheme (1958). These proposals subsequently led to the Equatorial Nile Projet. Egypt's focus was on this project with an over-year storage in Lake Mobutu Sese Seko combined with regulation in Lake Victoria and a diversion canal from the Sudd to Jonglie running parallel to the Bahr-el-Zaraf following the highlands on the edge of the swamp. The second choice for the route was along a direct line from Jonglei to the mouth of River Sobat, following the ridge. The length of the canal was 280 kilometers, having a capacity of 55 million m^3/day to provide 8 million m^3 of water for irrigation in Egypt.

32. When the project was presented to Sudan, the Sudan government commissioned the Jonglei Committee and Jonglei Investigation Team to study and examine in detail the impact of the project vis-a-vis Sudan's interests. The terms of reference of the team was also to recommend compensations required for damages to local interests related to flooding, grazing, agriculture, fishing and hunting, tribal communication and other issues. The tasks also included alternative canal alignments, impacts outside the Sudd region and the proposed construction programme. The investigation lasted from 1946 through 1953, and its findings were published in a massive document in 1954. The study was considered a landmark report and very comprehensive. It examined the hydrological, ecological, demographic, sociological, environmental, animal and grassland husbandry, crop husbandry and fisheries aspects. It's main recommendations rejected the reversal of the natural regime of the river, so that the livelihood of the nomadic pastoralist (over 1 million people at the time) would not be totally disrupted. It called for the maintenance of river level seasonal fluctuations and showed that this could be achieved by abstraction of no more than 55 million m^3 per day from Bahr-el-Jebel upstream of the Sudd.

33. In the investigation regarding the implications of the project, the team directed its focus on two aspects, namely; to mitigate the negative effects of the project and to present a revised operation of the project. In the event, the project was to be implemented along the proposal by Egypt, the team outlined a set of remedial measures such that implications would have minimal effect on the prevailing economic conditions and lifestyles. A major emphasis of this proposal was the provision of an alternative pasture land during the dry season equivalent to make up to that lost on the flood plain.

34. The other aspect of the proposal related to the operation of the project to mitigate adverse effect. The general principles of the revised operations were to simulate the natural fluctuations of the river to minimize negative impacts, and avoid the need for remedial measures, which according to the team were both expensive and untried, and would entail a drastic change in the livelihood of the people with all social and economic repercussions.

35. After 1954, political developments in Sudan, Egypt and East Africa had a profound influence on the history of planning of the Jonglei Canal Project. The East African countries were not agreeable to the use of East African

lakes as storage reservoirs, as large tracts of their territory would be inundated. Sudan was on one hand preoccupied with its independence coming while on the other it was looking to expand its area under cotton cultivation. Consequently it was going for its share of the Nile waters. In Egypt it was the time of the 1952 revolution, and second thoughts were being given about storing Egypt's lifeline outside her political border while at the same time there was the re-emergence of the idea of the High Aswan over-year storage project. Therefore, these new political, technical and economic developments have contributed to the new approaches and to fresh thinking.

36. In Egypt the Aswan dam concept was desperately needed, (being a timely and spectacular symbol) by the revolutionary government to justify and demonstrate that its intention and fundamental goal was to make the country an independent and prosperous nation. It was a scheme that fitted the revolutionary vision and was envisaged to make a significant impact towards responding simultaneously to many critical problems Egypt was facing.

IV. THE JONGLEI

A. The Jonglei Canal Project

37. The search to meet the irrigation water requirements of Egypt and Sudan continued after the Egyptian revolution in 1952 and the accession of Sudan to independence. The strong focus of Egypt was now concentrated to the realisation of an over-year storage at Aswan because this provided multiple solutions in the maintenance of summer river flow, in flood control and drought prevention which were all critical problems that needed to be resolved. The Jonglei had another positive phase in that it entertained the needs of Sudan for more water.

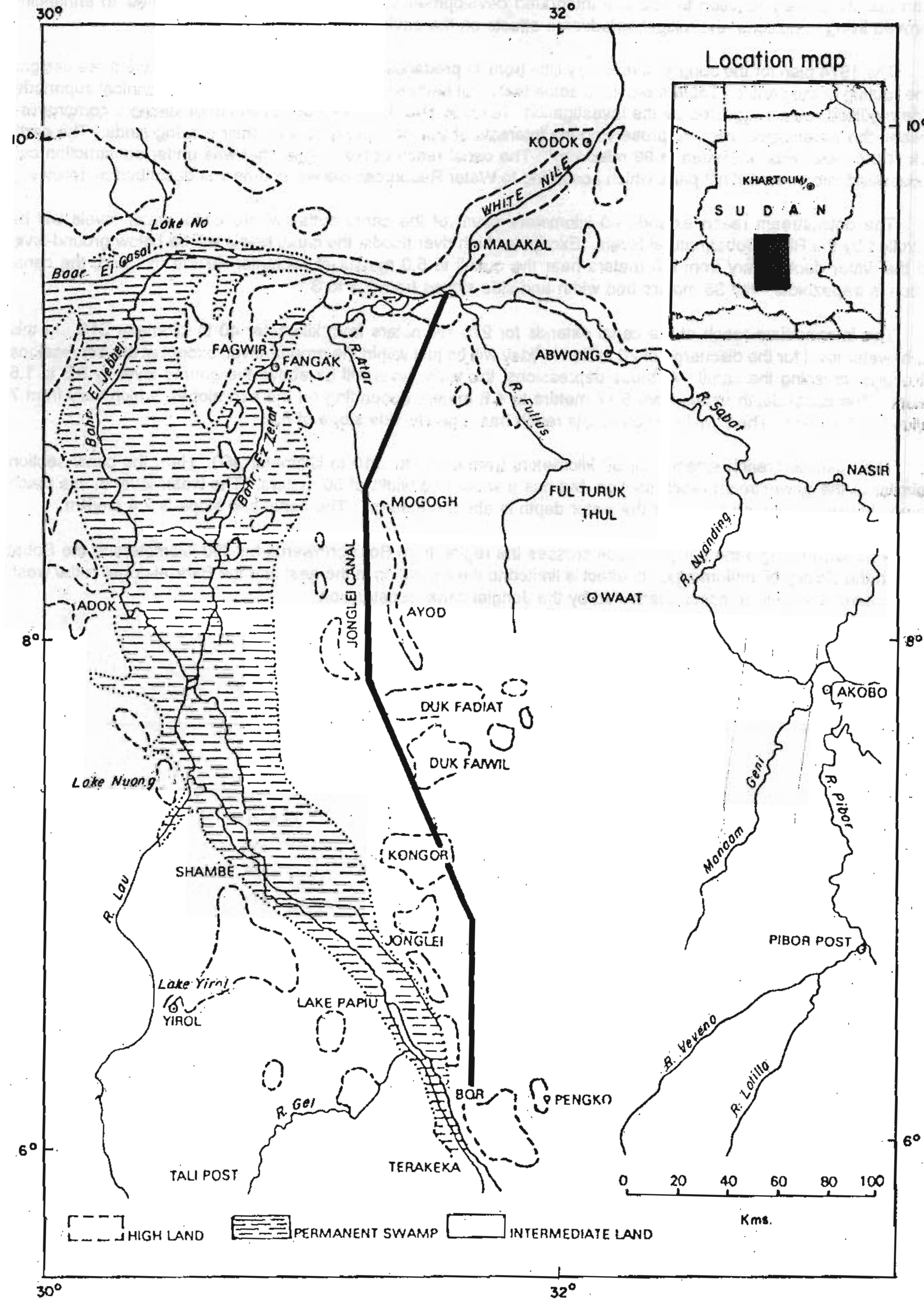
38. In 1959, Sudan and Egypt signed the Second Nile Water Agreement. Sudan now agreed to the building of the High Aswan Dam and to the resettlement of 50,000 Nubians after the inundation of 150 km of their homeland. New formulas for water shares were agreed upon to divide the net benefit of the High Aswan Dam of 22 billion m^3, of which 14.5 billion m^3 goes to Sudan and 7.5 billion m^3 goes to Egypt. These were in addition to 4 billion m^3, and 4.8 billion m^3 respectively agreed in 1929. An important provision of the 1959 agreement is that any project benefit to increase the yield of the Nile was to be shared between Egypt and Sudan in both cost and benefit. With the construction of the High Aswan Dam, the objectives foreseen of the Equatorial Nile Project and the Sudd diversion for providing water in low periods to Egypt were not any more needed. This was a fundamental change from the initial objectives.

39. A Joint Technical Commission was formed in 1960 for the purpose of studying and recommending projects for Sudan and Egypt. By 1974, three significant events took place since the work of the Jonglei Investigation Team which conditioned its revision. These were the great rains of the 1960's in the equatorial lakes, the construction of the Aswan, and the technological breakthrough in canal construction by the invention of the "Bucketwheel". In 1974 the Commission recommended the revival of the Jonglei scheme. The first phase of the Jonglei was to increase the Nile yield by diverting 20 million m^3 per day, or some 25 percent of the mean daily discharge of Bahr-el-Jebel upstream of the Sudd, from the river at Bor through 360 kilometer canal to the mouth of the river Sobat (see Fig. 3) by passing the swamps and reducing the evaporation losses. The net addition to the yield of the Nile is estimated at 4 billion m^3 annually measured at Aswan. This amount is to be equally divided between Sudan and Egypt.

40. Although the Jonglei Project was originally conceived to serve irrigated agriculture in Egypt, the interest of Sudan gained its share in the evaluation of the project. The benefits of the Jonglei Project in terms of more water being available for irrigation is obvious. The 4 billion meter cube per year extra water will mean the irrigation of an additional 250,000 ha each in Egypt and Sudan. In Sudan alone the increase of the GNP is estimated at 35 million pounds annually. Of course to the total estimated project cost of 70 million pounds (including 18 million pounds for the development of the Jonglei region) the costs to develop the areas to be irrigated have to be added.

41. The planning for the Jonglei had its primary objective in terms of making more water available through an engineering work and water management skills. However, after the revival of the project in 1974, socio-economic parameters have been given serious consideration. This was in fact one of the reasons for commissioning the Executive Organ for the Development Projects of the Jonglei area. This

THE JONGLEI CANAL : CONSERVATION PROJECT OF THE NILE



organ had its primary function to see that integrated development approach is adapted with a view to enhancing improved living conditions and mitigating adverse effects on the environment.

42. The 1974 plan for the Jonglei differs very little from its predecessor. The difference between the three designs is the routing of the canals. Table 4 provides some technical features of the three routings. The technical superiority of the modified route suggested by the Investigation Team in 1948 lies in its achievement of stiking a compromise between the water objectives and preserving the interests of the local population on their grazing lands. The earth work of the canal was estimated at 99 million m^3. The canal reach of the Jonglei that was under construction can be classified into three distinct parts which according to Water Resources Series volume 7 is described as follows.7/

43. The downstream reach extends 40 kilometers south of the canal outfall where canal water levels will be controlled by the River Sobat natural levels. Except for high river floods, the canal levels will be below ground-level and the water depths vary from 8.0 meters near the outfall to 5.0 meters at kilometer 40. In this part, the canal section is trapezoidal, with 38 meters bed width and side slopes from 2:1 to 3:1.

44. The intermediate reach of the canal extends for 270 kilometers from kilometer 40 to kilometer 310. In this reach, water level for the discharge of 20 million m^3/day will be just within the ground-level, except at the depressions of Konggor crossing the canal. At these depressions, the water level will be above the ground-level by 0.5 to 1.5 meters. The canal depth varies from 5.17 meters to 4.6 meters depending on the bed slopes, which vary from 7 cm/km to 11 cm/km. The canal section in this reach has a gentle side slope of 8:1.

45. The upstream reach extends for 50 kilometers from kilometer 310 to kilometer 360. Here the canal section is similar to the downstream reach section, but has a wider bed width of 50 meters. The water-level in this reach is much below the ground level and the water depth is about 4 meters. The canal bed slope is 7.4 cm/Km.

46. As shown in Fig.3 the Jonglei Canal crosses the region from Bor northwards for 360 kilometers to the Sobat mouth in the vicinity of settlements. Its effect is limited to the highlands in the east and the Bahr-el-Jobel in the west. The permanent swamp remains unaffected by the Jonglei canal construction.

Table 4

Comparison of initial, modified and 1974 plans for diversion 8/

	1938 (initial)	1948 (modified)	1974
Daily capacity	20 million m^3	twin 27.5 million m^3	20 million m^3
Length (km)	307	280	360
Number of reaches	7	6	6
Range of bed width (m)	48-51	76	52
Depth of water (m)	5	4	5
Water velocity (m/scc)	0.849-0.942	0.851-0.927	0.90

B. Relief and Soil and Soil Characteristics

47. The project area of the Jonglei canal is generally characterized by a very flat topography which is dissected by depressions and channels. The slopes are gentle in the north, north east and north west with 50 cm/km in the southern part and 10 cm/km in the northern part.

48 The area can be divided into four major types, namely: highlands, intermediate lands, toiches (swamps) and sudd soils.

49. The high lands lie slightly above the level of the flood plain and are permanently free from inundation. They are intensively used and are generally characterized by over-cultivation and over-stocking, as they form the only base for permanent settlement and refuge for people and cattle during the rainy season. The soils vary from heavy to light loam with clay contents being 15 to 40 percent.

50. The intermediate lands are flooded during the rainy season and become completely dry towards the end of the summer. These lands are mainly used for grazing during the early wet and early dry seasons. If drained, they could have considerable potential for cultivation. The soils are heavy alluvial with 35 to 70 percent clay content of the montmoriallonite type. These soils shrink during the dry season forming deep vertical cracks which close during the rainy season due to swelling. They are impermeable and give rise to poor surface drainage. This characteristic is very important in the consideration of the impact of Jonglei on ground water resources.

51. The toich lands are inundated for long periods from the water courses and they rarely dry out. They are extremely fertile but their use is limited to grazing only in the dry season. The soils are predominantly clay with sand accumulations occurring in old channels and water courses.

52. The SUDD is an area bounded on either side by interminable marches for the greater part of the year and seldom dries out below saturation point. These soils are too wet to be used and are not affected by human activities The organic content of the soil varies from a few centimeters to over one meter. A typical profile comprises a surface mat of horizontal roots, rhizomes and decomposing plant-remains, overlying a layer of humified peat.

C. Population

53. There are three tribesmen inhabiting the Jonglei area. These are the Dinka, Nuer and Shilluk. During wet season, the majority of the population live in the high lands close to the canal. Although they exist as three groups, they have strong similarities of culture, language and lifestyle. Livestock plays a significant role in the economic and social lives of the Dinka and Nuer who are mostly transhumant. Of the three tribesmen the Shilluk are a settled group with an organized political system. For their livelihood, they depend more on crop production and fishing than in cattle breeding. These tribesmen form only a small proportion of the population of the canal area.

D. Lifestyle and Economic Activity

54. Agricultural economy is predominant in Sudan accounting for more than 40 percent of the gross national product and 90 percent of the country's foreign earnings; 80 percent of the population (20 million) depend for their subsistence on agriculture and related activities10/. The area of the arable land is estimated at 58.9 million hectares. Of this, only 7 million hectares are effectively exploited, of which 1.7 million are irrigated and the rest rainfed. The area of the pasture land is 24 million hectares, while the tropical jungles occupy 50 million hectares 10/. Traditional agriculture which is primarily subsistence oriented, consists mainly of farming and pastoral activities which depend on rain, for crops and forage. Rain-fed agriculture constitutes about three quarters of the cultivated area and accounts for about 30 percent of the production, with irrigated agriculture constituting one quarter of the cultivated land and representing 50 percent of the production. The remaining 20 percent is contributed by livestock.

55. Inspite of the fact that Sudan produces a variety of crops, yet it is largely dependent on imports of food items. Not withstanding the fact that like the majority of Nile basin countries Sudan is also represented by low economic activity, it is endowed with rich natural resources which if properly managed would contribute to the socio-economic well being of its population.

56. In the Jonglei area the lifestyles and the economic activities of the various tribes, Dinka, Nuer, and shilluk like in other regions of the country are associated with farming and cattle raising. Aside from its economic significance, the livestock number implies high social values and prestige in the communities. The total cattle population in the canal area is estimated at about half a million.

57. The availability of water and grazing land which are governed by the wet and dry seasons are determining factors in controlling the migratory movement of the transhumant population. These people have their established homesteads on the ridges where they live in isolation during the wet season with their cattle. Their grazing pattern involves migration from the permanent settlements to the riverine grassland known as "toich" passing through the

intermediate land and then back to their home in the highlands.

58. The end of November or early December is generally the period when the recession of the flood starts. During this period water becomes scarce in the adjacent areas of the settlements and the grass becomes tall and dry. At this time, the men start to move with their stock of cattle towards the eastern intermediate land along the water courses and depressions where green pasture is also available. Towards the end of December or early January the eastern intermediate dry land begins to dry up and therefore the people with their herds travel to the toich grazing land. While moving to the toich, the cattle graze the western intermediate lands which are then burned to produce fresh regrowth. The travel to the riverine grassland may take more than one month depending on the availability of water in the intermediate land. The distance between the toich and the highlands extend from 2 to 80 kilometers.

59. Generally, the clans follow certain migration routes and they each have their particular grazing lands and camping areas. Usually by end of February, most of the livestock reach the toich grazing lands where the herdsmen set up their dry season camps in the vicinity of the water courses.

60. In April - May which is the start for the rainy season, water and pasture becomes available in the intermediate land and around the settlements. Hence the return migration homewards begins at this time. In the journey to the permanent settlement, small temporary camps are set up in the intermediate land. As the intensity of rain and biting-flies increases the people drive their animals to the high lands and protect them from mosquitoes and flies by keeping them in cattle-byres (luak) at night.

61. Farming is another main occupation for the inhabitants of the Jonglei area. The major crop is sorghum which along with other crops partially makes the staple food. In effect, the region is characterized by a sizeable deficit in grain production culminating in a need for import of sorghum as hunger befalls -- a common occurrence in the region. Based on information obtained from land use map (1976) which gives an indication of the land under cultivation, the total cultivated land in the project area is estimated at 30,000 acres. Despite, harsh environment and vulnerability to occasional flooding of the area, the Dinka and Nuer have been able to sustain with agriculture and livestock raising as major economic activities. Since the two activities are often below subsistence level of production, there is no cash surplus generated. What little cash is obtained is through reluctant sales of animal heads. The amount thus raised is used for purchase of basic commodities such as grain, consumer goods of bare necessities, payment of government taxes, school fees, purchase of better breed animals, and occasionally clothes. The region is faced with acute shortage of grains and subsequent to which famine prevails.

E. Wildlife

62. The project area is very suitable for habitation of wildlife. It has vast grassland and woodlands which are both dense and open. This environment has been conducive for diverse and numerous wild life presence in the area. The main species are: tiang, roan antelope, giraffe, mongalla gazelle, oribi, reedbuck, bushbuck, white-eared kob, and ostrich. The carnivore group of animals include: Jackal, gennet, civet, white-tailed mongoose, hyena and lion. Animals like waterbuck, Nile lechure and Grant's zebra also inhabit the project vicinity.

63. The animals have generally their migratory patterns and often they move from the south-east to the north-west. While this movement is an overall trend, different species have different patterns according to their water affinity and habitat preference.

F. Socio-economic and Environmental Impacts of the Jonglei Canal

64. Like any engineering project in land and water resources, the Jongei has its positive and negative impacts. The complexity of the problem and the magnitude of the risks often correspond with the project size. The Sudan Government was keen to see that detailed studies were conducted to consider the impacts of the canal prior to starting construction. Since 1904 when the idea of the Jonglei Canal was conceived, many studies have been made. In 1938 the Minister of Public Works, after being convinced that various solutions for bypassing the Sudd had been exhaustively examined decided that the Jonglei Canal scheme should be carried to the construction stage. The project seemed ready for execution after the completion of the studies by the Investigation Team in 1954.

65. The environmental and social impacts of the Jonglei project have led to widespread concerns both at national and international levels. The question regarding the influence on the climate in the area and even in the wider region arising from a reduction of the extent of the Sudd swamps was made an issue that disturbed the minds of many people. However, from studies on man-made lakes in Central Asia and on lake Nasser in Egypt, it is known that there has not been any noticeable change in climate. This view is also born out of the fact that the considerable increase of the Sudd over the last two decades did not result in increased precipitation in the area. This is evident when considering the limited quantity of water evaporating from the swamps compared with huge volumes available in the atmosphere. It is moreover realized that apart from micro-climatic effects in a very limited locality, the climate in a region is governed by phenomena acting on a much larger scale than can be influenced by a localized event like an increase or decrease of evaporation amounts in the Sudd. It can therefore, be stated that the canal will not induce climatic changes.

66. There were groups of people who feared that ground water in the Sahel region to the North will be drained by the off-take of water in the Canal from the Sudd. This was proven not to be the case, because, the Sudd is underlain by a stratum of impervious rock known as the Umm Ruwaba upon which lay a layer of impervious clay such that no hydraulic connection that permits water flow from the Sahel region occurs.

67. There were critics who believed that the Canal would draw water which would be needed in the rich pastures of the toich. Since the complaint of the inhabitants for the past twenty years has been rather of having too much water and not too little water, this was dismissed as being unrealistic. Further the charge that the toich pasture was heavily reduced in size was found to be an over exaggerated assertion, because even according to initial conditions the loss was only 19% and this has been brought down to only 10% in the modified project design. In addition the pasture was underutilized indicating that the construction of the canal did not induce any serious problem on the grazing land as would affect the lifestyle of the inhabitants.

68. Concern has been expressed regarding the impact upon traditional resource-use strategies. This is mainly because many people were thinking of the effects of the Equatorial Nile Project (ENP) which is quite different from the present Jonglei Canal Project. It is important to note that the ENP depended on timely storage at the lakes causing a reversal of the flow and envisaged an off-take capacity of 55 million cubic meters per day. This reversal of flow would have caused a reduction in the riverine or "toich" (swamp) grazing area, by flooding the expanse of land of Jonglei and north of Malakal, at a time of the year when it was most needed by cattle owning inhabitants of the Jonglei area. In addition, under the ENP the flows in the Bahr-el-Jebel, downstream of Jonglei would through the year only have varied between 30 - 35 million cubic meters per day. The "toich" land between Jonglei and Malakal, as well as the area of open water swamps, would have consequently been reduced considerably, thus depriving the area of its valuable grazing land and fish potential. It is after careful study of these consequences that the Jonglei Investigation Team came up with a new approach. The present project therefore, does not as such envisage any modification of flow from the equatorial lakes, but simply diverts 20 million cubic meters per day. Studies undertaken by the Permanent Joint Technical Commission for Nile water (PJTC) indicated that this amount of water could be withdrawn safely without undue changes in the Sudd. The Jonglei and a wide area around it are flooded and if this flooding continues to persist, the canal will be beneficial in reclaiming the swamp created by the floods. In the event of a series of low water years occurring, the canal operational rules have provisions to mitigate harmful effects. Sutciffe and Parks (1982) concluded that changes in the flooding of the region as a consequence of the canal as presently envisaged are minimal in comparison to the natural variability and the extent of the swamp area reduction. This conclusion was based on their mathematical model observations that considered elements of flow to the swamp, outflow from the swamps, rainfall, evaporation and the extent of the flooded area.

69. Concurrent with the engineering studies and surveys, other studies were conducted by the Jonglei Investigation Team in the years 1946-1954 into the socio-economic conditions of the region to determine the potentials for improved cattle breeding and for agriculture. These studies were supported by various international agencies and bilateral aid programmes. The alignment, adopted for the extension of the Jonglei Canal to Bor, is the result of such integrated studies, in which the interest and welfare of the population was a priority. The alignment which takes a more easterly route from Bor takes account of traditional land use patterns. The populated areas are all situated on the western side of the canal, so that it does not form an obstruction in the migration routes to the toiches on the borders of the Sudd to the pastoral groups. It is also expected that the canal will favorably affect the grazing areas west of it, since the eastern embankments will check the creeping flow approaching from the east.

According to the findings of the Jonglei InvestigationTeam even during the period of highest stress, in the wet season when stocks are confined to small areas in the highlands the restriction on movement and limitations of grazing field will not be so critical.

70. The provision of ferries and bridges will facilitate the crossing of the canal. Also the canal section was modified to facilitate swimming across by cattle and wildlife. It is expected however, that the canal being a permanent water source will attract a concentration of people and cattle, particularly at the crossing points. On the eastern side of the canal, the creeping flow backing up against the canal embankment will create pools, which will offer drinking water to humans, cattle and wild animals in the dry season creating new habitat nucili. It is therefore essential to contemplate taking measures to mitigate health hazards and avoid over grazing along these places of the canal embankment.

71. In due course of time, it is natural to expect that there will be competition between man and animal, and this is likely to intensify with increase in population and the increasing socio-economic progress. As can be observed from experience in other places, the opening up of hitherto isolated and closed areas in itself poses a threat to wildlife. Therefore to protect and preserve wildlife, the provision of game parks will become necessary. The creation of parks will of course have to be integrated with other development programmes.

72. To what ever limited extent, there is no question that the construction of the Jonglei Canal will interfere with the human and animal way of life. It is in particular considered to affect the movement of wild life. Extensive surveys have yielded a fairly comprehensive knowledge about the various species, their numbers and migration routes. Fortunately there are only a limited number of migration routes which cross the canal alignment and at such places ramps are constructed. The concern however, for wildlife is particularly for the tiang which have an established migratory cycle and which are the single most important species in the area. They can swim across but might sustain heavy losses. Arrangements are being made for the provision of water ponds on both sides of the canal, as it is expected that migration cycles of other species will also be curtailed and the wildlife will be divided between the east and west boundaries of the canal.

73. In addition to realizing the primary objective of the project for increasing the Nile yield by 4 billion m^3 to meet the expanding programmes of agriculture in both Sudan and Egypt the canal will have an important economic and social impact in the Jonglei area and in the southern region of Sudan in particular. The canal will shorten the navigation route by about 300 kilometers between Malakal and Bor, and together with the road that runs along the bank of the Jonglei, it will have a major impact on improving communication in the southern region of Sudan which is almost completely isolated throughout the wet season. The canal will certainly facilitate closer links with other parts of the country. The presence of such permanent water supply will no doubt lead to more stable and settled communities and improved services for them and their livestock. This would mean a change in the life pattern of the people from a semi-nomadic pastoral life to a sedentary one in which agriculture will gradually become the main economic activity.

74. This change is not one which is imposed but is a logical transformation or evolution rooted in a development process. In order to facilitate this gradual transition to a sedentary agriculture-based life, there is a pilot project in Bor where experiments in rainfed and irrigated agriculture were being conducted. The results were disseminated to the local population aiming at integrating cattle breeding and agriculture. Another pilot project was implemented near Konggor, which is oriented mainly to rainfed agriculture so that the results can be adopted by the local people. It is the intention to start more of such pilot projects along the canal, which in course of time will serve as nucili farms.

75. Along side pilot development schemes research was going ahead for planned development and modernization of the Sudd, building upon and updating the work of the Jonglei Investigation Team. The studies consisted of the environment and eco-system of the Upper Nile in two parts. The first being on Range Ecology Survey, Livestock Investigation and Water Supply including the effects of the Canal on the people that was published in 9 volumes in April 1983. The second dealt with Swamp Ecology Survey which was published in October 1983. These studies contained an enomous amount of information covering virtually every aspect of the Canal area - livestock, vegetation, wildlife, water supply, limonology, plant studies, invertibrate and fish studies and the advantages and disadvantages of the Canal upon the environment in the Jonglei Zone. The project was well studied although the conclusions were

not definitive.

76. The studies have indicated that the Jonglei Canal can be a new source of fish, which should be available in the area throughout the year. Surveys carried out indicate that the Sudd itself was not very rich in fish. It is open waters which offer favorable conditions for fish life. Since the appearance of water hyacinth in 1958, large areas of the swamp are covered with weeds, resulting in deoxygenation and consequent reduction in aquatic life including fish. The Jonglei Canal would therefore have created a new environment and opportunities for the fish industry, which has also good prospects for export to the outside world.

77. Even during the construction phases which unfortunately did not see completion, the impact on rural development had started to be felt. The National Council for the Development of Jonglei Canal area has focussed attention on promoting social and rural development. The access to the canal area has already enhanced construction of schools and health centers. Rural Development programmes including roads improvement, agriculture and veterinary services, research into farming systems and community water supply were in progress.

G. <u>Hydropolitics of the Jonglei in Sudan 2/</u>

78. Since the establishment of the Southern Regional Government in Sudan, views were expressed by the local people concerning the construction of the Jonglei. The floods of the 1960's and the civil war had driven many thousand Nilotes to the North where since 1972 they were exposed to the harsh realities of life. In many ways conditions were different from those in their isolated sanctuaries in the Upper Nile Province of Sudan. To cope with the changed pattern of life many received formal education and a broad exposure such that an intellectual elite could emerge. Consequently many read reports on the Jonglei project including the report of the Investigation Team. In time, a strong opposition developed against the scheme on the pretext that it Entails negative effects on the inhabitants of the Canal zone. However an agreement pertaining to the Jonglei scheme was signed between Egypt and Sudan in 1974. Three months later after the signing of the agreement the situation exploded into an uprising in opposition against the construction of the Jonglei Canal.

79. The principal argument of the opposition was that proper feasibility studies have not been undertaken to identify what impact the Canal would have on the inhabitants. There was also the challenge by the opposition group arising from their blief that the construction of the Jonglei would deplete the supply of fish, disturb weather patterns and rainfall, and even lead to an increase in desertification.

80. The issue of the Jonglei was attended by a committee constituted from members of the High Executive Council and the Regional Assembly. The Committee went to the provinces to discuss the problem and inform the people about the benefits of the Canal. It was explained that the inhabitants of the canal zone would receive social services such as schools, medicine and clean drinking water and other development activities including agriculture extension servicing, bridges, and ferries to ease the movement of people and cattle. The envisaged large-scale engineering scheme had by the instance of the event blossomed into an ambitious programme of social and economic development.

81. The National Council for the Development of the Jonglei Area was subsequently charged with "formulating socio-economic development plans for the Jonglei area and the promotion of studies of the effects of the construction of the canal on the lives and livelihood of the local inhabitants. The Council was responsible for implementing development projects, the procurement of funds, and the establishment of programmes of agriculture, industry, and public works. The Council itself was an omnibus body with a broad representation of politicians and civil servants which met regularly --- the actual work being delegated to the Jonglei Executive Organ (JEO). This action by the Government diverted and diminished the outcry against the canal, but the appointment of the Council (PJTC) and JEO implanted a strong rivalry that impeded smooth progress of the Canal construction. This was a crucial problem because the plans generated for the socio-economic development of the Canal Zone by JEO were not always compatible with the designs of the PJTG. Thus agency rivarly continued to persist.

82. While construction work on Jonglei was in good progress, there arose in September 1983, a strong opposition

to the Canal by some groups. Those who live along the canal expressed feelings of dismay as regards the progress of development activities in the region as a whole. Failures such as the Penyton mechanical farming scheme and the Konggor Integrated Rural Development Projects were marked as some of the projects that did not succeed. The complexity of the problem was getting serious against the Jonglei scheme particularly when the Compagnie de Constructions Internationales had completed nearly 250 kilometers of the canal at which sight creeping flow occured in 1983 to obstruct the water flow and create flooding. People saw this adverse effect and were further discontended against the continuing construction of canal.

83. It would be pertinent at this juncture to make reference to a dissertation entitled "Identifying, Selecting, and Implementing Rural Development Strategies for the Socio-economic Development in the Jonglei Project Area, Southern Region, Sudan 1981". In this theses, the author stressed on the issue argued that intensive development projects in the Northern Sudan will exhaust existing water supplies for irrigation by 1984 so that future developments must be supported by rainfed agriculture for the most suitable region of the Nilotic plains of the Southern Sudan. In effect this comment was extended to show that the construction of Jonglei will interfere with the traditional way of life of the local people. The paper, while admitting that the project will open opportunities for regional development and national integration far beyond localized schemes of Integrated Rural Development, it dismisses this positive aspect as being of marginal benefit. One can in a nutshell assess that the essence of the dissertation directs a criticism against the strategies for development in the context of the Jonglei project.

84. Finally Jonglei Canal project was being attacked. In November 16, 1983, nine expatriate employees were kidnapped. These were released with warnings to stop the construction of the Canal. However, construction resumed in January 1984. Again the Compagnie de Constructions Internationales was threatened to cease the construction and when this was not heeded to, the base camp at Sobat was attacked again on February 10, 1984 as it was being dismanttled to move to Bor in order to complete the construction work.

H. Legal

85. Not withstanding historical issues which have arisen over the use of shared water resources, the joint development of the Nile basin, for the equitable benefit of all riparian countries is now one of the major river basin development problems which has to receive serious attention than heretofore.

86. On the use and sharing of Nile waters, so far the existing agreements have been between Egypt and Sudan. The first agreement of Sudan with Egypt was in 1929[a] allocating 4 billion m^3 per year and the second in 1959[b] allocating 18.5 billion m^3 as measured at Aswan or 20 billion m^3 as measured at Sennar.

87. The 1959 agreement stipulates, among other things the following:

(i) The total share from the net yield of the Nile after the full operation of the Sudd el Aulia Reservoir shall be 18.5 billion m^3 for the Republic of the Sudan and 55.5 billion m^3 for the United Arab Republic of Egypt as measured at Aswan. The net yield was arrived at by agreeing on an established right of 48 billion m^3 for Egypt and 4 billion m^3 for the Sudan and after allowing for evaporation losses of 10 billion m^3 in the High Aswan Dam Reservoir for an average flow of 84 billion m^3.

(ii) Joint undertaking by the two countries will be carried out to construct conservation projects for the

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[a] This is an exchange of notes, between the Egyptian prime minister, Mohammed Mahmoud Pasha, and the British high commissioner, Lord Lloyd on behalf of Sudan that took place on 7 May 1929, which became known as the 1929 Nile Waters Agreement. The most important clause states that Egypt recognized Sudan's right to water adequate for its own development; so long as Egypt's "natural and historic rights are protected". The rights referred to were accompanied by the 1920 Nile Project Commission Report in which Egypt was guaranteed sufficient water to irrigate 5000 feddans (1 feddan = 1.038 acres). On basis of this, quantitative estimates are derived giving Egypt's acquired rights of 48 billion m^3 and Sudan's rights of 4 billion m^3. Another clause in the agreement prohibits the construction of irrigation and power works from being carried out on the Nile in the Sudan and the countries under British Administration except in agreement with Egypt. (Baston 1959, P.529; Okidi 1979, p.113; A.M. Ibrahim 1978)

[b] The most important message in the 1959 agreement focuses on the full utilization of the Nile Water based on cooperation between Egypt and Sudan. It stipulates the apportionment of the two countries including their acquired rights to be 18.5 billion m^3 for Sudan and 55.5 billion m^3 for Egypt. (Natural Resources/Water Series No. 13, ST/ESA/141, United Nations, New York 1984)

increase of the Nile yield from the water lost in the sub-basins of Bahr-el-Jebel, Bahr-el-Ghazal and the Sobat River. The benefits to be derived and the cost will be shared equally.

(iii) The establishment of a Permanent Joint Technical Commission for Nile Waters to be assigned with a task of drawing the outlines of conservation projects and its supervision, the drawing up of working arrangements for these projects and the undertaking of hydrological surveys and studies of the Nile.

(iv) As the riparian countries, other than the two Republics, claim a share in the Nile waters, the two Republics have agreed that they jointly consider and reach one unified view regarding the said claims. If the said consideration results in the acceptance allotting an amount of the Nile Waters to one or the other of the said States; the accepted amount shall be deducted from the shares of the two Republics in equal parts, as calculated at Aswan.

(v) The payment by Egypt to the Sudan of 15 million Egyptian Pounds represents full compensation for the damage resulting to the Sudanese existing properties as a result of the storage in the Sudd-el Aulia Reservoir.

I. Institutional Arrangements and Future Development Plans

88. The Permanent Joint Technical Commission for Nile waters was established following the conclusions of the Nile Water Agreement between Egypt and Sudan, to undertake the following responsibilities:

- Fostering cooperation between the Sudan and Egypt for the Nile control

- Undertaking studies to increase the river yield to meet future needs.

89. Since its establishment, the Commission has embarked upon a major programme of studies in the upper reaches of the river for reducing the loss of large quantities of water and thereby increasing its yield. The ill-fated Jonglei Canal that was under implementation but not seen its completion was the first in a series of projects which aimed to increase the Nile yield. Subsequent programmes were to concentrate on Sobat and Machar marshes, Bahr-el-Ghazal basin and the Equatorial Lakes. The Commission was supposed to have responsibilities for the operation and maintenance of the Jonglei Canal had it been competed.

90. A national Council for the Development of the Jonglei Canal Area was also established following the decision by the Sudan Government to proceed with the construction phase. The Council was headed by the Vice-President of the Republic with members from concerned central and regional ministries, competent individuals and local people's representatives. It was charged with responsibilities to undertake studies and prepare programmes for the development of the area; to promote social and economic progress and to mitigate adverse effects of the canal. A body known as the Jonglei Executive Organ was established to assist the council in carrying out its duties and responsibilities.

J. Present State of the Jonglei Canal 2/

91. In order to start the construction of the Jonglei Canal, the Permanent Joint Technical Committee put out tenders for bid. On December 28, 1976, a contract was signed between the Egyptian and Sudanese Ministers of Irrigation and the Compagnie de Construction Internationales (CCI), a subsdidiary of the large French Conglomerate Grands Travaux de Marseille International (GTM). The PJTC was to act as the principal consultant and employer.

92. The "Bucketwheel" giant machine in Pakistan which had to be dismantled to pieces and shipped to the Sobat base took two and half years to bring it to the first camp site in Jonglei. The assembly was completed in June 1978 when the"Bucketwheel" sputtered to life and the excavation of the Jonglei Canal commenced.

93. The "Bucket Wheel" is described as awesome - five stories high, weighing 2,300 tons and propelled on eight caterpillar treads. The machine was fully automated to keep wheel, to which are attached twelve buckets each with a capacity of 3 cubic meters simultaneously revolving and rotating 180 degrees, precisely on grade in a plain where

the slope is only 5 centimeters per kilometer which precision was accomplished by means of a laser automatically adjusted within the fixed limits. The buckets deposit the excavated soil onto a conveyer belt which straddles the canal to dump the material on the east bank, constructing an elevated all-weather road. At first the impenetrable viscous mud did not permit fast progress. During the first eighteen months the "Bucketwheel" had completed only 30 kilometers. Later on with modifications, to meet conditions in the Sudd, problems had been largely resolved by 1980, and the move ahead increased to 300 meters a day. One of the stumbling blocks during construction was logistics particularly of immense volumes of fuel consumed in tonnes by the voracious machines that worked 24 hours a day. Construction was suffering at the completion of 250 kilometers. Here the Nilotes were able to perceive the adverse effects of a big ditch without the benefits of the flowing canal. Hundreds of tiang also entered the ditch, became disoriented and persihed. There was in addition the hydrological problem of creeping flow which was not fully understood. It originated in the mountainous region along the Sudan - Uganda frontier; and in the rains, the water flowed down in spates to be absorbed into the shallow surface soils lying on top of the impermeable clays. From there it was "creeping", for months in a northwesterly direction to make its way eventually into the Sudd. In 1983, the creeping flow reached the canal which acting as a dam created flooding to the east. This situation gave rise to hostility toward the canal while it was still under construction.

94. The project was attacked twice first on November 16, 1983, and then on February 10, 1984. Thus the Compagnie de Constructions Internationales announced the termination of all work in the canal soon after the second attack, and so the "Bucketwheel" rests silently and rusting at kilometer 267.

V. CONCLUSIONS AND OBSERVATIONS

95. The Jonglei Canal is the first project to be implemented in the programme of water conservation for increasing the yield of the Nile by reducing the large amount of evaporation loses in the Sudd Region. The project if completed would have provided a wealth of practical information in the field of water development and water transfer. In association with the canal a series of studies have been conducted by the Executive Organ of the National Council for the Development of the Jonglei Canal Area. These studies include soil, land suitability survey, range-ecology, livestock development and water supply, swamp ecology and the ecosystem of the Sudd. The findings of these studies have usefully contributed to make necessary alterations to mitigate negative impacts and provided a valuable base in guiding the future water development programmes. The project and the studies associated with it had opened vast opportunities for international collaboration by the UNDP, specialized agencies and other bilateral funding and technical assistance organizations. It stimulated research activities within the universities and other research institutions on problems associated with water development. The Jonglei had been recognized as the most studied project in the Third World.

96. Had the project seen its completion, the monitoring and evaluation activities incorporated for the assessment of economic, social and environmental impacts would have been useful to enrich experiences in such undertakings. Primarily such studies would have had their applications so that the national institutions take necessary measures to avert or minimize the impact of certain negative consequences.

97. In summary, it can be said that the Jonglei had distinct economic advantages as well as some shortcomings which is normally the price to be paid for development. There was careful planning and a comprehensive development policy, exercised by Sudan as prerequisite in determining coherent development. In so doing, a good balance was expected to be achieved between long-term interests of the local people and the preservation of a unique piece of nature. While studies carried out would have yielded good dividends, the continued post-development study also would have been equally indispensable to mitigate serious consequences. It is very unfortunate that the work of the Jonglei Canal Project could not be completed.

REFERENCE

1. International River Basins and Regional Development in Africa M69-2350 — G. Dekker

2. Water International, 13 (1988) 144-153 — Robert O. Collins

   The Jonglei Canal: Illusion or Reality — Department of History, University of California, Santa Barbara, USA

3. Nile Basin Integrated Development Fact Finding Mission Report (UNDP) July 1989

4. Aide-Memoire on the Development of the Nile River Basin — ECA/NRD/NBS/1 21 March 1988

5. Sudan Irrigation 1957

6. Development of the Nile River System — A.M. Ibrahim 1978

7. Large Scale Water Transfers — Water Resources Series Vol. 7, 1985

8. Water Resources Development — Volume 3, number 2

9. The Environmental impact of Jonglei Canal Project in the Sudan — A.M. Ibrahim

10. Inland Water Transport in Africa — Y. Wolde Emmanuel/1978

11. The Major Regional Project on rational utilization and conservation of water resources in the rural areas of the Arab states with emphasis on traditional water systems. — UNESCO/ACSAD 1986

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