THE UNIVERSITY OF CHICAGO

THE WATER BUDGET OF THE TIGRIS AND EUPHRATES BASIN

A dissertation submitted to the faculty of the Division of the Social Sciences in candidacy for the degree of Doctor of Philosophy

DEPARTMENT OF GEOGRAPHY

RESEARCH PAPER NO. 54

By

Wafiq Hussain Al-Khashab

CHICAGO · ILLINOIS

DECEMBER, 1958

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CHAPTER I

DELIMITATION OF THE WATER PROBLEM

The country of Iraq, through which the Tigris and Euphrates rivers flow, long has been recognized as being in an area of water deficiency though at the same time enjoying the reputation of an area of high agricultural productivity. The many civilizations and empires which have prospered in the "valley of the two rivers" have owed their success to the productivity of the Tigris and Euphrates basin and its agricultural productivity rather than to wealth acquired from neighboring areas. This productivity was made possible through use of the waters of the Tigris and Euphrates rivers in irrigating agricultural land in the otherwise dry areas.[1]

Iraq now is undergoing vast programs of economic development. These programs are aimed at improving and expanding the economic base of the country through more efficient utilization of the basic resources of the land. One of these basic resources is water, and, as in the past, it will continue to be one of the more important and enduring of the basic resources.

The problem of wise utilization and management of the water resources of Iraq has undergone much study in recent years as well as in the past. Water utilization at present is patterned after a plan adopted by the government in 1955. That plan was formulated by Knappen, Tippetts, Abbett, McCarthy Engineers, and based upon the control, regulation, and storage of the waters of the Tigris and Euphrates rivers as the basis upon which the government expects to maximize the benefits obtained from water resources, to eliminate the danger of flood, and to overcome the conflict between navigation and irrigation over the available water.

In order to control and regulate the water supply, five storage reservoirs are planned in the Tigris Basin (Fig. 1): three on the upper courses of the tributaries of the Tigris, Derbendi Khan on Diyalah, Dokan on the Lesser Zab, Bekhme on the Greater

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[1]Ahmed Sousa, Irrigation in Iraq (Baghdad: New Publishers, 1945), pp. 21-34.

Zab, and the remaining two, Tharthar and Eski Mosul, on the main stem of the river. In the Euphrates Basin the plan calls for constructing three storage reservoirs, one on the main river above Hit, and the remaining two in Lake Habbaniyah and Abu-Dibbis (Fig. 1). Tharthar on the Tigris and Lake Habbaniyah and Abu-Dibbis on the Euphrates will be used, primarily, to reduce the danger of flood in the Tigris and Euphrates basins. The chief areas of flood damage hazard are in the lower reaches of the Tigris and Euphrates basin; primarily in the irrigated areas in the Mesopotamian trough. The rest of the reservoirs are designed, mainly, to store water which will be used for irrigation, navigation, and possible generation of hydroelectric power.

The government plan concerning water utilization calls for the expansion of the irrigated areas from the present 4.7 million acres to about 8 million acres. The area suggested for expansion is located in southern Iraq, where all the presently irrigated land is located, and where more than half of Iraq's population dwells. The pattern of cultivation on the expanded areas is planned to be more intensive than the pattern prevailing in the presently irrigated areas. The plan also calls for the construction of drainage systems simultaneously with the installation of the irrigation systems in the proposed expansion areas. Similarly, major new drainage facilities will be provided for the presently irrigated areas. A system for operating the storage reservoirs has been adopted to maintain the required depth of water for year-round navigation in the lower part of the Tigris River. The generation of hydroelectric power from these reservoirs is only in the realm of possibility at the present time. Definite plans concerning the extent and magnitude of power generation have not yet been formulated.

By carrying out the adopted plan of water utilization, the government expects a direct improvement of the present level of living among the farming communities in the irrigated areas. This improvement will be shown in the provision of land for landless farmers, the increase of gross agricultural production which in turn will increase the farmer's income and, finally, the elimination of frequent conflict between navigation and irrigation over the use of water in the lower part of the Tigris.

The present plan is not based upon a detailed assessment of existing conditions of water supply and use in Iraq. Such an assessment would seem desirable in order to delineate more clearly the present and possible future problems which may affect expanded water use, and to suggest alternatives, other than expansion, for

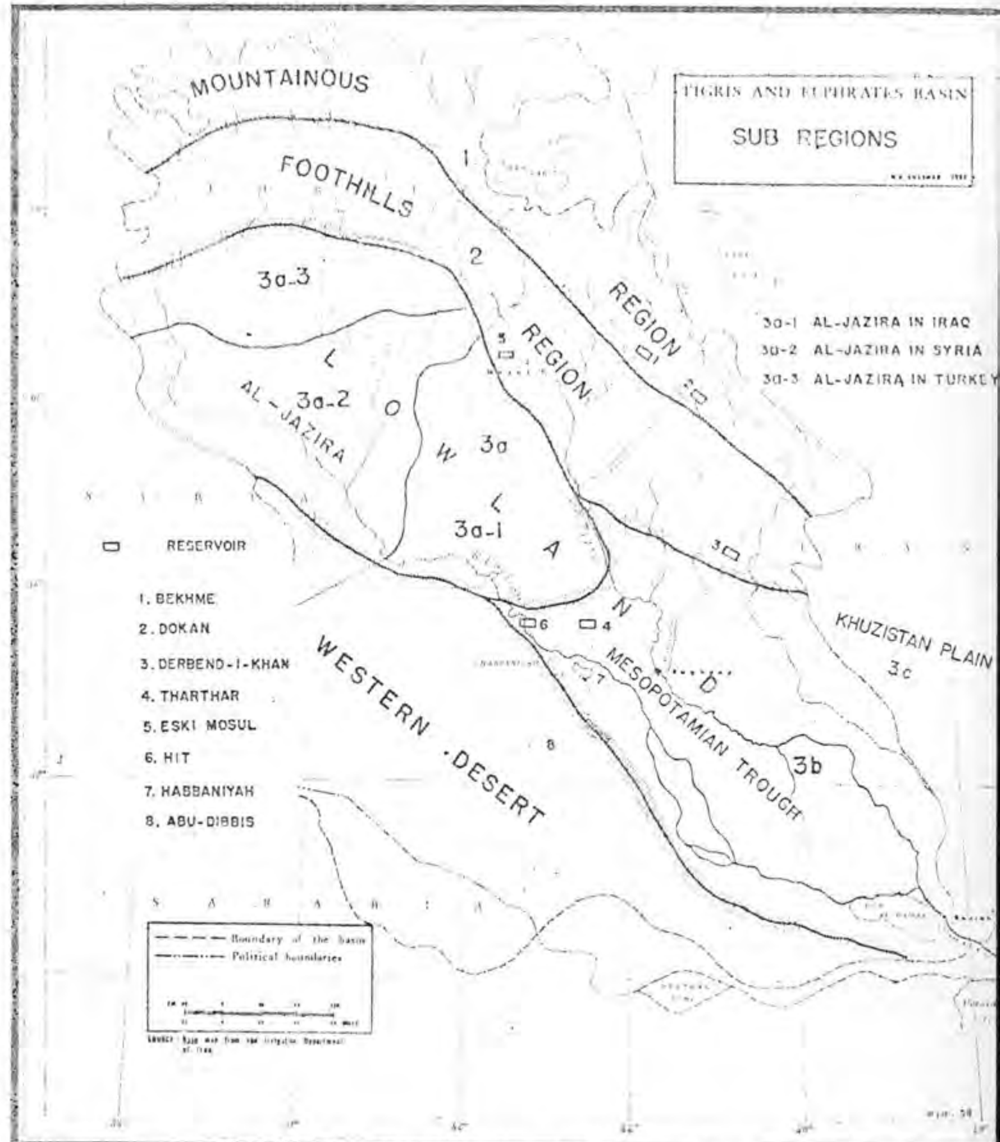

Fig. I

maximizing the benefits from water resources utilization.

An understanding of Iraq's present water supply and its utilization is in the interest of sound and fruitful planning. This seems so fundamental that it has prompted the author to make it the subject of the current study.

Characteristics of the Study Area

To assess thoroughly the water supply of the Tigris and Euphrates in Iraq, it will prove fruitful to examine first those elements in the physical setting insofar as they relate to the source and areal distribution of the water resources and then to examine the manner in which the water is used by man.

Because of Iraq's place in the drainage area of the Tigris and Euphrates rivers and the partitioning of the Tigris and Euphrates basin by several nations, a thorough examination of the water problem must include the entire basin as the study area, both in terms of water supply and of water use.

Physiography of the Tigris and Euphrates Basin

The basin of the Tigris and Euphrates rivers is roughly oblong in shape, with the longer axis running northwest and southeast. The drainage area of the basin amounts to about 784,500 Km.[2] located in five countries: Iraq, Turkey, Syria, Iran, and Saudi Arabia--as shown in Table 1.

The basin is rimmed by mountains on three sides. The Anti-Lebanon mountain range of Lebanon and Syria and the Taurus mountains of Turkey bound the basin on the west. The Pontain mountain chain and the Ararat highlands bound the basin on the north. On the east, the watershed runs along the Zagros and Lourish mountains of Iran.

The elevation of the basin decreases gradually from north to south. Four topographic regions, based on elevation and land form, can be recognized.[1] The four topographic regions are shown in Figure 1 and are: (1) the high and rugged mountains in the [illegible] and northeastern parts of the basin, (2) the foothills region which forms a transition between the mountain regions to the north and the lowlands to the south, (3) the lowlands, and (4) the western [illegible].

[1]Knappen, Tippetts, Abbett, McCarthy Engineers, Development Plan for the Tigris and Euphrates Rivers, Iraq (Baghdad: Development Board, 1955), pp. 11-17.

TABLE 1

THE DISTRIBUTION OF THE AREA OF THE TIGRIS AND EUPHRATES BASIN AMONG THE SHARING COUNTRIES[a]

Country	Area in Km.[2]	Per Cent of Basin
Iraq	359,000	46.0
Turkey	162,000	20.5
Iran	146,000	19.0
Syria	70,000	9.0
Saudi Arabia ..	45,000	5.5
Total	784,000	100.0

[a]Knappen, Tippetts, Abbett, McCarthy Engineers, The Development of the Tigris and Euphrates River System, Iraq (Baghdad: Development Board, 1955), chap. II, p. 1.

The mountains occupy the northern and eastern parts of the basin. This is an area of rugged folded and volcanic mountains with limited land suitable for cultivation. Elevations in this area vary from 1,500 meters to 3,500 meters above sea level. The general ridge line of the mountains is from northwest to southeast. This area constitutes the rainiest and coldest part of the basin, with precipitation exceeding 1,000 mm. annually and temperatures frequently falling below freezing.[1] The greater proportion of the area is located in Turkey and Iran.[2] A smaller part is in Iraq, where it is called "Kurdistan."

The foothills form a folded tectonic zone of transition between the high mountains bordering the basin and the flat lowlands within. The foothills appear in a broad zone south of the mountains. In Iraq the foothills are confined between the eastern banks of the Tigris River on the west and the Zagros mountains on the east. The northern continuation of this region in Turkey comprises the central drainage area of the Tigris and Euphrates rivers, while the southward continuation in Iran forms the central drainage area of the Tigris tributaries. Elevations in this region vary from

[1]Ali H. Al-Shalash, "The Climate of Iraq" (Unpublished A.M. thesis, Department of Geography, University of Maryland, 1957), p. 13.

[2]Sirri Enric, "The Climate of Turkey According to Thornthwaite's Classification," Annals of the Association of American Geographers, XXXIX, No. 1 (March, 1949), 33.

600 meters to 1,500 meters above sea level. The land rises in steps towards the east and northeast. Each step is marked by ridges. Jabel Hamrin and Jabel Makhul in Iraq represent such ridges. The rainfall in the foothills varies from 300 mm. in the lower limits to about 800 mm. in the upper parts. Most of the region is located in Turkey and Iraq, but a small part is located in Iran.

To the south of the foothills lies a broad, extensive lowland, decreasing in elevation in a southward direction and reaching its lowest elevation at the head of the Persian Gulf in southern Iraq. Elevations on the lowlands vary from 600 meters in the north to sea level in the south. Much of the southern part of the lowlands is only a few meters above sea level.

Two sub-regions, based on elevation, can be recognized in the lowlands--"Al-Jazira" in the north and the "Mesopotamian trough" in the south.[1] The Al-Jazira is an undulating lowland located mainly between the Tigris and Euphrates in Iraq. The western extension of the area comprises the Syrian part of the basin (Fig. 1, 3a-2) while the northwestern extension is within Turkey (Fig. 1, 3a-3). The Syrian part of Al-Jazira is the only cultivated part of this sub-region.[2]

The southern limit of Al-Jazira is approximately a line extending from Hit on the Euphrates to Belled on the Tigris.[3] To the south of this line the Mesopotamian trough extends as a uniformly flat plain comprising most of southern Iraq (Fig. 1, 3b), and continues to southwestern Iran, forming the "Khuzistan plain." The latter is an alluvial plain of about 30,000 square kilometers located completely in Iran (Fig. 1, 3c). All the presently irrigated lands of Iraq are located in the Mesopotamian trough. Extensive patches of swamps exist in the area. The greater part of the swamps is permanent while the rest is seasonal, occurring during irrigation and flood periods. The swampy areas in the country comprise about 30,000 square kilometers, or slightly over 5 per cent of the total area of Iraq.[4] The extreme flatness of the land and the inefficient

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[1] Hans H. Boesch, "El-Iraq," Economic Geography, XV, No. 4 (October, 1939), 341.

[2] International Bank for Reconstruction and Development, The Economic Development of Syria (Baltimore: The Johns Hopkins Press, 1955), p. 42.

[3] Hans H. Boesch, loc. cit., p. 341. [4] Ibid., p. 345.

irrigation practices make drainage a critical problem in the irrigated areas of this part of Iraq.

All of the Mesopotamian trough is located in Iraq. The greater part of the Al-Jazira is also located in Iraq. A small part of the Al-Jazira is located in Syria and Turkey, but none is located in Iran. Generally speaking, the lowlands are mainly located in Iraq and Syria.

The western desert region represents the vast area situated to the west of the Euphrates in Syria, Iraq, and Saudi Arabia. The largest proportion of the desert is located in Iraq. It comprises about 60 per cent of the total area of the country.[1] The desert rises gently from east and south towards the west and northwest. The region is greatly dissected by numerous wadis descending from the high plateau towards the Tigris-Euphrates trough. Most of these wadis are 100 to 150 feet deep.

Drainage

The headwaters of the Tigris and Euphrates rivers are located in the mountain region of Turkey. Flowing from the headwater area, the two rivers traverse the foothills region in Turkey. The Euphrates enters Iraq after crossing the Al-Jazira area in Syria for 600 km., while the Tigris enters Iraq directly after leaving Turkey.

There are no important tributaries of the Euphrates in either Syria or Iraq. The Tigris has four major tributaries, all of which join the main stem of the river in Iraq. All the tributaries of the Tigris have their headwaters in the eastern mountains of the basin. The Greater Zab, the largest tributary (see Table 2), has its headwaters in Turkey, while the Lesser Zab and the Diyalah have theirs in Iran. The Ahdaim, the smallest of the tributary rivers, has its headwaters entirely in Iraq.

Erosion in the headwater areas constitute the major source of sediment in the Tigris and Euphrates. This is caused mainly by rainfall on the bare mountains and foothills of the basin in Turkey, Iraq, and Iran. The presence of large quantities of silt in the water is a continual menace to the irrigation canals in southern Iraq. The steep gradient of the rivers (1 meter per 3 kilometers) discourages the deposition of sediment, leaving stream beds rather

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[1] Gordon Hasted, The Physical Background of Iraq, translated in Arabic by J. M. Khalaf (Baghdad: Arabian Press, 1948), p. 6.

stable. River valleys are deep, which makes it necessary to use pumps for lifting the water for the adjoining higher areas.

TABLE 2

MAJOR RIVERS AND TRIBUTARIES OF THE TIGRIS AND EUPHRATES BASIN

River	Drainage Area in Sq. Km.	Length of River in Km.
Euphrates	109,500	2,737
Tigris	166,155	1,851
Mainstem	68,280	160
Greater Zab	26,473	392
Lesser Zab	22,250	400
Ahdaim	10,983	230
Diyalah	31,896	386
Total	275,655	

[a]El Kholy, The Hydrology of River Tigris, prepared for the Iraq Government, Directorate General of Irrigation (Baghdad: Al Rabbitta Press, 1952), p. 173.

The two major rivers flow in a southeasterly direction in Iraq. As they enter the lowlands, especially the Mesopotamian trough, their gradient becomes more gradual (about 1 meter per 20 kilometers in the Euphrates, and per 40 kilometers in the Tigris). Deposition of sediment occurs in this part of the basin. Because there is no great difference in elevation between river beds and the surrounding irrigated areas, gravity canals are used to divert the waters for irrigation.

The Tigris and Euphrates rivers join together in southern Iraq to form a single river, Shatt-al-Arab (the river of the Arabs), which discharges into the Persian Gulf. The Karon River is a tributary of Shatt-al-Arab, but it is located outside the political boundary of Iraq. (In the area of junction Shatt-al-Arab is the political boundary, so that the Karon River never actually enters

Climate

Three climatic types can be recognized in the Tigris and Euphrates basin: humid, steppe (semi-arid), and desert. These climatic types coincide, roughly, with the topographic regions of the

basin (Fig. 1). The humid climate is confined to the mountain region of the basin (Fig. 1, 1). It is characterized by high precipitation (between 1,500 and 800 mm. annually), and low temperatures (below freezing during the winter). Steppe climate prevails in the foothills (Fig. 1, 2) with precipitation ranging between 800 and 300 mm. annually, while desert climate predominates in the lowlands (Fig. 1, 3) and is characterized by precipitation of less than 300 mm. annually.

Both temperature and precipitation are strongly influenced by the surface configurations of the basin. Because the elevation of the basin increases from the south to the north, the mean annual temperature decreases in the same direction. The mean annual temperature at Basrah, which is located at the lower part of the Mesopotamian trough, is 75° F. At Baghdad, in the upper limits of the Mesopotamian trough, it is 72.7° F. In the northern part of the lowlands, Al-Jazira, the mean annual temperature is lower than the Mesopotamian trough. At Mosul, in the Iraqian section of Al-Jazira, the mean annual temperature amounts to about 66.9° F. In Deir Ez-Zore, the Syrian section of Al-Jazira, it is about 69° F, while in Urfa, the Turkish section of Al-Jazira, it is about 62.3° F. In the foothills region, in Diyarbaker in the Turkish part of the basin, the mean annual temperature is 60.8° F and is, generally, lower than that in the mountain regions.

The temperature in the basin reveals a great degree of continentality, as evidenced by large annual and diurnal ranges. The degree of continentality is greatest in the central part of the basin, and decreases toward the north and the south. The southern parts of the basin show less continentality as a result of the influence of the Persian Gulf. This is evident from comparison of the mean annual ranges of Basrah and Baghdad (38.9° F and 60.2° F, respectively). Similarly, the northern parts of the basin show less continentality as a result of higher elevation. This is shown by a comparison of the average annual range at Mosul (49.1° F) with that of Baghdad (60.2° F).

Rainfall in the basin is also influenced by the topography. The mountain region in the north is an area of high rainfall, while the lowlands are characterized by low amounts of rainfall. The rainfall increases from the south and southwest towards the north and northeast. The lowest amount of rainfall occurs in the Mesopotamian trough, ranging from 108 mm. at Sulman, in its lower limits, to about 134 mm. at Baghdad, in the upper limits of the trough. In the Al-Jazira, rainfall increases steadily. In Hassetdie, in the

Syrian section of Al-Jazira, it is 264 mm.; in Mosul, in the Iraqian section of Al-Jazira (Fig. 1, 3a-1), it is 376 mm. In the foothills, in Diyarbakor in Turkey, precipitation reaches 489 mm., while in Bingol it is 820 mm. In the mountain region it exceeds this amount, reaching about 1,500 mm. in the highest parts.

The winter season (December, January, and February) is the wettest part of the year. Most parts of the basin receive from one-half to over three-quarters of their total annual rainfall during this period. Sulman and Kut, in the southern lowlands, receive as much as 71 per cent and 67 per cent, respectively, of their annual rainfall during this period. This percentage decreases toward the northern parts of the basin due to the fact that a considerable amount of the rainfall comes during the spring period. Mosul, in the northern limits of the lowlands, receives 52 per cent of its annual rainfall during the winter. Amadia, in the mountain region, receives only 44 per cent, while Rawanduz (in the mountain region of northern Iraq) receives only 33.5 per cent.

During the Spring season (March, April, and May) rainfall is considerably less. However, here, too, rainfall increases from the south to the north. In Sulman, Iraq, it constitutes 16 per cent of the annual rainfall, in Mosul 30 per cent, and in Amadia 36 per cent.

Summer is an extremely dry season throughout the basin. From June to September there is generally no rain. During the Autumn, rainfall received throughout the basin is less than that of Spring and much less than that of Winter. Sulman receives only 3 per cent of its annual rainfall during the Autumn, Mosul 18 per cent, and Amadia 20 per cent. Because precipitation is the initial source of water in the basin, both Summer and Autumn are periods of low water supply.

Cloudiness is an important phenomenon which is associated with rainfall and temperature. The higher parts of the basin have the highest amounts of cloudiness, the highest amounts of rainfall, and the lowest temperatures. Cloudiness, in general, also increases from south to north. In Sulman the mean percentage of sky covered by cloud amounts to 1.6. Toward the north it increases until it reaches 2.1 at Baghdad and 2.7 at Mosul.[1]

[1] Ali H. Al-Shalash, op. cit., pp. 71-72.

Vegetation

The distribution of vegetation is strongly controlled by temperature and rainfall, and there is a close correlation between the climatic and vegetation patterns in the basin. The climatic conditions as well as the vegetation distribution are, in turn, determined to a considerable extent by topography.

The vegetative cover in the basin shows a transition from the colder, wetter, forested areas of the mountains to the rough areas of steppes with moderate temperature and less rainfall, and to the hot, dry, desert areas. Two vegetation regions can be distinguished--the mountains and foothills region, the lowlands and the desert.

In the mountains and foothills region the vegetation types fluctuate with elevation. In the higher parts of the region, above 2,400 m., especially in the western part of the basin and in the Ararat highlands in the east, above 2,700 m., an alpine vegetation prevails. This consists principally of grasses in association with Alpine flowers, mosses and lichens. The shrubs are mainly different kinds of juniper.

Below this Alpine vegetation a thick forest begins. The forests cover areas of elevations up to 800 m. as far south as Diyarbaker and Sirit in Turkey and Dohok, Zakho and Sulmaniyah in Iraq. The larger part of the forest cover has been destroyed by over-grazing and cutting of timber and shrubs for use as fuel, so that only coarse shrubs, principally oak trees, are left while greater portions of the mountains and foothills are bare and subject to erosion. A few patches of forest are encountered in the Turkish parts of the basin around Mt. Bingol and Mus, where the areas are thinly populated and far from cities and villages.

In the lowland the rainfall decreases rapidly and the length of the Summer season increases. The vegetation is of a steppe type, though there are different grasses and palm trees in the irrigated land along the river banks and irrigated canals. In the northern part of the lowlands, Al-Jazira, the vegetation consists principally of different kinds of grasses and bulbous plants and several varieties of thistles and thistle-like plants. In the southern part of the lowlands, the Mesopotamian trough, there is a heavy vegetation of common reeds, sedges, tube grasses, and water lilies. The marsh borders are covered chiefly by mint and Bermuda grass.

Soils

Information concerning types, characteristics, and distribution of soils in the Tigris and Euphrates basin is meager and limited to the lowlands, mainly the Mesopotamian trough. Generally, the soils of the Al-Jazira and foothills of northern Iraq are old residual soils derived from mixed and tufaceous rocks. The silt clay type predominates throughout these areas. In the Mesopotamian trough the soils are recent alluvials derived mainly from mixed lime and sandstone rocks. The silt clay, silt loam, and sand loam types predominate in most of the areas. These soils are characterized by low organic matter and high salinity. Salinity usually increases from north to south throughout the Mesopotamian trough. A general comparison between the soils in Al-Jazira and foothills, in northern Iraq, with the soils in the Mesopotamian trough of southern Iraq, shows that the former have higher organic matter, no salinity, and no major drainage problem, while the latter have low organic matter, high salt content, and a conspicuous drainage problem.

Present Settlement

Occupations.--The major occupations of the people living in the basin are agriculture and animal husbandry. In Iraq nearly 60 per cent of the population derives its income directly from working on the land.[1] Similarly, the main occupation of the settled parts of Al-Jazira in both Syria and Turkey, is agriculture. The rest of the population is engaged in commerce, personal and public services, manufacturing and handicraft, transportation, and government service.

In Iraq, it has been estimated that the persons engaged in these non-agricultural occupations amount to 500,000 in number, of which only 75,000 are engaged in manufacturing and handicrafts.[2] Commerce represents the largest occupational group after agriculture, employing 100,000 persons who live chiefly in small towns throughout the countryside which serve as trade centers and collection points for agricultural produce. The other non-agricultural occupations include government service, transport, and personal services.

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[1]International Bank for Reconstruction and Development, The Economic Development of Iraq (Baltimore: The Johns Hopkins Press, 1952), p. 128.

[2]Ibid., p. 129.

Most of the cultivated areas are concentrated in the lowland parts of the basin and in the foothill region in both Iraq and Turkey. The scantiness of rainfall in the Mesopotamian trough and the Al-Jazira sections makes cultivation in those areas virtually impossible without irrigation. Slightly over 90 per cent of the irrigated areas are located in the Mesopotamian trough in Iraq. The other 10 per cent of the irrigated areas are located in the Al-Jazira in Syria.[1] The remaining parts of Al-Jazira, other than the Syrian section, have no irrigated cultivation at present. In the remaining sections of Al-Jazira and in the foothills of Iraq and Turkey, cultivation is dependent entirely upon rainfall.

From a consideration of the physical setting in relation to the occupations of inhabitants of the basin, two major regions of water utilization can be recognized--a region of nourishment and a region of depletion. The region of nourishment covers the higher parts of the basin, in Turkey and in Iran, where most of the water originates but where little is used. The region of nourishment covers the higher parts of the basin, in Turkey and in Iran, where most of the water originates but where little is used. The region of depletion represents the lowlands of the basin, in Iraq and Syria, where most of the water is used.

Population distribution.--On the basis of a comparison of population distribution with physical and occupational factors the basin may be divided into four population regions. The first coincides roughly with the western desert and includes the greater part of the Al-Jazira region in Syria, Turkey, and Iraq. This region has no sedentary population. It is mostly a home for the Bedouins who move, with their livestock, from place to place.

Of the remaining three regions, to which the sedentary population is confined, the most important is the lower part of the lowland region of the basin, the Mesopotamian trough, which represents the alluvial plain watered by the Tigris below Samarra and by the Euphrates below Hit. The total population of this region is 3,250,000, or 70 per cent of the total sedentary population in Iraq.[2] In this region practically all the irrigated areas of Iraq

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[1]D. Warriner, Land Reform and Development in the Middle East, A Study of Egypt, Syria, and Iraq (London: Oxford University Press, 1957), p. 78.

[2]J. H. G. Lebon, "Population Distribution and the Agricultural Regions of Iraq," Geographical Review, XLIII, No. 2 (April, 1953), 223-28.

and 70 per cent of the annual cultivated areas, are located.[1] This is chiefly a rural area, though there is a concentration of towns in the west and northwest of the region which serve as centers of commodity exchange for the agricultural areas.

The two remaining regions are the foothills and the mountains, where rainfall is sufficient for non-irrigated cultivation and where Winter-sown barley and wheat are accordingly the basis of husbandry. Rainfall cultivation is practiced on approximately 2.3 million acres located mainly in the foothill region of Iraq. Sheep, cattle, horses and mules are grazed on stubble, fallow, rough pasture, and scrub.

In the foothills region piedmont plains are usually well dotted with small villages. The highest density occurs in Iraq, in the southern limits of the foothills, where the three largest urban settlements, Mosul, Kirkuk, and Erbil are located.[2] The Turkish part of this region is sparsely settled.[3]

In the mountain region the population is scattered. However in many broad, longitudinal valleys and intermontane basins the Kurdish inhabitants are numerous. Towns are small and infrequent, tending to be located in the larger valleys at sites commanding routes across the valley. Sulmaniyah (33,000 people) and Halabja (less than 20,000) are the largest cities in Iraq in this region.[4]

The Nature of the Problem

The Importance of Water to Iraq and Other Countries in the Basin

Iraq, with an area of 168,000 square miles and a population of about 5,000,000, occupies the southern part of the Tigris and Euphrates basin. About 20 per cent of the total area of Iraq is located in the mountain and foothill regions of the basin. The remaining 80 per cent is in the lowlands.[5]

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[1] International Bank for Reconstruction and Development, The Economic Development of Iraq, p. 137.

[2] J. H. G. Lebon, loc. cit., p. 227.

[3] International Bank for Reconstruction and Development, The Economy of Turkey (Baltimore: The Johns Hopkins Press, 1951), p. 16.

[4] J. H. G. Lebon, loc. cit., p. 228.

[5] Jassim M. Khalaf, The Water Resources of the Lower Colo-

The basic occupation of the people is agriculture, upon which about 60 per cent of the population depend for their livelihood, though only a relatively narrow belt of the mountains and foothills in northern Iraq have sufficient rainfall to sustain agriculture without irrigation, the two rivers and their tributaries provide water for irrigation of the lowlands of the Mesopotamian trough. The total cultivated area in Iraq at present amounts to 7 million acres. About 30 per cent of the total cultivated area depends solely upon rainfall, the rest depending entirely upon irrigation.[1]

The economic and social level of the people of Iraq has risen and fallen with the advance and decline of agriculture. With the fall of the great Abbasaid Dynasty to Hulagu Khan in 1258 and the deliberate destruction by Timur, in the fifteenth century, of the irrigation systems upon which her prosperity depended, Iraq was plunged from an economy of abundance to one of bare subsistence.[2]

With the establishment of the new state in 1932, Iraq initiated programs for restoration and expansion of the irrigation systems to increase production and raise the level of living of the people. One of the basic difficulties which faced the new government was the limited capital available to finance the needed development program. As a result, the rate of development was slow and the economic condition of the country remained poor. Even at the present time the per capita yearly income is I.D. 30 (equivalent to $84.00).[3]

The recent increase of oil production in Iraq has offered new opportunities for economic development. At the end of World War II, the yearly production was under 5 million tons. By 1955, only ten years later, the yearly production was raised to 30 million tons. The revenues accruing to Iraq under the existing profit-sharing agreement (on the basis of 30 million tons yearly production)

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rado River Basin (Ph.D. dissertation, Department of Geography, The University of Chicago [Chicago: Private Edition, 1951]), p. 193.

[1] International Bank for Reconstruction and Development, The Economic Development of Iraq, p. 137.

[2] Ahmed Sousa, op. cit., pp. 33-34.

[3] International Bank for Reconstruction and Development, The Economic Development of Iraq, p. 131.

amount to I.D. 70 million a year or the equivalent of $196 million a year.[1]

The government of Iraq realizes that oil is an exhaustible resource whereas land and water are renewable resources. The exhaustion of the oil resources may be remote, but with substantial and increasing production, it is inevitable. It was with this consideration in mind, and the urgent desire to raise the level of living of the people of Iraq, that the government established the Development Board in 1950. In 1955 a Ministry was created to supervise the board, and provided with funds that equal 70 per cent of the oil revenues.[2]

The Development Board sponsored a survey in 1951 to seek a plan for the economic development of Iraq. The survey was carried out by the International Bank for Reconstruction and Development. From information made available by the survey a plan which offered several programs for consideration was formed and submitted to the Development Board. These programs dealt mainly with agriculture, industry, transportation, and education. The report indicated that any development program for Iraq must, obviously, put a primary emphasis on agriculture because both industry and commerce depend in turn upon farming and animal husbandry.[3] The Development Board accepted the plan and asked, in 1952, Knappen, Tippetts, Abbett, and McCarthy, a consulting engineer firm in New York, to make a report on the use of the available waters of the Tigris and Euphrates rivers and their tributaries for irrigation and navigation, and to formulate long-range plans for the most efficient utilization of these waters.[4]

Meanwhile the Development Board initiated the development program in several of the aspects suggested in 1951. Between 1951 and 1955, irrigation and land reclamation constituted a large proportion of the expenditures of the Development Board, as shown in Table 3.

In 1954, the Development Board asked Lord J. A. Salter to review the various projects adopted for the development of Iraq.

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[1]J. A. Salter, Development of Iraq: A Plan for Action (Baghdad: The Development Board, 1955), p. 13.

[2]Knappen, Tippetts, Abbett, McCarthy Engineers, op. cit., p. 1.

[3]International Bank for Reconstruction and Development, The Economic Development of Iraq, p. 4.

[4]Knappen, Tippetts, Abbett, McCarthy Engineers, op. cit., pp. 1-2.

TABLE 3

EXPENDITURES OF THE DEVELOPMENT BOARD, BETWEEN 1951-1955[a]

	1951-52	1952-53	1953-54	1954-55
Administration	99,637	213,875	260,712	650,000
Irrigation	841,441	2,560,643	4,781,402	6,864,367
Communications	626,887	1,751,635	1,913,991	4,928,778
Buildings	788,164	2,265,229	2,445,684	4,256,912
Land reclamation ..	772,023	1,535,246	2,319,377	2,637,170
Industry	....	81,429	465,965	994,469
Total	3,128,152	8,308,052	12,187,081	20,331,696

[a]J. A. Salter, The Development of Iraq: A Plan of Action (Baghdad: The Development Board, 1955), p. 20.

The review showed, as had been suggested in 1951, that the greater part of the development of Iraq should be in the form of increased agricultural production.[1]

General development in Iraq, then, is directed to a considerable extent toward agricultural expansion. If most of the cultivated areas at the present time depend upon irrigation, it is obvious that agricultural development will be affected largely by the amount of water available in the country. Agricultural development must be associated with water development programs in order to provide agriculture with the maximum possible benefits from the water,

However, a great proportion of the water of the Tigris and Euphrates rivers originates in other countries, and the amount available for development in Iraq depends upon the present and future intensity of water use in the upstream areas. The existing and potential water uses in Turkey, Iran, and Syria show that the water supply of the Tigris and Euphrates rivers is important to these countries as well as to Iraq. Syria, at the present time, depends upon the Euphrates River to irrigate more than half of her irrigated land. The importance of this river is increasing, due to the current and future expansion of irrigation in the country. Turkey is considering plans for hydroelectric power, for which the water of the Tigris and Euphrates is essential. Similarly, possible future irrigation expansion in Khuzistan, Iran, will have to depend upon the waters of the Diyalah and Lesser Zab rivers. Thus, other

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[1]J. A. Salter, op. cit., p. 120.

countries in the basin besides Iraq may become significant users of the rivers.

The Scope and Method of the Study

Water development if it is to maximize benefits from water use should be directed in such a way as to eliminate water losses and maintain a high degree of efficiency. This presupposes an acquaintance with the present conditions of water utilization. Previous studies of water resources of Iraq concerned themselves mainly with how the resources should be utilized within the country, but none of them surveyed the water balance for the entire basin.

The author proposes in the present study to survey the quantity and distribution of present water supply and the quantity of present water uses in the Tigris and Euphrates basin in order to assess a budget showing the amount of water supply and the types and extent of present uses. It is hoped that such information will help those people concerned with the development to direct their efforts toward improving the present conditions by maintaining a more efficient utilization.

The study does not attempt an appraisal of all the conditions which would enter into the design of an integrated development of the Tigris-Euphrates basin for multiple purposes. It omits a review of flood control needs, of power potentials and markets, of the silt problem, and of the very serious questions of soil salinization. Thus, it takes the water balance as a point of departure and asks what implications the water balance findings may have for the larger issue of wise water policy for Iraq.

The headwaters of Iraq's major rivers, the Tigris and Euphrates, are located in other countries. Many of the tributaries also have their sources beyond the Iraqi border. An evaluation of Iraq's water resources must, therefore, include an estimation of the amount of water imported by these rivers and tributaries into Iraq, as well as the amount of water which originates in Iraq.

[illegible] difficulty of such an estimation is the lack of river [illegible]ing stations outside of Iraq, so that the river flows upstream [illegible] and are not gauged. For an estimation of the water resources which would include the entire drainage basin, the Water Balance Method of Thornthwaite and Mather, 1955, can be used.[1] This is

[1]C. W. Thornthwaite and J. R. Mather, The Water Balance ("Publications in Climatology," Vol. VIII, No. 1; Centerton, New Jersey: Laboratory of Climatology, 1955).

a method by which the runoff of the entire Tigris and Euphrates basin can be determined climatologically, as based on precipitation and temperature data. Other methods for estimating water loss through evaporation and transpiration--Blaney-Criddle method--and water runoff--Ionides method--exist. However they are either limited in applicability or much too general to give an approximate assessment of the differentiation in the moisture conditions over the entire basin. The Blaney-Criddle method estimates evaporation and transpiration for areas having a vegetation cover only, and cannot possibly be used to show evaporation conditions for the extensive barren areas of the basin. The Ionides method, although it can be applied to estimate the total runoff of the Tigris and Euphrates basin [runoff = 0.75 (rainfall in mm. ÷ 100)] does not actually indicate any differentiation in the runoff distribution because it assumes the same evaporation coefficient all over the basin and disregards the influence of elevation and vegetation in modifying the amount of evaporation.

The water balance method is employed in this study because of its comprehensive concept of potential evapotranspiration which assumes a complete vegetation cover over the entire basin, and thus will enable the author to show the distribution of evaporation and transpiration conditions of the entire basin. The various evaporation and transpiration rates can then be used to show the differentiation in the runoff distribution in the basin. Because the potential evapotranspiration of the water balance method indicates the maximum possible evaporation and transpiration from areas completely covered with vegetation, it can be used to estimate the maximum amount of water which can be applied for irrigation.

The water balance method regards precipitation as the initial water supply of the basin. Losses through evaporation and transpiration are determined as based on potential evapotranspiration, then subtracted from the precipitation in order to estimate the runoff. The latter may be expressed on a map of the basin, from which may be measured the amount of water originating in Iraq and the amount imported from the upstream countries. Such measurements may have an important bearing on the type and extent of relationships between Iraq and the upstream countries with respect to water control. The interpretation of the runoff map of the basin, by indicating the major areas of water supply, has significance for any plan for water-shed management or river control.

For estimating the monthly water supply in Iraq the stream gauging records will be used because they are easy to compute and more readily available than the computations of the monthly water runoff through the water balance method. If the water balance method provides an estimate of the annual water supply similar in magnitude to the amount measured through stream gauging stations, then the monthly stream gauge measurements should not differ radically from a monthly water balance estimate.

The present uses of water will be classified as withdrawal and non-withdrawal uses. Withdrawal uses constitute water uses for irrigation, residential, municipal, industrial and livestock uses, while non-withdrawal uses constitute navigation--which exists principally in southern Iraq--and water for the recently planned hydroelectric power stations.

Further differentiation will be made between the consumptive uses, which physically remove the water molecules, and the nonconsumptive uses, which return the water to the stream or ground without diminution of the quantity.

The amount of water used for irrigation will be determined by estimating the present water diversion from the rivers. Water used for residential purposes will be estimated by determining the per capita annual consumption as based on samples selected from urban centers. The per capita annual consumption will be applied to the whole population to determine the volume of water used annually through these uses. An estimate will also be made of the amount of water used for municipal purposes. The industrial water use will be assumed to be the difference between the amount of water sold in each municipality and the water used for domestic and municipal purposes.

Although navigation does not make any direct consumptive uses of water, it is dependent upon a regular flow of a certain magnitude. By estimating the discharge which is needed to maintain the stage necessary for navigation, the amount of water used for navigation can be obtained.

The efficiency of utilization can be estimated from the amount of water which is lost in the process of satisfying these uses or from the conflict of uses, which are indications of inefficient planning. The amount of water loss will be assumed to be the difference between the amount of water required to satisfy these uses and the amount of water which is used at the present.

Both the amount of supply and the amount of water used at the present will be presented in a budget form to show the extent of current utilization and to indicate the degree of use efficiency and some of the present problems of water utilization.

Limitations of Available Data

Information available for this investigation is of two types: climatological and stream discharge records. The distribution of this information, as revealed by Figure 2, shows that the higher parts of the basin have a meager amount of available data, while the lowlands of the basin, especially Iraq--where the water uses are concentrated--has the greater amount of available information. Recently there has been a major effort to set up new climatological and stream gauging stations, especially in the mountain and foothill regions of the basin.

The climatological data are limited in number, uneven in distribution, and represent differing periods of time (Fig. 3). There are only eighteen stations in Iraq with data on both temperature and precipitation (Table 4). The other countries of the basin have even fewer such stations. The Turkish part of the basin has eight stations, the Syrian part four, and the Iranian part, two. Thus, the total climatological stations number 32.

Additional rain gauge stations exist in the basin, but they provide precipitation data only and for different periods. These stations number 31--eight are located in Turkey, two in Iran, and twenty-one in Iraq (Table 4). The longest precipitation records (slightly over 50 years) are available for three stations: Baghdad, Basrah, and Mosul. About half of the remaining stations have records for ten to twenty years, while the rest of the stations have records for less than ten years, usually for three years (Fig. 3).

Stream discharge measurements are available for the Tigris and Euphrates rivers and their tributaries, mainly in Iraq (Table 4). Thirty-two discharge sites have stream discharge measurements for differing periods (Fig. 4). These periods are longer for stations on the main streams than for those on the tributaries. More than half of the stream gauging stations have records for over 40 years. Most of the rest have records for 15 to 20 years, while a very limited number--only three--have records for less than five years (Fig. 4). The discharge stations on the main rivers have records which are continuous and which represent a longer period than do those of most of the climatological stations.

The discharge sites are located in either the lower or middle parts of the rivers and tributaries (Fig. 2), far from the political boundaries. Thus, although the discharge data provide information about the total water supply of Iraq, it is limited in revealing the distribution of the water in the different areas of

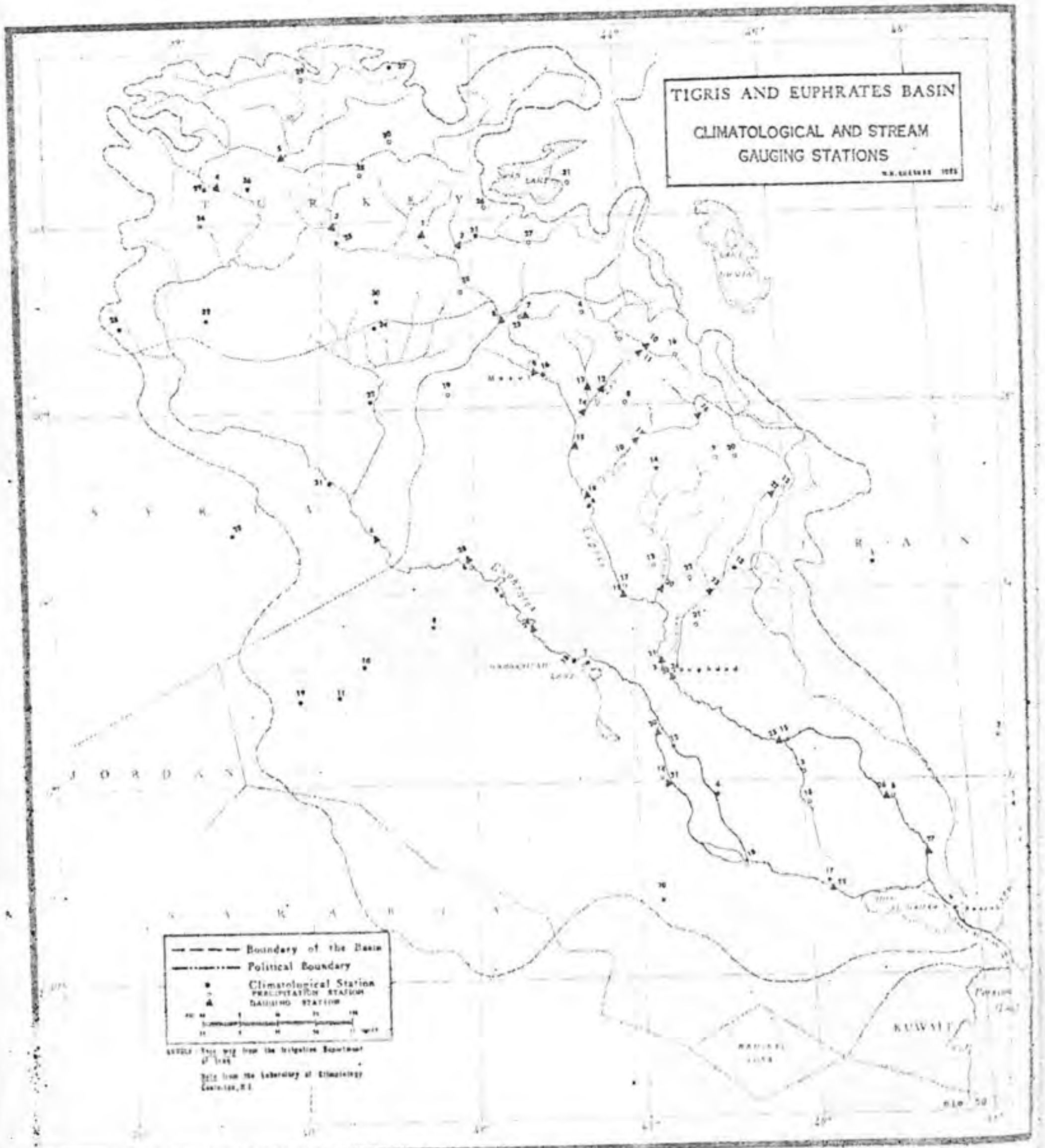
TIGRIS AND EUPHRATES BASIN
CLIMATOLOGICAL AND STREAM GAUGING STATIONS
J O R D A N
K U W A I T
Boundary of the Basin
Political Boundary
Climatological Station
Precipitation Station
Gauging Station

Fig. 2

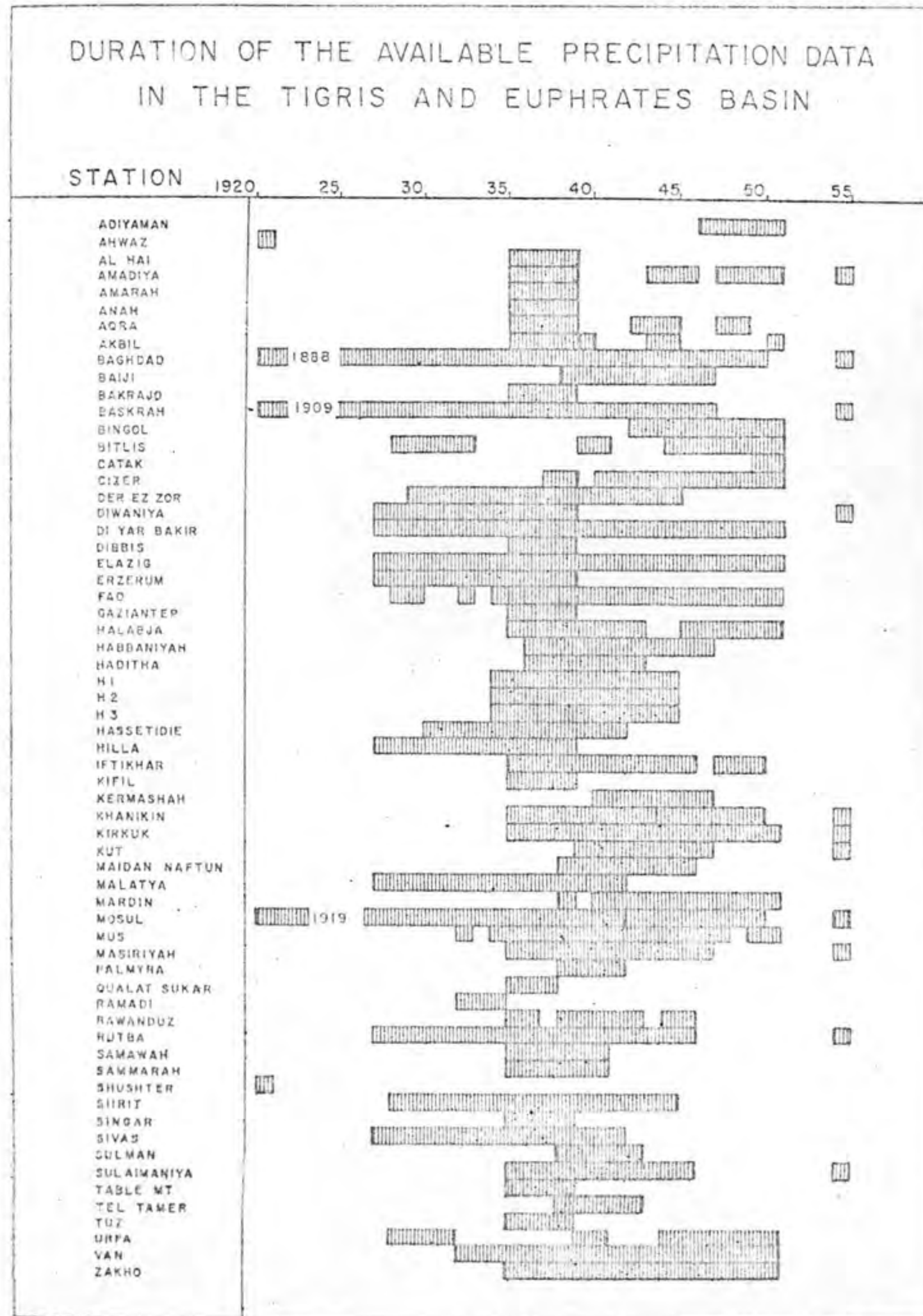
DURATION OF THE AVAILABLE PRECIPITATION DATA
IN THE TIGRIS AND EUPHRATES BASIN
STATION
1920
25
30
35
40
45
50
55
ADIYAMAN
AHWAZ
AL HAI
AMADIYA
AMARAH
ANAH
AQRA
AKBIL
BAGHDAD
1888
BAIJI
BAKRAJO
BASKRAH
1909
BINGOL
BITLIS
CATAK
CIZER
DER EZ ZOR
DIWANIYA
DI YAR BAKIR
DIBBIS
ELAZIG
ERZERUM
FAO
GAZIANTEP
HALABJA
HABBANIYAH
HADITHA
H 1
H 2
H 3
HASSETIDIE
HILLA
IFTIKHAR
KIFIL
KERMASHAH
KHANIKIN
KIRKUK
KUT
MAIDAN NAFTUN
MALATYA
MARDIN
MOSUL
1919
MUS
MASIRIYAH
PALMYRA
QUALAT SUKAR
RAMADI
RAWANDUZ
RUTBA
SAMAWAH
SAMMARAH
SHUSHTER
SIIRIT
SINGAR
SIVAS
SULMAN
SULAIMANIYA
TABLE MT
TEL TAMER
TUZ
URFA
VAN
ZAKHO

Fig. 3

the basin or the contributions of the upstream areas to the water supply of Iraq.

TABLE 4

CLIMATOLOGICAL AND STREAM FLOW STATIONS IN THE TIGRIS AND EUPHRATES BASIN

Type of Data	Iran	Iraq	Syria	Turkey
Climatological stations	1. Kermanshah 2. Maidan-i-Naftun	3. Baghdad 4. Baiji 5. Basrah 6. Diwaniyah 7. Habbaniyah 8. Haditha 9. H. 1 10. H. 2 11. H. 3 12. Hillah 13. Khaniquin 14. Kirkuk 15. Kutel-Hai 16. Mosul 17. Nasiriyah 18. Ramadi 19. Rutba 20. Sulman	21. Deir Ez-zor 22. Hassetdie 23. Palmyra 24. Tel-Tamer	25. Diyarbaker 26. Elazig 27. Erzrum 28. Gaziantep 29. Malatya 30. Mardin 31. Siirit 32. Urfa
Rain gauge stations	1. Ahwaz 2. Shushter	3. Al-hai 4. Amadiya 5. Amara 6. Anah 7. Aqra 8. Arbil 9. Bakrajo 10. Dibbis 11. Fao 12. Halabjai 13. Iftikhar 14. Kifil 15. Qualat Saleh 16. Rawanduz 17. Sammarah 18. Sammawah 19. Singar 20. Sulmaniya 21. Table Mt. 22. Tuz 23. Zakho	.....	24. Adiyaman 25. Bingol 26. Bitlis 27. Catak 28. Cizer 29. Erzinjan 30. Mus 31. Van

TABLE 4--Continued

Type of Data	Iran	Iraq	Syria	Turkey
Stream gauging stations	.....	7. Zakho 8. Faish Khabour 9. Mosul 10. Teswe 11. Bekhme 12. Eski Kelek 13. Mangubah 14. Guwair 15. Shargat 16. Dokan 17. Al-tun Kupri 18. Fatha 19. Sammarah 20. Injanah 21. Baghdad 22. Berbendi Khan 23. Disch Site 24. Diyalah Confluence 25. Gharraf 26. Ammarah 27. Qualat Saleh 28. Anah 29. Hit 30. Hindiyah 31. Kifil 32. Nasiriyah	6. Meskene	1. Besiri 2. Billioris 3. Hatunkoy 4. Keban 5. Kemaliye

DURATION OF THE AVAILABLE STREAM GAUGING STATIONS IN THE TIGRIS AND EUPHRATES BASIN

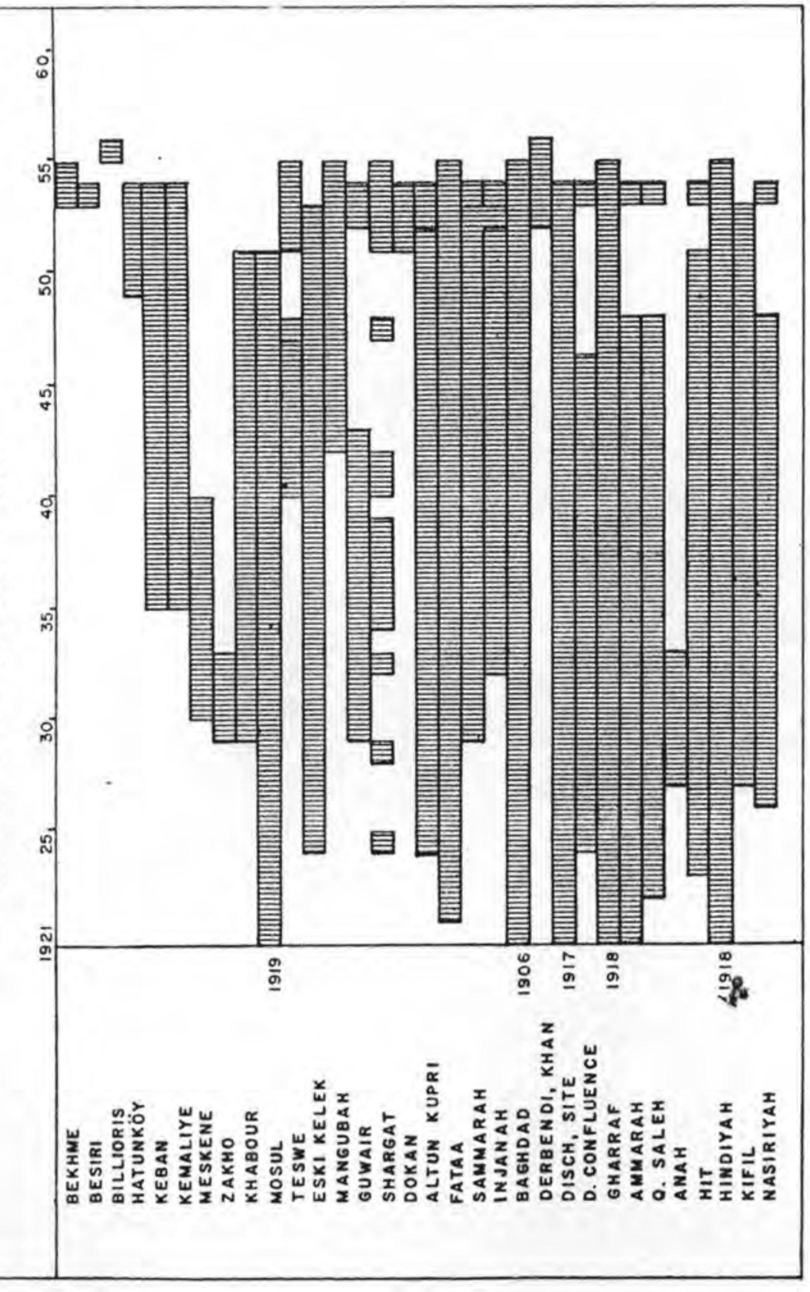

Fig. 4

CHAPTER II

THE WATER SUPPLY

The water supply of Iraq is provided by the Tigris and Euphrates rivers and by the tributaries of the Tigris: the Greater Zab, Lesser Zab, Ahdaim, and Diyalah. The Tigris and Euphrates waters supply a vast tract of irrigated lands in their flood plain and delta region before joining to form the Shatt-al-Arab which empties into the Persian Gulf. The Karon River, which is a tributary of the Shatt-al-Arab, discharges outside the political boundary of Iraq and thus it does not contribute to the water supply of Iraq.

The principal part of the water supply of Iraq is derived from its rivers; yet most of the flow is acquired in the countries upstream. It is prudent, therefore, to consider the water supply of the entire Tigris and Euphrates basin in order to evaluate and understand the basis of the water supply of Iraq.

The Water Balance of the Tigris and Euphrates Basin

The analysis of the water balance of the Tigris and Euphrates basin must be based to a considerable extent upon the amount of precipitation falling over the basin. Besides the precipitation, however, other elements--such as topography, soils, and temperature --enter into the analysis since they exert certain modifications on the disposition of the precipitation within the basin. Part of the precipitation will be evaporated and transpired by the plants, subject to differences in the amount of soil moisture, and the remainder runs off. The disposition of precipitation can be stated according to the following fundamental hydrological equation:

$$P = E \pm \Delta ST + S$$

in which precipitation P is equal to the sum of evapotranspiration E, corrected for changes in soil moisture ΔST, and S is the water surplus or runoff.

Changes in soil moisture are important from month to month, but on an annual basis the change in soil moisture is negligible.

If, then, the three major elements of the equation--precipitation, evapotranspiration, and surplus--can be estimated well, an estimate of the average annual water supply of the basin can be made. If monthly changes in soil moisture can be estimated adequately, the average monthly water supply can also be derived.

The amount of precipitation can be determined from rain gauge data. The determination of the amount of evapotranspiration and soil moisture, however, has always been more difficult. A method for determining these quantities was introduced by C. W. Thornthwaite through the concept of potential evapotranspiration.[1] The potential evapotranspiration is defined as the amount of water that would evaporate from the soil and transpire from the plants, from a surface completely covered with vegetation, assuming that there is never a shortage of water. The amount of water which is subject to loss to the atmosphere through evaporation and transpiration depends upon the climatic energy available for vaporizing the water. Thus, the potential evapotranspiration represents the climatic demand for water; in other words, it is the natural water need.

Application of the Thornthwaite Water Balance Method

The relation between the potential evapotranspiration and the precipitation determines the quantity of the actual evapotranspiration. If the precipitation is more than potential evapotranspiration, in any season, the actual evapotranspiration will be equal to the potential evapotranspiration. By contrast, during a dry season when the precipitation is less than potential evapotranspiration, the actual evapotranspiration will be equal to the sum of the precipitation and the moisture available from the soil. At the same time, because the total available moisture may be less than the natural need, a concurrent water deficiency may occur. The amount of water deficiency is determined by the quantitative relation between the actual and potential evapotranspiration as expressed in the following equation:

$$D = PE - AE$$

where D is the water deficit, PE is the potential evapotranspiration, and AE is the actual evapotranspiration.

[1]C. W. Thornthwaite, "Report of the Committee on Transpiration, 1943-1944," Transaction of American Geographical Union, XXV (1944), 683-93.

The relation of precipitation to potential evapotranspiration in each month determines whether the month is in a wet or dry season of the local climate. During a dry season, when potential evapotranspiration is greater than precipitation, moisture may be withdrawn from the soil according to the difference between precipitation and potential evapotranspiration and according to the amount of soil moisture available. The latter quantity can be derived from special tables prepared by Thornthwaite and Mather which regard the available soil moisture as being less readily available as the soil moisture content decreases. On the other hand, when the precipitation is more than the potential evapotranspiration, there is an excess of water and a wet season occurs. The excess water first replenishes soil moisture to its capillary capacity. After the demands of the soil are satisfied, any further surplus runs off, gathering in the streams and rivers. Because precipitation is subject to loss through evapotranspiration, runoff is quantitatively less than precipitation.

Within the basin diversified water balances prevail because of varying topographic, vegetative, and climatic influences. Sample water balances for climatological stations in the basin are given in Table 5 and Figure 5 for Gaziantep, Turkey, and for Mosul, Iraq. These samples illustrate two types of water balances occurring in different parts of the basin, the Winter surplus type and the negligible surplus type respectively.

In the sample water balances the dry season in Gaziantep extends from May through October. At Mosul it extends from April through October. During the wet season, from October through March or April, the trend of precipitation is opposite that of potential evapotranspiration. During this period actual evapotranspiration is also less than precipitation at both Gaziantep and Mosul. The excess water is used to replenish the soil moisture first, and until the soil moisture storage reaches 300 mm., the assumed capillary capacity of the soil according to the water balance method, no surplus will occur.[1] Table 5 shows that the excess water raises the soil moisture storage in Gaziantep to 300 mm. After recharging the soil moisture to 300 mm., all the excess water becomes surplus and runs off. This amount is 168 mm. in Gaziantep. On the other hand, there is an excess of precipitation over the potential evapotranspiration at Mosul, but the amount of excess water fails to raise the soil moisture storage to 300 mm.; thus, no water surplus occurs.

[1]C. W. Thornthwaite and J. R. Mather, op. cit., pp. 56-61.

TABLE 5

AVERAGE MONTHLY WATER BALANCE OF SELECTED CLIMATOLOGICAL STATIONS IN THE TIGRIS AND EUPHRATES BASIN[a]
(Millimeters)

	J	F	M	A	M	J	J	A	S	O	N	D	Y
						Gaziantep, Turkey							
PE[b]	3	6	16	46	94	139	175	158	105	54	23	6	825
P	121	105	67	56	22	8	1	3	5	41	69	116	614
ΔST	-110	0	0	0	- 65	- 84	- 67	- 34	- 14	- 2	- 46	-110	...
ST	300	300	300	300	235	151	84	50	36	34	80	190	...
AE	3	6	16	46	87	92	68	37	19	43	23	6	446
D	0	0	0	0	7	47	107	121	86	11	0	0	379
S	8	99	51	10	0	0	0	0	0	0	0	0	168
						Mosul, Iraq							
PE	6	10	25	54	129	189	217	201	145	81	23	10	1,100
P	73	73	46	44	16	1	0	0	1	9	55	58	376
ΔST	- 67	- 63	- 21	- 8	- 70	- 72	- 42	- 19	- 8	- 2	- 22	- 48	...
ST	147	210	231	223	153	81	39	20	12	10	32	80	...
AE	6	10	25	52	86	73	42	19	9	11	33	10	376
D	0	0	0	2	43	116	175	182	136	70	0	0	724
S	0	0	0	0	0	0	0	0	0	0	0	0	0

[a]Data obtained from the Laboratory of Climatology, Centerton, N.J.

[b]Abbreviations: PE, potential evapotranspiration; P, precipitation; ΔST, change in soil moisture storage; ST, soil moisture storage; AE, actual evapotranspiration; D, water deficit; S, water surplus.

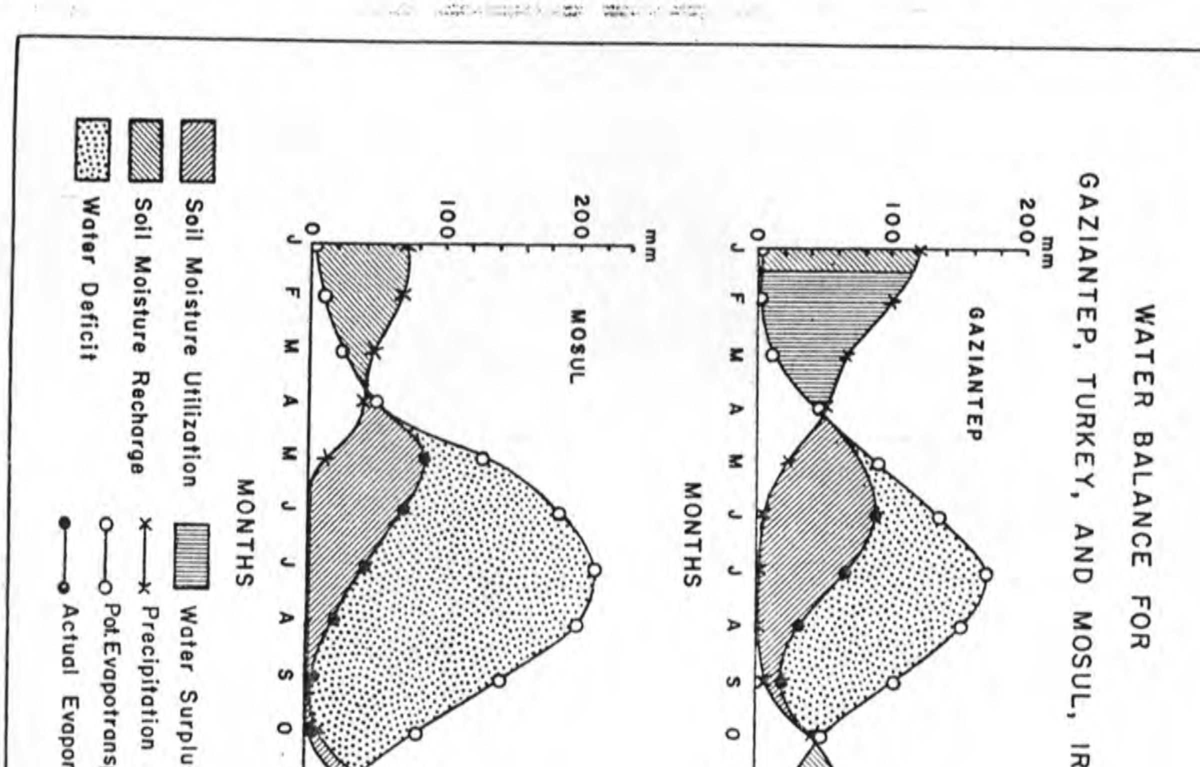

Fig. 5

Figure 4 shows that during the wet period, while a water surplus occurs at Gaziantep from the beginning of January until the end of May, the same period in Mosul is characterized only by recharging of the soil moisture and not by a reliable surplus. Of course, it may be true that for any short period of time, when very intense precipitation occurs, the soil moisture at Mosul may be replenished to capillary capacity and there may be some surplus which, over the year, averages to a positive, though negligible, amount rather than the zero derived in Table 5 by the water balance method.

The four basic elements--precipitation, potential evapotranspiration, water surplus, and water deficit--remain as most important in determining the average annual water balance. The application of the water balance method to the entire basin permits the appraisal of the moisture conditions of the basin and the determination of the water supply.

The Distribution of the Water Balance Elements in the Basin

The four basic water balance elements are presented on maps of the basin (see Figs. 6, 7, 8, and 9) in order to show the patterns of their distribution and to incorporate an areal dimension into the estimate of the water supply of the basin.

Thirty-two climatological stations for which both temperature and precipitation data were available for various periods of time were utilized in constructing the maps. These stations are located mostly in the southern parts of the basin in Iraq and Syria. A very limited number are located in Turkey and Iran. Additional data of precipitation for 31 rain gauge stations were obtained mostly for the three-year period, 1936-1939.[1] Seventeen of these supplementary stations are located in the northern and mountainous parts of the basin in Iraq and Turkey. The potential evapotranspiration, water surplus, and water deficit data were computed for the 32 climatological stations by the staff of the Laboratory of Climatology in Centerton, New Jersey, according to the method described

[1]These additional data are compiled from M. G. Ionides, The Regime of the Rivers Euphrates and Tigris (London: E. and F. N. Spon Company, 1937), p. 37; Knappen, Tippetts, Abbett, McCarthy Engineers, op. cit., chap. iii, pp. 1-4; The Meteorological Service of Iraq, Rainfall in Iraq--1936-1939, Publication No. 3 (Baghdad: The Government Press, 1940); and C. W. B. Normand, Climate and Weather of Iraq (Baghdad, 1919).

by Thornthwaite and Mather.[1]

The maps of the water balance elements were based on average values computed from climatological data which certainly vary in their magnitude according to the climatological conditions prevailing in any specific year. Although averages do not represent the conditions prevailing for every specific year, they are a short cut to a general estimation of the moisture conditions over a period of years and they indicate the supply that may be available with storage. The values were plotted on a 1:2,000,000 scale relief map of the basin prepared by the Irrigation Department of Iraq.[2] Isarithm patterns were constructed to fit the data and also were made compatible with the significant features of relief. In areas where data were limited or unavailable, as in the highest parts of the basin, interpolation of the isarithms was guided by the relief pattern.

Average annual precipitation.--The interpolation of the average annual precipitation map was based on the fact that the relief pattern has an acknowledged effect on the processes which control the precipitation distribution. The precipitation stations were sufficiently abundant throughout most of the basin to enable the precipitation isarithms to be constructed, with confidence, up to an elevation of 1,000 meters. There were almost no precipitation data available for places above this elevation.

In a preliminary rainfall map Ionides indicated that these higher parts of the basin had more than 600 mm. of precipitation, but he did not exclude the possibility that the precipitation could be greater.[3] In 1956 Shalash constructed a precipitation map of Iraq showing the 1,000 mm. precipitation isarithm crossing the higher parts of Kurdistan in northeastern Iraq.[4] Yet both maps omitted parts of the basin, especially the mountainous parts to the north and northeast, where even greater precipitation totals should be expected.

In order not to overestimate the amount of precipitation in

[1]C. W. Thornthwaite and J. R. Mather, op. cit., pp. 14-55.

[2]F. F. Haigh, Iraq Irrigation Commission, The Control of the Rivers of Iraq and the Utilization of Their Waters (Baghdad: Baghdad Press, 1951).

[3]M. G. Ionides, op. cit., p. 33.

[4]A. H. Shalash, op. cit., p. 52.

the basin it was assumed that the gradient of the precipitation isarithms above 1,000 meters of elevation was not different from the gradient in the lower area. The general pattern of the isarithms indicates a continuous increase in precipitation from the lower to the middle elevations of the basin and essentially no increase nor decrease in the upper parts of the basin.

As shown in Figure 6, a general tendency for an increase in precipitation from south to north is apparent. The part of the basin which is located in southern Iraq appears to be an area of limited initial water supply. There is a gradual increase in precipitation toward the higher elevations, with the 900 mm. isarithm roughly separating the lowlands to the south and the uplands to the north. It outlines quite reliably the areas having 1,000 meters or more of elevation.

The 1,500 mm. isarithm of precipitation bounds the highest parts of the basin. These parts border the basin on the northeast, north, and northwest. The regions which have precipitation of between 900 and 1,500 mm. are rather wide and fairly continuous in the northeastern parts of the basin; they become narrower toward the south and toward the northwest and are absent in the southeast along the ranges of the Zagros and Lourish mountains. Most of these higher areas are the location of the headwaters of the major rivers and the tributaries.

Average annual potential evapotranspiration.--The method for constructing the average annual potential evapotranspiration map (Fig. 7) is essentially the same as one described by Carter.[1] The method considers that latitude, altitude, and nearness to water are factors affecting the distribution of potential evapotranspiration. The effect of nearness to water was eliminated in drawing the map shown as Figure 6 since large bodies of water are absent within the Tigris and Euphrates basin. Because the basin extends through only a few degrees of latitude, the effect of latitude is less dominant than that of altitude. The latter is considered the most important factor in the distribution of potential evapotranspiration in the basin.

Potential evapotranspiration decreases rapidly with elevation through the lowlands and less rapidly in the higher areas. The

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[1]D. B. Carter, "Maps of Water Requirements for Southwest Asia" (Unpublished manuscript, Laboratory of Climatology, Centerton, New Jersey, 1957), p. 6.

general order of isarithms indicates an uninterrupted decrease from the southern and lower parts to the northern and higher parts of the basin.

The distribution of potential evapotranspiration indicates a pattern contrary to the pattern of precipitation. The highest parts of the basin have the lowest amounts of potential evapotranspiration, 200 mm. or less. The lowlands of the basin have the highest potential evapotranspiration--a natural water need exceeding 1,300 mm.--yet the lowlands have a precipitation of less than 300 mm.

The 1,000 mm. isarithm of potential evapotranspiration marks the general change in the topography of the basin. To the north of the 1,000 mm. isarithm there is an uninterrupted decrease of potential evapotranspiration with elevation toward the summits of the ranges and the headwaters of the basin. Most of the areas which have less than 1,000 mm. of potential evapotranspiration are located in Turkey and northeastern Iraq. To the south of the same isarithm there is a continuous but gradual increase in the potential evapotranspiration. Most of this latter area is located in Syria and Iraq.

Average annual water deficit.--The interpolation of the average annual water deficit map (Fig. 8) was similar to the technique used by Carter for constructing water requirement maps for Southwest Asia.[1] The important factor influencing the distribution of water deficit is relief. The water deficit decreases with altitude, though slowly. In the sheltered valleys where a rain shadow occurs there is (in many areas) an abrupt increase in the water deficit.

The distribution of the average annual water deficit in the basin, shown in Figure 8, indicates that the higher parts of the basin, which have the lowest potential evapotranspiration have the lowest amount of water deficit, less than 100 mm. The lowlands, in the southern parts of the basin, which have the highest potential evapotranspiration and the lowest precipitation, have the highest amount of water deficit, more than 1,200 mm.

The 800 mm. isarithm of water deficit separates, roughly, the lowlands and uplands of the basin. This isarithm passes through Mosul in Iraq and almost coincides with the northern limits of Syria. All the areas south of this isarithm have a continuously increasing deficit toward the lower elevations. North of this isarithm

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[1]*Ibid.*, pp. 6-7.

the water deficit decreases toward the uplands until the lowest deficit is reached in the highest areas. The greater part of these latter areas is located in Turkey; a minor proportion is located in Iraq and Iran; none is in Syria.

Average annual potential evapotranspiration and water deficit maps which were constructed by Carter for Southwest Asia coincide basically with the maps of potential evapotranspiration and water deficit of the Tigris and Euphrates basin presented in this dissertation. This is logical since the same climatological data and the same interpolation techniques were utilized. However, the Tigris and Euphrates maps are more detailed since they are drawn on a larger scale. The two sets of maps coincide in value and location of the areas of greatest and least potential evapotranspiration and water deficit. The series of maps in this dissertation magnify the water balance information available for that part of Southwest Asia occupied by the Tigris and Euphrates basin. Moreover, the present series of four maps are valuable in being complementary. Any point in the area has values on the four maps which fit the basic equation,

$$S = P - (PE - D)$$

in which S is water surplus, P is precipitation, PE is potential evapotranspiration, and D is water deficit, all in their average annual values.

Average annual water surplus.--In drawing the average annual water surplus map (Fig. 9) special attention was directed toward the higher parts of the basin where lack of climatological data was a hindrance to construction of the previous three maps. The estimated precipitation, potential evapotranspiration, and water deficit values of these areas as presented in the previous three maps were used in conjunction with basic hydrologic equations to estimate the water surplus of these areas.

On the summits of some of the highest mountains the values of 1,500 mm. of precipitation, 200 mm. of potential evapotranspiration, and 100 mm. of water deficit were presented in the previous maps. Water surplus at the summits of the mountains was therefore estimated by substituting in the following equations for the average annual water balance:

$$P = AE + S$$

and $$D = PE - AE$$

or $$AE = PE - D$$

thus, $$P = PE - D + S$$

or $$S = P - (PE - D)$$

For all the summit regions, therefore, the average annual water surplus, the runoff, is 1,400 mm.

On the basis of this and similar estimates for various critical elevations, the isarithm of 1,400 mm. of average annual water surplus was constructed around the highest areas of the basin. For the rest of the basin there were 33 climatological stations for which water balances had been computed. Five of these stations had a significant surplus and all were in the uplands of the basin. Four were in Turkey.

The construction of the average annual water surplus isarithms was essentially similar to the method used by Carter in constructing the surplus maps of the land around the Mediterranean and Black Seas.[1] Water surplus increases with elevation at a rate greater than that of precipitation because of the inverse change in precipitation and potential evapotranspiration values with altitude. Thus, in the higher areas of the basin the gradient in the pattern of water surplus is shown as steeper than that of precipitation.

The distribution of the average annual water surplus, as indicated in Figure 9, shows that the greatest amount of water surplus is located in the areas which have the greatest precipitation, the least potential evapotranspiration, and the least water deficit. These areas contribute the principal part of the stream discharge. The area which has a water surplus greater than 1,000 mm. appears continuously in the northeastern part of the basin; it becomes discontinuous towards the northwest. The largest proportion of this region is located in Turkey and a small proportion is located in Iraq and Iran. Turkey can be regarded as the primary supplier of water in the basin, while Iraq and Iran must be considered secondary suppliers. By contrast, practically all the region which has less than 100 mm. of water surplus is located in the lowlands of Iraq and Syria.

The Water Supply of the Basin

The water surplus map, shown in Figure 9, presents the average annual water supply of the basin. In order to determine the volume of the average annual water supply, the map of water surplus

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[1]D. B. Carter, The Water Balance of the Mediterranean and the Black Seas ("Climatology," Vol. IX, No. 3; Centerton, N.J., 1956), p. 139.

was planimetered. The patterns formed by successive isarithms were measured by planimetry and the average depth of the strip was multiplied by the area of the strip in order to arrive at the volume. This was done for each river and tributary separately. The computed water surplus is presented in Table 6.

TABLE 6

COMPUTED AVERAGE ANNUAL WATER SURPLUS OF THE TIGRIS AND EUPHRATES BASIN (In Million Cubic Meters)

River	Euphrates	Tigris	Greater Zab	Lesser Zab	Ahdaim	Diyalah	Total
Computed surplus	26,367	17,026	11,622	7,019	812	6,224	69,070

The computed surplus represents the initial runoff in each river basin. However, not all of this runoff is recorded through the gauging stations because some loss may occur above the gauging stations by evaporation from the irrigated areas and water bodies. Thus, the computed surplus should be adjusted in order to be compared with the discharge records of each river. The estimation of the evaporation loss above the gauging station depends upon the size of the evaporating body, the depth of the water, and the amount of water deficit. Since there are no extensive water bodies above the gauging stations, other than the rivers themselves, the loss will come primarily from the irrigated areas. The size of the irrigated areas multiplied by the average annual water deficit will give the volume of water loss by evaporation which is not supplied by precipitation. On the average annual water deficit map the isarithm of water deficit which passes through the center of each irrigated tract was selected to be representative of the average annual deficit of the area.

Table 7 shows the size of the irrigated areas, the representative water deficit, and the estimated water loss through evaporation by which the water supply, transported from the mountains, is dissipated above the stream gauging stations.

The volume of the evaporated water was subtracted from the water surplus of the basin to obtain the estimated runoff at the place where the stream gauges are located. The adjusted computed runoff in the Tigris and Euphrates is shown in line 1 of Table 8.

TABLE 7

WATER LOSS THROUGH EVAPOTRANSPIRATION ABOVE GAUGING STATIONS

Basin	Irrigated Area (1,000 Meshars)[a]	Irrigated Area (1,000 Acres)	Representative Water Deficit (mm.)	Estimated Volume of Evapotranspiration (Million Cubic Meters)
Diyalah	588[b]	361	800	1,176
Euphrates (Syria)	824[c]	506	800	1,648
Tigris	negligible		negligible	negligible
Greater Zab	negligible		negligible	negligible
Lesser Zab	negligible		negligible	negligible
Ahdaim	negligible		negligible	negligible

[a]One meshar = 0.614 acres = 2,500 sq. m.

[b]Knappen, Tippetts, Abbett, McCarthy Engineers, Development Plan for the Tigris and Euphrates Rivers, Iraq (Baghdad: The Development Board, 1955), chap. v, p. 26.

[c]D. Warriner, Land Reform and Development in the Middle East, A Study of Egypt, Syria, and Iraq (London: Oxford University Press, 1957), p. 78.

Runoff measured by gauging stations on the major streams is tabulated in line 2 of the same table (Table 8).

TABLE 8

COMPARISON BETWEEN COMPUTED AND MEASURED RUNOFF IN THE TIGRIS AND EUPHRATES BASIN[a] (Million Cubic Meters)

River	Euphrates	Tigris	Greater Zab	Lesser Zab	Ahdaim	Diyalah	Total
Adjusted runoff	25,000	17,026	11,622	7,019	812	5,048	66,246
Measured runoff	26,410	18,499	13,719	7,650	969	6,167	73,414

[a]Data compiled from Knappen, Tippetts, Abbett, McCarthy Engineers, Development Plan for the Tigris and Euphrates Rivers, Iraq (Baghdad: The Development Board, 1955), chap. iii, pp. 21-38.

A comparison of lines 1 and 2 in Table 8 shows that practically all the runoff originating in the basin, except in the Euphrates and Diyalah basins, passes through the gauging stations without any significant evaporation loss upstream from the gauges. Some losses may occur through evaporation from the channels of the rivers, but the volume is inconsequential because the area of the streams is small.

This can be illustrated by computing the amount of water evaporated from the channel in a segment of the river. The length of the river between Baghdad and Kut on the Tigris, for instance, is 350 kilometers. The width of the river is 350 meters and the total area is approximately 121 million square meters. The average annual water deficit of the same area is 1.1 meters. Thus, the total amount of water evaporated from that part of the river is 133 million cubic meters annually. This amount can be considered negligible since it represents only 0.3 per cent of the supply of the river in that area.

The difference between the two sets of figures presented in Table 8 is so slight that for many purposes of estimating water supply one of them could be substituted for the other. In addition to the close agreement between the two, certain basic advantages of the water balance method over the stream gauge measurements are evident. The average annual water surplus map shows the locations of the major areas of water nourishment in addition to the quantitative aspects of the water supply. The nourishment areas have a high average annual water surplus and, thus, are important to any future program for water conservation. The average annual water deficit map shows the distribution of the major areas of water depletion through evaporation. Because the average annual water deficit represents the amount of water by which precipitation fails to satisfy the water need, it shows the amount of water which should be added to the cultivated parts of the basin, in addition to the precipitation, to satisfy the water need. Water deficit, therefore, expresses the irrigation requirement.

The water balance method provides invaluable estimates of irrigation requirements. Confidence in the method and its estimates is encouraged by the agreement of the measured and computed runoff. The one clear disadvantage of the method, however, is the necessarily extensive computational work required to obtain twelve monthly runoff amounts for areas with and without snow, although the previous agreement indicates it would be well worth the effort if stream gauge records for monthly flow were lacking, or if differ-

ences within the areas from which monthly surplus comes were regarded as critical to some program. Thus, to estimate the water supply of Iraq on a monthly basis the more convenient monthly stream discharge records will be utilized; to estimate the irrigation requirements of Iraq, the climatically derived water deficit will be utilized.

The Water Supply of Iraq

Almost all the water which originates in the basin is available in Iraq, although the water supply of the basin does not come from Iraq alone. The proportion contributed by every country to the water supply of the basin was measured through planimetry of the annual water surplus map according to the political boundaries in each river basin. The results of the planimetry are shown in Table 9, where it may be seen that Iraq contributes 24 per cent of the basin's annual water supply, Turkey contributes 70 per cent of the annual water supply, and Iran contributes only 6 per cent. The larger part of Turkey's contribution comes through the water supply of the Euphrates and the main stem of the Tigris. A smaller part of the contribution comes through the water supply of the Greater Zab River. The contributions of both Iraq and Iran come mainly through the water supply of the tributaries of the Tigris.

The two major rivers and their tributaries contribute strikingly different amounts to the water supply of Iraq. The Euphrates is the largest contributor, followed by the Tigris tributaries and the main stem of the Tigris, as shown in Table 9. However, if the Tigris River and its tributaries are considered as one unit, the Tigris contributes 62 per cent of the water supply of the basin, while the Euphrates contributes only 38 per cent.

A well-developed seasonal variation in the water supply is characteristic of all streams in the basin. In Table 10 the measured monthly water supply of the basin shows that the maximum, 14,312 million cubic meters, occurs in late April and the beginning of May, while the minimum, 1,898 million cubic meters, occurs in September.

The seasonal changes in the supply, as shown in Figure 10, indicate that the supply begins to increase in November. Throughout the Winter the supply for all rivers increases generally. Figure 10 shows how much the rate of increase between December and February is greater than the increase between September and December. As Spring advances, the supply increases steadily. The maximum supply

TABLE 9

CONTRIBUTIONS OF THE COUNTRIES TO THE ANNUAL WATER SUPPLY OF THE TIGRIS AND EUPHRATES BASIN[a]
(Million Cubic Meters)

River	Annual Water Supply	Iraq Supply	Per Cent from Iraq	Iran Supply	Per Cent from Iran	Turkey Supply	Per Cent from Turkey
Tigris, main stem	17,026	......	......	......	......	17,026	100
Greater Zab	11,622	7,500	58	......	......	4,100	42
Lesser Zab	7,019	4,300	64	2,719	36	......	......
Ahdaim	812	812	100	......	......	......	......
Diyalah	6,224	4,000	66	2,224	34	......	......
Euphrates	26,367	......	......	......	......	26,367	100
Total	69,070	1,662	23	4,943	7	47,493	70

[a]Saudi Arabia and Syria do not contribute any significant quantity to the water supply of the rivers.

TABLE 10

THE AVERAGE MONTHLY WATER SUPPLY OF THE TIGRIS AND EUPHRATES BASIN IN IRAQ[a]
(Million Cubic Meters)

River	Gauging Station	J	F	M	A	M	J	J	A	S	O	N	D	Annual	Years of Records
Tigris Main-stream	Mosul	1,270	1,979	2,512	3,964	3,421	1,693	829	453	380	431	651	916	18,499	(33) 1919-52
Greater Zab	Eski Kelek	720	1,130	1,800	2,720	2,806	1,595	814	455	339	344	466	530	13,719	(27) 1925-52
Lesser Zab	Altun Kupri	635	977	1,369	1,423	1,037	578	343	225	187	198	271	407	7,650	(27) 1925-52
Ahdaim	Injanah	163	183	198	146	70	29	16	14	14	14	47	75	969	(19) 1933-52
Diyalah	Discharge site	514	531	1,052	1,186	790	385	275	232	219	240	310	433	6,167	(28) 1924-52
Euphrates	Hit	1,572	1,616	2,577	4,873	5,973	3,136	1,519	948	759	849	1,122	1,466	26,410	(27) 1924-51
Total		4,874	6,416	9,508	14,312	14,097	7,416	3,796	2,327	1,898	2,076	2,867	3,827	73,414	

[a]Data compiled from Knappen, Tippetts, Abbett, McCarthy Engineers, Development Plan for the Tigris and Euphrates Rivers, Iraq (Baghdad: The Development Board, 1955), chap. iii, pp. 28-31.

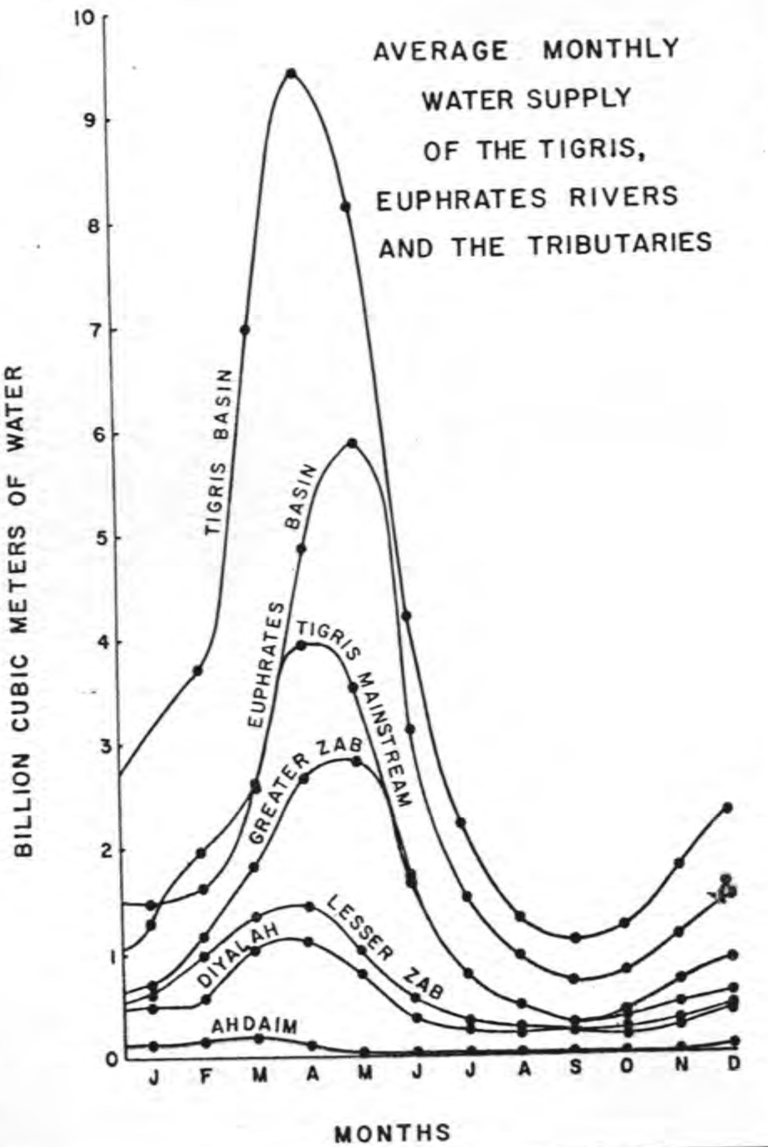

Fig. 10

occurs during the last two weeks of April and the first two weeks of May, except in the Lesser Zab and Diyalah rivers, where the maximum supply tends to occur earlier--in the last two weeks of March and the first two weeks of April. This is because the basins of the latter three rivers are lower in altitude, and thus less of the precipitation is in the form of show.[1] The small quantity of snow at the lower altitudes tends to melt earlier when the advancing Spring season brings an increase in temperature. After May, the monthly supply begins to decrease continuously, until the lowest amount of the supply occurs in September.

A variation of the supply occurs also from year to year. The measured water supply of both major rivers for a period of years is presented in Table 11. The supply of the Euphrates at Hit is considered representative of the supply of that river in Iraq. This station has the longest records of all the stations and is located to the north of the main irrigated areas, above the zone where diversions are made for irrigation. The site of the Diyalah confluence with the Tigris is considered representative of the supply of the Tigris in Iraq, since the Diyalah is the last significant tributary which adds to the supply of the Tigris. The period selected for examination of annual variability of the water supply extends from 1924 to 1946.

That the water supply of both rivers was subject to an extreme variability from year to year is shown in Figure 11. On the Tigris the range of variability was 45 billion cubic meters, resulting from a difference in the supply between 19 billion cubic meters in 1930 and 64 billion cubic meters in 1946. On the Euphrates the range of variability was 26 billion cubic meters, ranging from 10 billion cubic meters in 1930 to 36 billion cubic meters in 1941.

The reliability of the water supply of Iraq, in the period 1925-1946, was measured by constructing a table to show the frequency of occurrence of the supply in each river. Table 12 was constructed by tabulating the water supply of each river for the different years in order of magnitude according to the following equation:[2]

$$F = \frac{m}{n} 100$$

[1] M. G. Ionides, op. cit., p. 140.

[2] Stanley S. Butler, Engineering Hydrology (Englewood Cliffs, N.J.: Prentice-Hall, 1957), p. 43.

where m is the order of the supply, n is the total number of years, and F is the per cent of years during which the supply is equal to or greater than the supply of order m.

TABLE 11

WATER SUPPLY OF THE TIGRIS AND EUPHRATES IN IRAQ, 1925-1946[a]
(Billions of Cubic Meters)

Year	Euphrates at Hit	Tigris at Diyalah Confluence
1925	16.6	23.3
1926	28.5	55.7
1927	16.6	35.6
1928	19.6	35.4
1929	31.6	45.1
1930	10.2	18.9
1931	24.1	34.2
1932	17.0	30.0
1933	15.3	36.4
1934	17.7	31.9
1935	31.9	34.9
1936	31.3	41.9
1937	27.7	40.0
1938	33.8	52.3
1939	29.7	51.3
1940	35.0	58.5
1941	35.9	54.2
1942	34.8	56.2
1943	32.1	50.0
1944	34.4	41.1
1945	27.3	37.7
1946	33.5	63.5
Mean annual supply	26.4	42.2

[a]F. F. Haigh, Iraq Irrigation Commission, *The Control of the Rivers of Iraq and the Utilization of Their Waters* (Baghdad: The Baghdad Press, 1951), pp. 39, 47.

Figure 12 demonstrates that in more than 90 per cent of the years in the period of the study a supply of 16 billion cubic meters of water was provided by the Euphrates River, while the mean supply of the same river, 26.4 billion cubic meters, occurred about 60 per cent of the years. In the Tigris River a supply of 30 billion cubic meters was provided more than 90 per cent of the years, while the mean, 42 billion cubic meters, occurred about 50 per cent of the years.

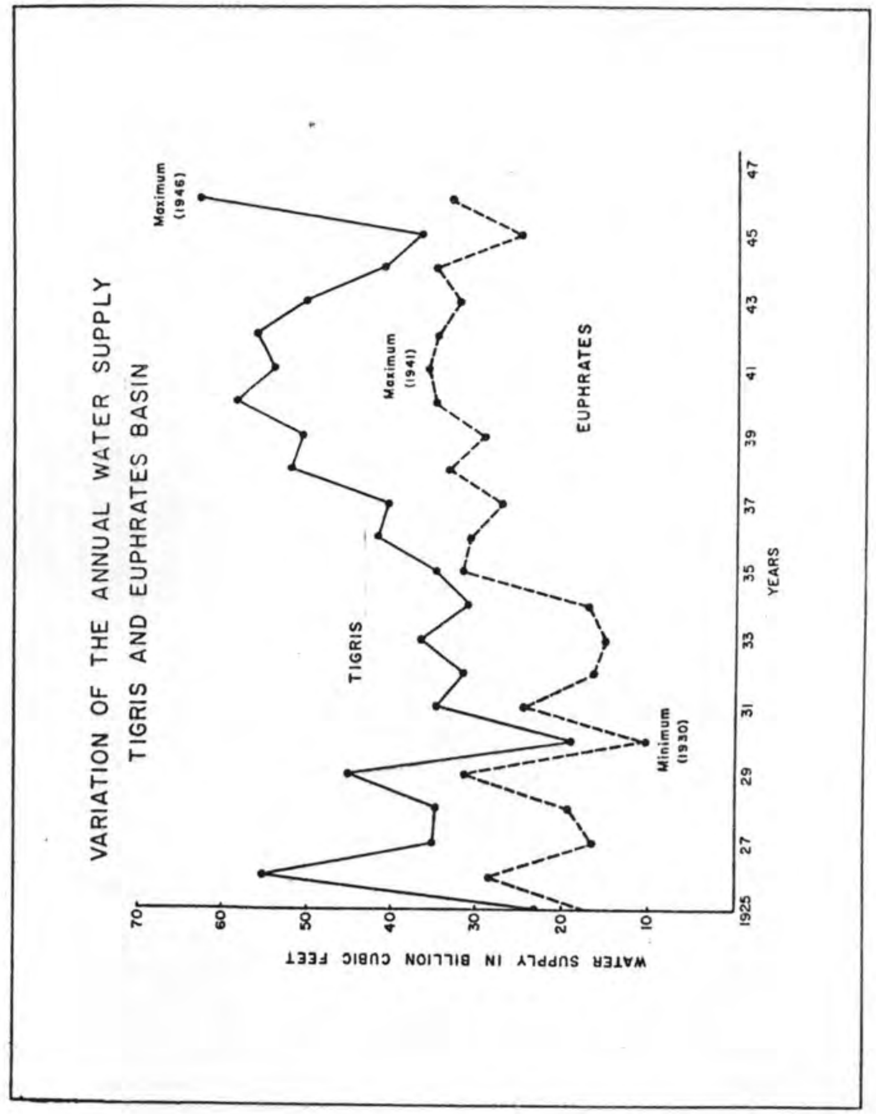

Fig. 11

TABLE 12

DATA OF ANNUAL WATER SUPPLY FOR THE TIGRIS AND EUPHRATES RIVERS, 1924-1946
(In Order of Magnitude and Occurrence)

Tigris			Euphrates		
Order No.	Annual Water Supply in Billions of Cubic Meters	Occurrence in Per Cent of Years	Order No.	Annual Water Supply in Billions of Cubic Meters	Occurrence in Per Cent of Years
1	63	5	1	36	6
2	58	10	2	35	12
3	56	15	3	34	18
4	54	20	4	33	23
5	52	25	5	32	29
6	51	30	6	31	35
7	50	35	7	30	41
8	45	40	8	29	47
9	42	45	9	28	53
10	41	50	10	27	59
11	40	55	11	24	65
12	38	60	12	23	70
13	37	65	13	20	76
14	36	70	14	18	82
15	35	75	15	17	88
16	34	80	16	15	94
17	32	85	17	10	100
18	31	90			
19	23	95			
20	19	100			

It may thus be noted that although the rivers of Iraq have been providing a system of irrigation for many thousands of years, there have been cases in which the water supply was so little that it failed to meet agricultural requirements. Recent cases which illustrate the situation occurred during 1935 and 1944 when most of the fruit trees of the Diyalah District were nearly annihilated by droughts.[1] Sausa attributes the damage to lack of water for irrigation, though the effect was so localized that it is not apparent from the records of streamflow shown in Figure 11. This yearly irregularity of water supply exposes the agricultural lands to the danger of inundation by flood in some years and deprives them of sufficient water in others.

It therefore has been essential in drawing up a comprehensive expansion or improvement plan of water use for irrigation in

[1]Ahmed Sausa, op. cit., pp. 13-14.

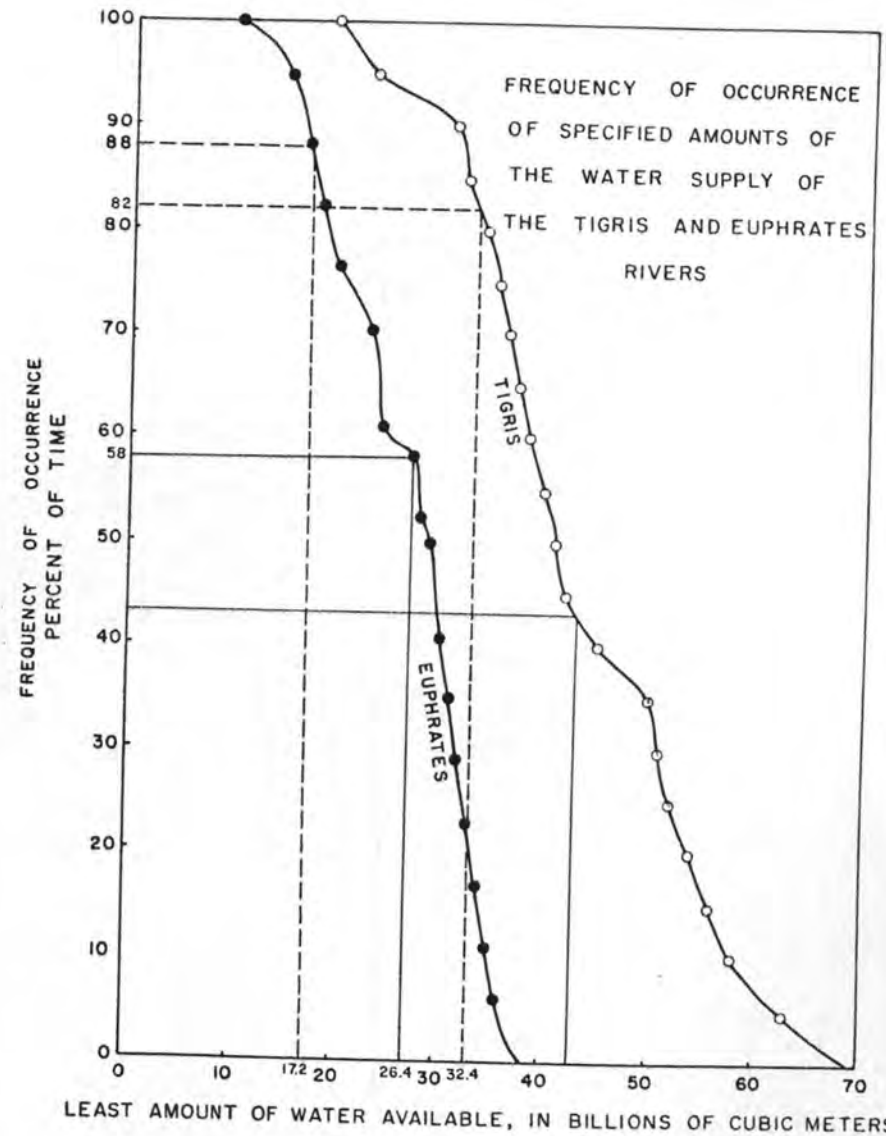

Fig. 12

Iraq to consider the monthly and annual supply in the country. Moreover, it is essential to provide for storage reservoirs in order to achieve the greatest feasible concurrence between water supply and water requirements.

CHAPTER III

WATER UTILIZATION

Almost all of the water supply of the Tigris and Euphrates basin is available in Iraq. The average annual water supply of Iraq amounts to about 73 billion cubic meters, but the water which leaves Iraq through the Shatt-al-Arab amounts to only 27 billion cubic meters.[1] Consequently, there is a diminution in the water supply within Iraq of about 46 billion cubic meters or 63 per cent of the total annual water supply of the basin.

Evaporation from the river channels is negligible as compared with total depletion. Seepage through the river beds is also believed to be minor; it has been estimated that only 3 per cent of the total supply of the rivers is lost through seepage.[2] Thus, it must be assumed that the greatest cause of diminution of the water supply within Iraq is the diversion and use of the water by or for man and his activities, and by the extensive swamps supplied by the rivers.

The recognizable water uses in Iraq at present are irrigation, residential, municipal, industrial, and navigation. These uses can be classified generally into two types: withdrawal uses, which include the first four uses above, and a non-withdrawal use, navigation.

The withdrawal uses may in turn be classified as consumptive or non-consumptive. Only part of the water withdrawn for these uses is consumed through evaporation and transpiration or through processes which involve a physical change in the state of the molecules of water. The other part of the withdrawn water returns to the stream or seeps into the ground and ultimately flows to the stream. Thus, part of the withdrawn water may become available again for later use.

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[1]C. B. Cressey, "Water in the Desert," Annals of the Association of American Geographers, XLVII (1957), 113.

[2]F. F. Haigh, op. cit., pp. 25-26.

Withdrawal of Water for Irrigation

Among water uses in Iraq at present irrigated areas are the largest consumer of water. Irrigation is responsible for much of the diminution in the water supply, through crop consumption, losses, and wastes.

Withdrawal for Irrigated Areas

The withdrawal of water for irrigation in Iraq is devoted mainly to the delta and flood plain of the Tigris and Euphrates rivers extending north to the alluvial fan of the Diyalah River. This area, shown in Figure 13, coincides with the Mesopotamian trough, which is shown in Figure 1. It occupies the southern half of the lowlands of the Tigris and Euphrates basin. Withdrawals for irrigation eventually seep to extensive swamp areas. In respect to soils, methods, and quantities withdrawn and consumed, the irrigated areas in Iraq are rather similar to the irrigated areas in Pakistan and Egypt, which are located in the flood plain and delta of the Indus River and the flood plain and delta of the Nile. Similar climatic conditions reveal the same indications of water thirst in Egypt[1] and in India,[2] where similar values of precipitation, water need, and water deficit prevail.

At present, water is withdrawn for a total irrigated acreage amounting to 4.7 million acres (equivalent to 7.7 million meshars). This represents about 60 per cent of the total irrigable acreage (about 8 million acres) in the country. Due to the practiced fallow-system of cultivation, the remainder, about 3.3 million acres, is not used in any given year. In Table 13 it is revealed that a great proportion of the total irrigated acreage is devoted to annual crops, while perennial cropping is practiced in only a small part of the land. The irrigated areas cropped with annuals are devoted mainly to grains but include beans in addition to wheat and barley. Perennial irrigated areas are devoted to alfalfa, citrus fruits, dates, and deciduous fruits.[3]

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[1] D. B. Carter, "Maps of the Water Requirements for Southwest Asia," loc. cit., p. 7.

[2] V. P. Subrahmanyan, "The Water Balance of India According to Thornthwaite's Concept of Potential Evapotranspiration," Annals of the Association of American Geographers, XLVI, No. 1 (March, 1956), 300-11.

[3] D. H. Davies, "Observations on Land Use in Iraq," Economic Geography, L, No. 2 (April, 1957), 123.

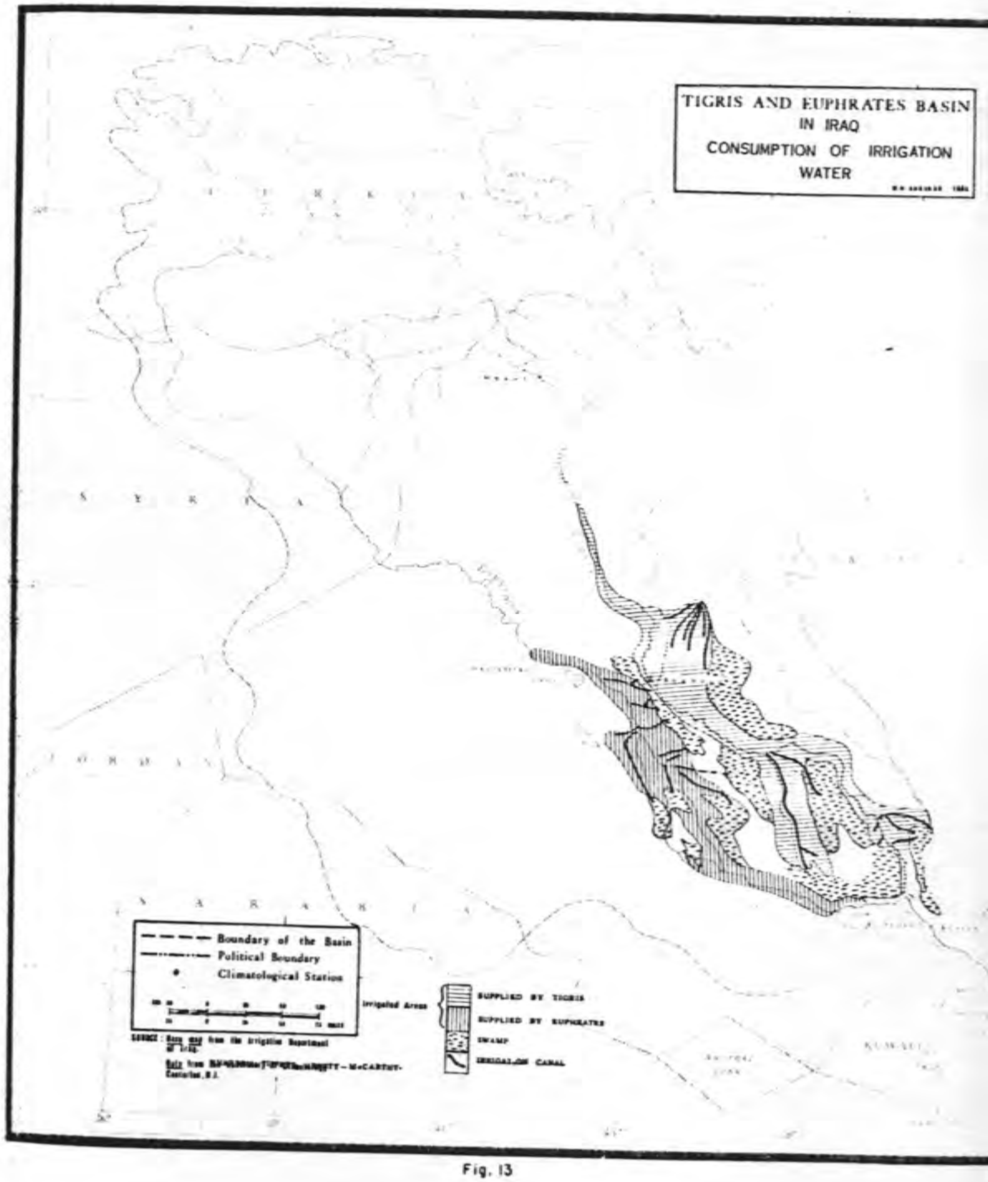

Fig. 13

TABLE 13

ACREAGE AND CROP PATTERN OF THE IRRIGATED AREAS IN IRAQ[a]
(In 1,000's)

	Euphrates		Tigris		Total	
	Acres	Meshars	Acres	Meshars	Acres	Meshars
Gross area	3,068	4,912	4,990	8,127	8,006	13,039
Cultivable area ..	2,414	3,931	3,992	6,501	6,406	10,434
Crop pattern perennial	308	502	401	653	709	1,155
Annual	1,509	2,475	2,528	4,118	4,037	6,575
Acreage irrigated every year:						
Area planted to crops Dec.-May[b].	1,817	2,959	2,929	4,771	4,746	7,730
Area planted to crops June-Nov.[c]	462	752	650	1,059	1,112	1,811

[a]Data compiled from Knappen, Tippetts, Abbett, McCarthy Engineers, Development Plan for the Tigris and Euphrates Rivers, Iraq (Baghdad: The Development Board, 1955), chap. v, pp. 24-26, 34-36.

[b]This period represents shitwi (Winter) cultivation and includes wheat, barley, beans, and all the perennials, such as alfalfa, citrus fruits, dates, and deciduous fruits.

[c]This period represents saifi (Summer) cultivation. In addition to the perennial crops, rice, cotton, and vegetables are irrigated during this season.

Two seasons of irrigation cultivation are recognized in Iraq. The shitwi (Winter) season extends from December to May and the saifi (Summer) season extends from June to November. During the shitwi season both the perennial and the annual crops are irrigated. During the saifi season, irrigation is practiced only on the perennials and some few annual crops, such as rice, cotton, and vegetables. Although the total cultivated irrigated acreage amounts to 4.7 million acres (7.7 million meshars), water is provided for irrigating about 5.9 million acres (10 million meshars) of crops.

Types of Irrigation Withdrawals

Water is withdrawn from the river for the irrigated areas in two different ways, by gravity and by pumping. In the gravity

method water is diverted from the rivers through canals which are designed to be lower than the natural level of the river and to utilize the difference in elevation for water flow. These canals are usually constructed by making a break in the river's bank so that the water will flow through. There is very little control over the amount of water which flows in such canals and, especially during the season of large supply, a tremendous amount of water enters the canals and floods the cultivated areas. Half the irrigated areas in Iraq are supplied with water by gravity. On the remainder of the area, installation and operation of pumps for irrigation is controlled by the government through a licensing system.[1]

In both diversion methods the water is supplied from canals and laterals to the cultivated areas through ordinary flooding. The water flows from the field ditches without any levees to guide it. This method is used primarily because of the low expense involved in water application.

Consumption of Water in Irrigation

The consumptive use of water in irrigation is defined as the loss of water through evaporation and transpiration from land covered by vegetation of any kind.

The initial water supply to satisfy the consumptive use is precipitation. If the precipitation is available in sufficient amount during the growing season, it may satisfy the consumptive use of the plants. In many cases the precipitation does not coincide either in time or in amount with the consumptive use. Under these circumstances irrigation will be necessary for plant growth. The amount of water, exclusive of precipitation, which is needed for the growth of the plants is computed from the consumptive use minus precipitation, corrected for soil moisture availability.

The estimation of the consumptive use of water on the basis of climatological data has been practiced by irrigation engineers for many years. In 1924, G. R. Hedke developed the effective heat method to determine consumptive use.[2] In 1940, Robert L. Lowry and Arthur F. Johnson found a linear relation between annual consumptive use of water and heat supply.[3] In 1941-1942, Karl V.

[1]Knappen, Tippetts, Abbett, McCarthy Engineers, op. cit., p. 3.

[2]I. E. Houk, Irrigation Engineering (New York: John Wiley and Sons, 1951), I, 35.

[3]R. L. Lowry and A. F. Johnson, "Consumptive Use of Water

Morin and Harry F. Blaney developed formulas for consumptive use of water from temperature, daytime hours, and humidity records. In 1945, Wayne D. Criddle and Blaney simplified one of the formulas and developed the present version of their method.[1] In 1944, C. W. Thornthwaite developed a method for determining actual and potential evapotranspiration.[2] This procedure was utilized by D. B. Carter for determining the irrigation requirements in Northwestern United States.[3] Carter considered potential evapotranspiration as equivalent to the consumptive use. He constructed a hydrologic model in which only 80 per cent of the precipitation was considered effective in offsetting the consumptive use. In this way irrigation requirements were computed as the difference between the potential evapotranspiration and the effective precipitation, with certain considerations of the available soil moisture storage.

Potential evapotranspiration can also be utilized to compute irrigation requirements in Iraq since it may be substituted for the consumptive use of water. However, instead of considering precipitation effectiveness as 80 per cent of the total precipitation, it must be considered as 100 per cent because estimates of precipitation effectiveness are not available for Iraq. Although a discrepancy may occur by such an assumption, the discrepancy will be quite small since the average annual precipitation falling over the irrigated areas amounts to less than 300 mm.

In 1952, the irrigation requirements of Iraq were computed by Knappen, Tippetts, Abbett, and McCarthy engineers by applying the Blaney-Criddle method for determining the consumptive use of water by plants. The data of the climatological station at Hillah, Iraq, can be utilized to illustrate the difference between the estimates of the Blaney-Criddle method and the Thornthwaite water balance method. Results are summarized in Table 14. The estimated irrigation requirements for Hillah according to the Blaney-Criddle

for Agriculture," Transaction of American Society of Civil Engineers, CVII (1942), 1243-1302.

[1]Harry F. Blaney, "Climate As an Index of Irrigation Needs," Water, Yearbook of Agriculture (Washington, D.C.: Government Printing Office, 1955), p. 343.

[2]C. W. Thornthwaite, op. cit.

[3]D. B. Carter, "The Relation of Irrigation Efficiency to the Potential Development of Irrigated Agriculture in the Pacific Northwest" (Unpublished Ph.D. dissertation, University of Washington, Department of Geography, 1957).

method are greater than the estimates based on the potential evapotranspiration of the Thornthwaite water balance method. However, there is no convincing demonstration of the applicability of the Blaney-Criddle method, which is based on somewhat subjective judgments of each crop's needs for water in various environments. But the Thornthwaite water balance method has already been demonstrated to be applicable in the Tigris and Euphrates basin, which gives it an advantage over the Blaney-Criddle method.

TABLE 14

COMPARISON OF ESTIMATED IRRIGATION REQUIREMENTS OF HILLAH, IRAQ
(In Millimeters)

Consumptive Use Method		Precipitation[b]	Irrigation Requirements Method	
Blaney-Criddle[a]	Thornthwaite[b]		Blaney-Criddle[a]	Thornthwaite[b]
1,907	1,271	168	1,649	1,103

[a]Data compiled from Knappen, Tippetts, Abbett, McCarthy Engineers, Development Plan for the Tigris and Euphrates Rivers, Iraq (Baghdad: The Development Board, 1955), chap. v, p. 38.

[b]Data obtained from the Laboratory of Climatology, Centerton, N.J.

The volume of water consumed in irrigation in Iraq was computed by the Thornthwaite water balance method from the average monthly water deficit of eleven climatological stations which are located either within the irrigated tracts or close to them. The criterion for choosing the stations was that they should represent average conditions for the irrigated area in terms of both the potential evapotranspiration and precipitation values. The average monthly water deficit of the representative stations was multiplied by the size of the irrigated tract to get the volume of the withdrawal which is consumed; these values are shown in Table 15.

Because irrigation is not required for about half the Winter season, the irrigation consumptive uses shown in Table 15 are negligible from December to February in either river basin. This period of no irrigation consumption extends into the beginning of March, in the Tigris. In March and April the irrigation requirements increase at an accelerated rate until they reach the maximum

TABLE 15

AVERAGE MONTHLY IRRIGATION CONSUMPTIVE USE IN IRAQ
(Million Cubic Meters)

Irrigated Area	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Tigris[a]	.....	.....	17	565	1,637	540	541	487	352	74	.....	.....	4,213
Euphrates[b]	.....	13	74	438	1,006	74	76	74	65	37	7	.....	1,864
Total	.....	13	91	1,003	2,643	614	617	561	417	111	7	.....	6,077

[a]Based on average monthly water deficit at Baghdad, Baiji, Basrah, Khaniquin, Kut, and Mosul.

[b]Based on average monthly water deficit at Diwaniyah, Habbaniyah, Hillah, Nasiriyah, and Ramadi.

in May. After May the volume of the irrigation consumptive use drops considerably since the actual irrigated acreage is much less than that in the Winter season. The irrigation consumptive use of Iraq, at present, amounts to 6,077 million cubic meters of water annually. This amount corresponds to an average depth of about 315 mm. of water over the total presently irrigated areas.

Non-Consumptive Use of Water in Irrigation

Besides the diminution of the water supply to satisfy the consumptive use of the crops, certain losses are entailed in irrigation practices, such as farm losses through deep percolation and seepage. A large part of the losses are possibly economically justifiable under the present inefficient irrigation practices in order to assure that the amount of water which will be delivered to the crops is at least sufficient for the irrigation requirement.

It is a common belief among the farmers in Iraq, as in other parts of the world, that the application of more water to the crops will bring more growth and a larger harvest from the crops. Thus, the amount of water which is actually diverted depends mainly on the supply. If the water actually diverted exceeds the requirement for consumptive uses plus the justifiable losses, the excess water may be designated as wasted water, since it is avoidable, unjustifiable, and not necessary. Unfortunately, little is known of the losses on the irrigated farms or from the canals and there are no comprehensive data on the volumes wasted in irrigation. However, the non-consumptive utilization of water cannot deplete the total supply over a long period and the water not consumed must therefore be incorporated as return flow with the remainder of the undiverted water supply. Large quantities of water may be stored below irrigated land and show themselves in a rising water table.

The swamps, which surround many of the irrigated areas, are the primary consumers of the lost and wasted water from irrigation. As shown in Figure 13, the entire irrigated areas in Iraq are bordered with swamps, and almost in all cases the canals which carry the diverted water end up in the swamps or close to them. The water which is diverted from the river goes through the following processes, illustrated in Figure 14. At the point marked 1, water is diverted from the river to be carried through the irrigation canal, 2, where part of it is lost through seepage and a small part is consumed by evapotranspiration. The remainder is applied

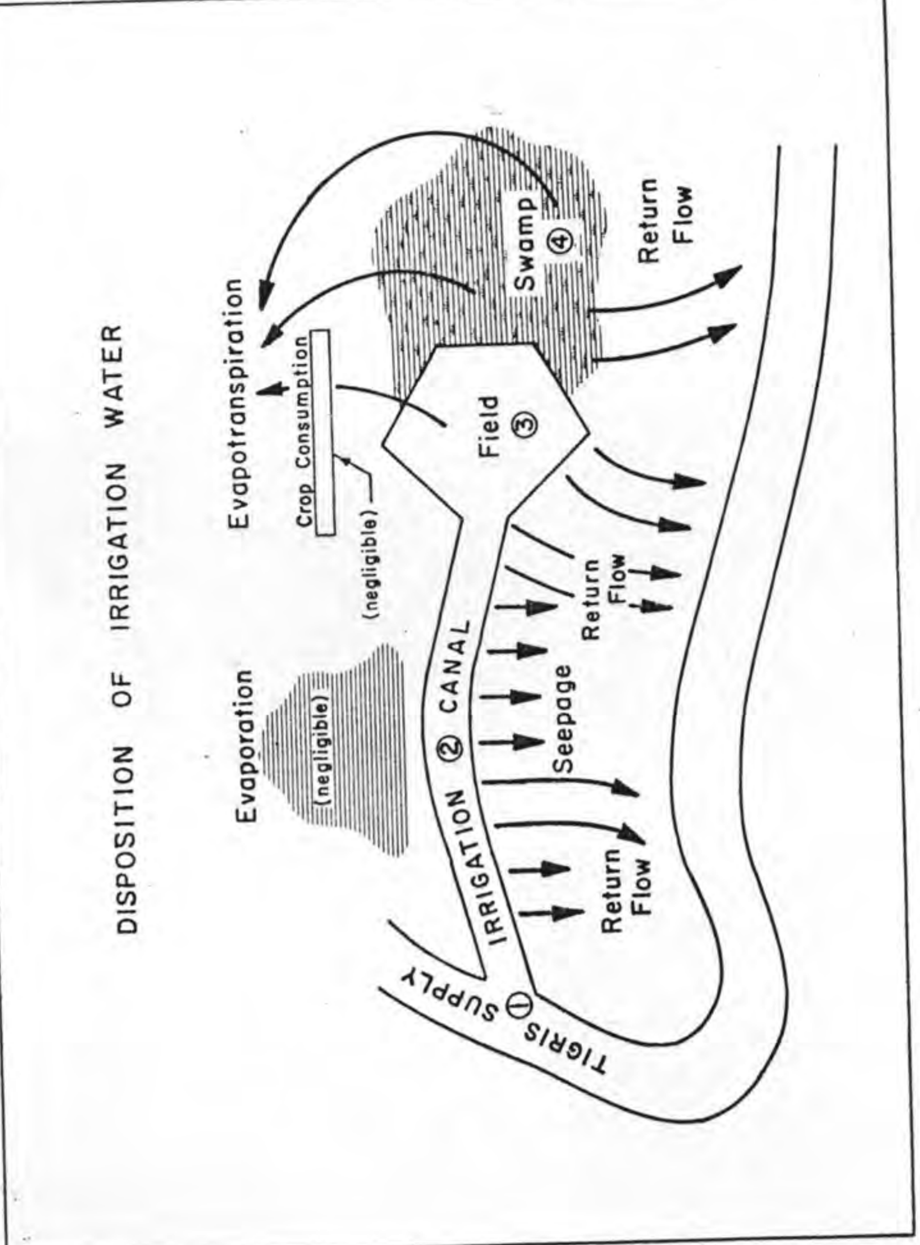

Fig. 14

to the field, 3, where a large part is consumed by the plants and by evaporation, but probably a larger part is lost through deep percolation. What is left will flow into the swamps directly, 4, but the swamps also receive the flow from seepage and deep percolation through the soil. The swamps present an exposed water surface during parts of the year and much water is consumed from them by evaporation and transpiration.

Withdrawal Losses of Water by Swamps

In addition to the consumptive uses in irrigation, the swamps dissipate further large amounts of the water supply of Iraq. The difference between the large volume of water carried into the irrigation and swamp zone of Iraq by the combined water sources and the small volume of water carried away from the irrigation and swamp zone to the Persian Gulf by the Shatt-al-Arab reveals the consumption of water swamps and irrigated lands. The incoming water supply to the irrigated zone is the sum of the Euphrates, Tigris, and Diyalah streamflows, 71,000 million cubic meters. The outflow in the Shatt-al-Arab is 27,000 million cubic meters. The water consumed through irrigation and through the swamps is thus 44,000 million cubic meters. Deducting the consumption for irrigation, 6,077 million cubic meters previously determined, leaves the consumption in the swamps as 38,000 million cubic meters. There is no estimate of the volume of water stored underground as revealed by rising water tables.

The volume of water evaporated from the swamps also depends upon the extent and the character (seasonal or year-round) of the swamps and the rate of evaporation and precipitation which, of course, comprise the water deficit. It can be seen from Figure 8 that the northern limit of the swamps lies between the 1,100 mm. and 1,200 mm. isarithms of average annual water deficit and the southern limit lies between the 1,200 mm. and 1,400 mm. isarithms.[1] An average of 1,300 mm. of water deficit is therefore taken as representative of the consumption from the swamps areas.

The extent of the swamps in Iraq is not exactly known. No attempts have been made to do any actual mapping of the swamps in the country. The various available maps of Iraq indicate only the general location of the swampy areas with no distinction between

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[1] D. B. Carter, "Maps of Water Requirements for Southwest Asia," loc. cit., p. 8.

permanent or seasonal swamps. However, the water deficit, 1,300 mm., suggests that the swamp area should be about 30,000 square kilometers in order to account for the depletion of stream flow of 38,000 million cubic meters attributed to the swamps. An average area of swamp of 30,000 square kilometers is slightly over 5 per cent of the total area of the country. This estimate of the swamp area is not far different from an earlier one made by Boesch, in which he considered the area of the swamps as 5 per cent of the total area of the country.[1]

However, part of the swamps is seasonal in character. In this case, the swamps have less water than the year-round swamps. Inasmuch as data are not available to show the extent and location of this type of swamps, the author assumed, tentatively, that it comprises at least 25 per cent of the total estimated area of swamps in the country. Evaporation from the seasonal swamps is less than that of the year-round swamps and probably does not exceed half of the annual evaporation rate, about 650 mm. Under these assumptions, about 28,000 million cubic meters of water evaporate from the year-round swamps (21,000 square kilometers multiplied by 1,300 mm. of evaporation rate), and approximately 5,000 million cubic meters evaporate from seasonal swamps (7,500 square kilometers multiplied by 650 mm. of evaporation rate). All the swampy areas in Iraq account for the evaporation of about 33,000 million cubic meters in the average year. If the total crop consumption of the irrigated areas (about 6,000 million cubic meters annually) is added to the estimated total evaporation from the swamps (about 33,000 million cubic meters) and the total (about 39,000 million cubic meters) is subtracted from the total depletion (about 44,500 million cubic meters), a total ranging between 4,000 and 5,000 million cubic meters of water remains unaccounted for. This amount is neither consumed by crops, nor evaporated from the swamps. Furthermore, it is not returned to the water source (rivers). It may then be assumed that this water usually seeps to the water table of the irrigated areas. The fact that the water table of the irrigated areas is rising encourages such an assumption. But until the data on fluctuations of the water table in the irrigated areas become available, this figure remains only as a rough estimation.

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[1]H. Boesch, loc. cit., p. 35.

Other Withdrawal Uses

Other withdrawal uses in Iraq are residential, municipal, and industrial. These uses were ignored in previous water studies of Iraq either because they were considered relatively unimportant or because of lack of data.[1] Inasmuch as precise data are lacking it is necessary to estimate the water withdrawn for those uses in order to show their relative importance in the present water budget of Iraq.

The term "residential water use" is employed here to indicate water which is used in the residential units to satisfy ordinary household needs such as drinking, cooking, laundry and personal cleanliness. Municipal uses include the water used for parks, fountains, fire protection and street cleaning. Industrial water may be used either as raw material, as process water, or for miscellaneous services in the industrial plant.[2]

These uses are represented in fourteen cities, in which 32 per cent of the country's population live.[3] The remaining 68 per cent of the population lives in small villages where municipal and industrial water uses do not exist; the residential uses in these villages are satisfied from wells and from irrigation canal water. In the cities, the residential uses are supplied with water by the municipalities. All the industrial and municipal water uses are found in these cities.

Under the social and economic conditions prevailing in Iraq in 1957, residential, industrial and municipal uses of water are relatively unimportant in terms of the amount of water they withdraw. The low level of living, the low quality of the residential units, and the absence of sanitary conveniences make the per capita residential water consumption in Iraq lower than that in countries with higher gross national product such as the United States and the United Kingdom.[4] In the United States it has been esti-

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[1]The two most intensive studies of water utilization in Iraq, The Haigh Commission Survey, The Control and Utilization of the Rivers of Iraq, 1951, and the Knappen, Tippetts, Abbett, McCarthy Engineers report, The Development of the Tigris and Euphrates Rivers, Iraq, 1955, made no reference to these uses.

[2]Harry E. Jordan, "Industrial Requirements of Water," American Water Works Association, XXXVIII (1946), 66-67.

[3]International Bank for Reconstruction and Development, The Economic Development of Iraq, p. 127.

[4]Francis S. Friel, "How To Estimate the Future Water Supply Needs of a Growing Community," Water Works Engineering, CIX (December, 1956), 1114-15, 1136.

mated that the per capita consumption for residential uses is 50 gallons per day.[1] In Iraq, few houses have water installed for sanitary and drinking purposes, other water-using machines are rare, and the per capita consumption may be expected to be considerably less.

Municipal uses are limited in number and restricted to three large cities of Baghdad, Mosul, and Basrah. Fire departments are limited to these cities. Parks are rare. In Mosul, the second largest city in Iraq, there are only two parks, neither of which exceeds 200 acres in size. Street washing is carried on in the larger cities during the Summer season only. If similar municipal uses of water in the United States, where they are carried on to a much greater extent, are estimated to be 10 gallons per day, it is justifiable to assume that the per capita use in Iraq is lower than 10 gallons per day, and probably not more than 4 gallons per capita per day.[2]

Industrial use of water can be expected to be small in Iraq since it has none of the major water-using industries; that is, steam electric plants, steel industry, and wood pulp industry. Oil refining is carried out in a limited scale. The aforementioned industries account for about 80 per cent of the total industrial water intake in the United States.[3] The number of employees in manufacturing in the country amounts to 90,291, of which half are engaged in industries which do not use significant amounts of water--for example, tailoring, shoemaking, carpentry, and the tobacco industry.[4] Industries which use water such as the soap, cement, fruit-packing, and dairy industries, exist on a small scale.

Water for residential, municipal, and industrial uses in Iraq is obtained from the municipal supply, which is in all instances a government enterprise. The supply depends primarily on the waters of the Tigris and Euphrates and their tributaries, be-

[1] H. F. Jordan, "The Problems That Face Our Cities," Water, A Yearbook of Agriculture, 1955 (Washington: Government Printing Office), p. 651.

[2] Ibid.

[3] Jack B. Graham and Meredith F. Burrill, Water for Industry, American Association for the Advancement of Science, Publication No. 45 (Washington, D.C.: The American Association for the Advancement of Science, 1956), p. 109.

[4] Government of Iraq, Ministry of Economics, Principal Bureau of Statistics, Statistical Abstract, 1955 (Baghdad: Zahra Press, 1956), p. 100.

cause underground water is not utilized at present. To the best of the author's knowledge, private wells are not used on a large scale at this time to meet these uses. The total amount of water withdrawn for these uses is known through the official statistics, but the amount of water used for each purpose is not available. It is therefore necessary to estimate the amount of water used for each purpose within the reported total withdrawal.

The amount of water used for residential purposes was computed according to per capita per day consumption of water. The latter was estimated by using two samples, selected from two large cities in Iraq, Baghdad, and Basrah. More than 90 per cent of the families in Baghdad have water piped into their homes.[1] Data are not available on Basrah to estimate such a percentage; however, the author's familiarity with the city encourages him to assume that the situation is not too different from that in Baghdad. (The samples were selected by the Directorate of the Municipal Water Supply of Baghdad and Basrah in response to the request of the office of the cultural attaché of the Embassy of Iraq in Washington, D.C.) The Baghdad and Basrah samples were taken in residential quarters where water use is metered. Each sample contains two hundred single-family residential units. The water bought in each of these units was obtained from the offices of the above-mentioned directorates for the year 1955. The data for the whole year were added together, and then averaged, to obtain a figure for average family water consumption per year. The average annual per capita consumption was obtained by applying the average family size in Iraq of six persons. The application of this figure to the population of the cities is assumed to provide a rough approximation of water used for residential purposes.

Table 16 explains the steps for obtaining the average annual per capita water use for residential purposes.

The estimated daily per capita use in Iraq is similar to the estimated maximum per capita daily water use in Aleppo, Syria, which reached 25 gallons in 1952.[2] It is also similar to the estimated per capita use of 20 gallons in Karachi, Pakistan, and of

[1] The Committee of Water Supply of Baghdad, Administrative Report of 1953, Report No. 27 (Baghdad: Rabbita Press, 1956), p. 5.

[2] Ernst Walter, "Die Wasserversorgung Aleppos," Gas und Wasser Warme, XI, 2 (1957), 33.

17 gallons in Mandalay, Burma.[1] Thus, the per capita water use in Iraq for residential uses is quite similar to that of areas in which the same type of culture, a similar level of living, and a similar agricultural economy, prevail.

TABLE 16

ESTIMATED AVERAGE DAILY PER CAPITA CONSUMPTION OF WATER IN BAGHDAD AND BASRAH, IRAQ
(Range of Consumption
Gallons Per Unit Per Year)

Sample	Number of Units	Maximum	Mean	Minimum	Total Gallons of Water Bought (p.a.)
Baghdad	100	95,000	39,600	22,000	3,960,000
Basrah	100	102,000	30,039	7,400	3,039,000
Total: 2 samples	200	102,000	34,999	7,400	6,999,000

1. $\frac{6,999,000}{200}$ = 34,999 gallons per family per year

2. $\frac{34,999}{6}$ = 5,833 gallons per capita per year

3. $\frac{5,833}{365}$ = 16 gallons per capita per day

Using the estimate of 16 gallons per day per capita, the annual residential water use in the urban areas of Iraq amounts to 46 million cubic meters. The residential use of water is expected to be relatively less in rural areas because water is there less readily available, and because conveniences usually identified with urban areas are absent. The rural per capita consumption of water will probably not exceed half that of the urban consumption. If the urban per capita consumption were applied to the rural population, the maximum present residential water use in Iraq would amount to 132 cubic meters annually (29,040 million gallons), or the equivalent of 5,833 gallons per capita, 34,999 gallons per family, per year.

[1]United Nations Economic Commission for Asia and the Far East, Water Resources Development in Burma, India and Pakistan, Flood Control Series No. 11, Part 2 (Bangkok: United Nations Publication, 1956), pp. 93, 43.

At present, estimates of livestock consumption of water in Iraq are not available. Such estimates are available in the United States; these can be used to obtain a rough estimate of the livestock water consumption in Iraq. In the Cheyenne River Basin of the United States it is generally conceded that cattle consume about 10 gallons of water per day.[1] If this estimate is applied to the total livestock population of Iraq (7,500,000 in 1955), the water consumption of livestock in the country should amount to about 125 million cubic meters annually, none of which is assumed to be used non-consumptively. Livestock are usually supplied with water from the irrigation ditches, especially in the Mesopotamian trough, unless they are owned by the Bedouins. In the latter case wells in the scattered Bedouins camps--mainly in the western desert and Al-Jazira areas--are the major source of water. The estimated livestock consumption is not greatly different from the total estimated residential water use of the country.

Because both the municipal and industrial water uses depend upon municipal water supply, the municipal water withdrawal may be taken to represent those uses plus the urban residential water use. The municipal water uses were considered to be 25 per cent of that of the United States, in order to arrive at an approximate figure of such water use in Iraq. On this assumption, the municipal water use in Iraq amounts to 7 million cubic meters annually. The industrial water use for each municipality will then represent the difference between the total water withdrawn and the amount of water used for urban residential and municipal purposes. It is recognized that other methods, such as water use per unit of product or water use for employee, might be used to estimate water use in industry.[2] However, statistics concerning the amount of manufacturing production are not available in Iraq; the employees are not classified according to the type of industry in which they are engaged. Accordingly, the previously suggested method is considered to be satisfactory, at least in that it gives a general estimate.

As shown in Table 17, the estimated water use for industry amounts to 29 million cubic meters annually, which is about two-thirds as much as that used for residential use. The industrial

[1]R. C. Cwiller and H. V. Peterson, Effect of Stock Reservoirs on Runoff in the Cheyenne River Basin Above Angostura Dam, U.S. Geological Survey Circular 223 (Washington: U.S. Government Printing Office, 1953), p. 12.

[2]National Association of Manufacturers and the Conservation Foundation, Water in Industry (New York, December, 1950), p. 23.

TABLE 17

WATER WITHDRAWAL FOR RESIDENTIAL, MUNICIPAL, AND INDUSTRIAL USES IN THE MUNICIPALITIES OF IRAQ
(In Million Cubic Meters)

Urban Area	Population[a]	Water Withdrawn[b]	Residential and Municipal Use (Estimated)[c]	Industrial Use (Estimated)[d]
Mosul	273,000	8.0	7.8	negligible
Diwaniyah.	61,000	2.6	1.8	0.8
Montafiq .	81,000	1.9	1.9	negligible
Basrah ...	219,000	8.9	6.3	2.6
Ammarah ..	192,000	1.0	1.0	negligible
Kurkuk ...	147,000	11.6	4.2	7.5
Karbala ..	71,000	1.8	1.8	negligible
Diyalah ..	42,000	1.7	1.7	negligible
Hilla	80,000	0.7	0.7	negligible
Arbil	69,000	1.4	1.4	negligible
Baghdad ..	558,000	34.3	16.1	18.3
Sulmaniyah	79,000	0.8	0.8	negligible
Kut	81,000	0.7	0.7	negligible
Dulaim ...	85,000	0.7	0.7	negligible
Total.		76.1	46.9	29.2

[a]Government of Iraq, Ministry of Economics, Principal Bureau of Statistics, Statistical Abstract, 1955 (Baghdad: Zahra Press, 1956), pp. 2-3.

[b]Ibid., p. 195.

[c]Based on samples selected from Baghdad and Basrah.

[d]Estimated as the difference between water sold in the municipalities and the residential and municipal water uses of those municipalities.

use of water is significant only in three cities: Baghdad, Kirkuk, and Basrah. Mosul uses a negligible amount because the industries existing there, such as tailoring and shoemaking, are not water-using ones. It is noticed that more than 50 per cent of the industrial water was used in Baghdad (18.3 million cubic meters), where approximately half of the industries employing twenty persons or more are located.[1] Kirkuk, the leading oil producer in Iraq, is second after Baghdad, while Basrah, the largest date-producing and packing center, is third.

[1]J. A. Salter, op. cit., p. 71.

The total water withdrawn for residential, municipal, and industrial water uses in Iraq, both in cities and rural areas, amounts to approximately 168 million cubic meters annually. In the United States it has been reported that cities rarely consume more than 10 per cent of their water withdrawals, the remainder being returned to the water source.[1] If this figure is applied to Iraq, the amount of water consumed by these uses can be summarized as follows:

TABLE 18

ESTIMATED CONSUMPTION OF RESIDENTIAL, MUNICIPAL, INDUSTRIAL AND LIVESTOCK WATER USES IN IRAQ
(In Million Cubic Meters Annually)

Use	Withdrawal	Consumptive	Non-Consumptive
Residential			
Urban	46	4.6	41.4
Rural	86	8.6	77.4
Municipal	7	.7	6.3
Industrial	29	2.9	26.1
Livestock	125	125.0	....
Total	293	141.8	151.2

If the 10 per cent figure were accurate for Iraq, the amount of water consumed by these uses would be less than .003 per cent of the total water consumption for all purposes. Even if all the withdrawn water were consumed, it would account for less than .03 per cent of the total consumption for all purposes. It would be conservative, when computing the water consumption of Iraq, to assume that all the water withdrawn for these uses is consumed, 100 per cent, because sewage systems, which facilitate the return of the unconsumed water to the stream or to the ground storage do not exist in Iraq at this time.

The amount of water withdrawn for these uses is less than .25 per cent of the mean water supply and less than .33 per cent of the minimum supply. The uses, therefore, are relatively insignificant in terms of the amount of water withdrawn by them.

[1]G. F. White, "The Facts About Our Water Supply," Harvard Business Review, XXXVI, No. 2 (March-April, 1958), 88.

Non-Withdrawal Uses

Navigation on the lower Tigris constitutes the major non-withdrawal water use. Hydroelectric power has not been considered in the study because it does not exist at this time. Furthermore, the government plan to utilize the storage reservoirs on the tributaries of the Tigris to generate hydroelectric power has been tentatively drawn and limited to Bekhme Reservoir only to generate 600,000 Kw. There is no indication that such a plan will be carried out in the near future.

Navigation is mainly practiced between Baghdad and Basrah, a reach where railroads do not exist and where roads are unpaved (Fig. 15). Different types of craft are used in navigation, ranging from steam or Diesel-powered tow-boats with a draft of one-and-one-half meters, to barges of shallow draft, about one meter, and smaller craft propelled by sail.

Except for petroleum, no statistical information is available about the type of materials transported by river, although the principal items are assumed to be cereals, bricks, hides, sand, and gravel. Petroleum is transported from Basrah to the rural communities upstream which use white oil for heating, cooking, and light; and black oil for operating the pumping machines for irrigation.

The required depth for the present practiced navigation is 1.4 meters below Baghdad, which corresponds to an average discharge of 275 cumecs.[1] Below Ammarah the required depth is 1.8 meters, which corresponds to an average discharge of 60 cumecs.[2] When the river is at a lower depth a series of pools form with crossings (shoals) between them, making navigation difficult or impossible for all except small craft of less than one meter.

Except during the dry years, navigation is usually practiced between Baghdad and Ammarah without difficulty. Figure 16 shows that the mean supply provides an adequate depth for navigation throughout the year. During the dry years navigation is faced with difficulties during Summer and early Autumn. For example, during the year of 1951, the supply of the Tigris was below the mean at Baghdad. The number of journeys made upstream decreased from 295 in 1950 to 190 in 1951. Similarly, a decrease occurred in the downstream journeys from 398 to 180. The depth of the river was inadequate during

[1]Knappen, Tippetts, Abbett, McCarthy Engineers, op. cit., chap. iv, p. 19.

[2]Ibid., p. 25.

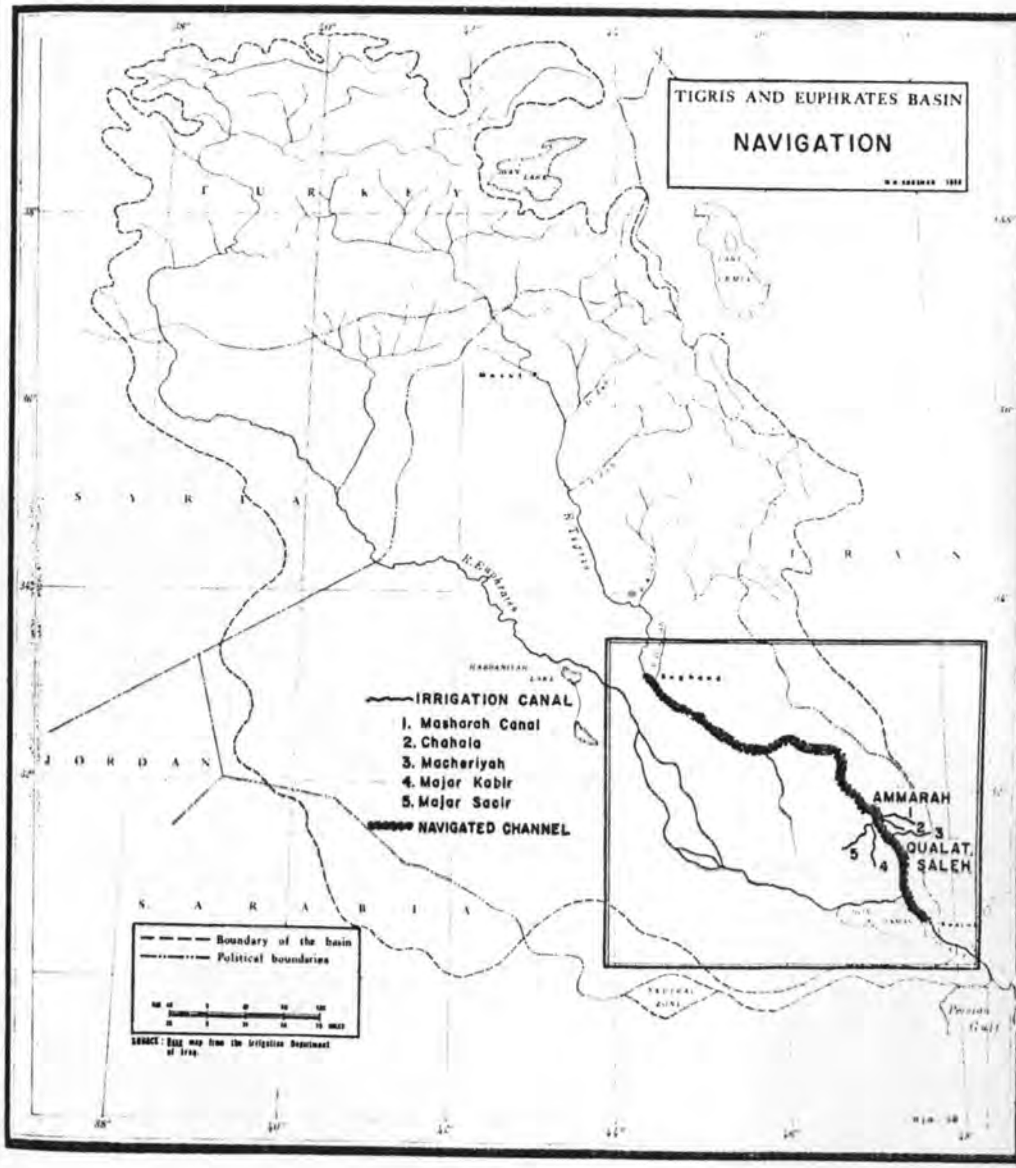

Fig. 15

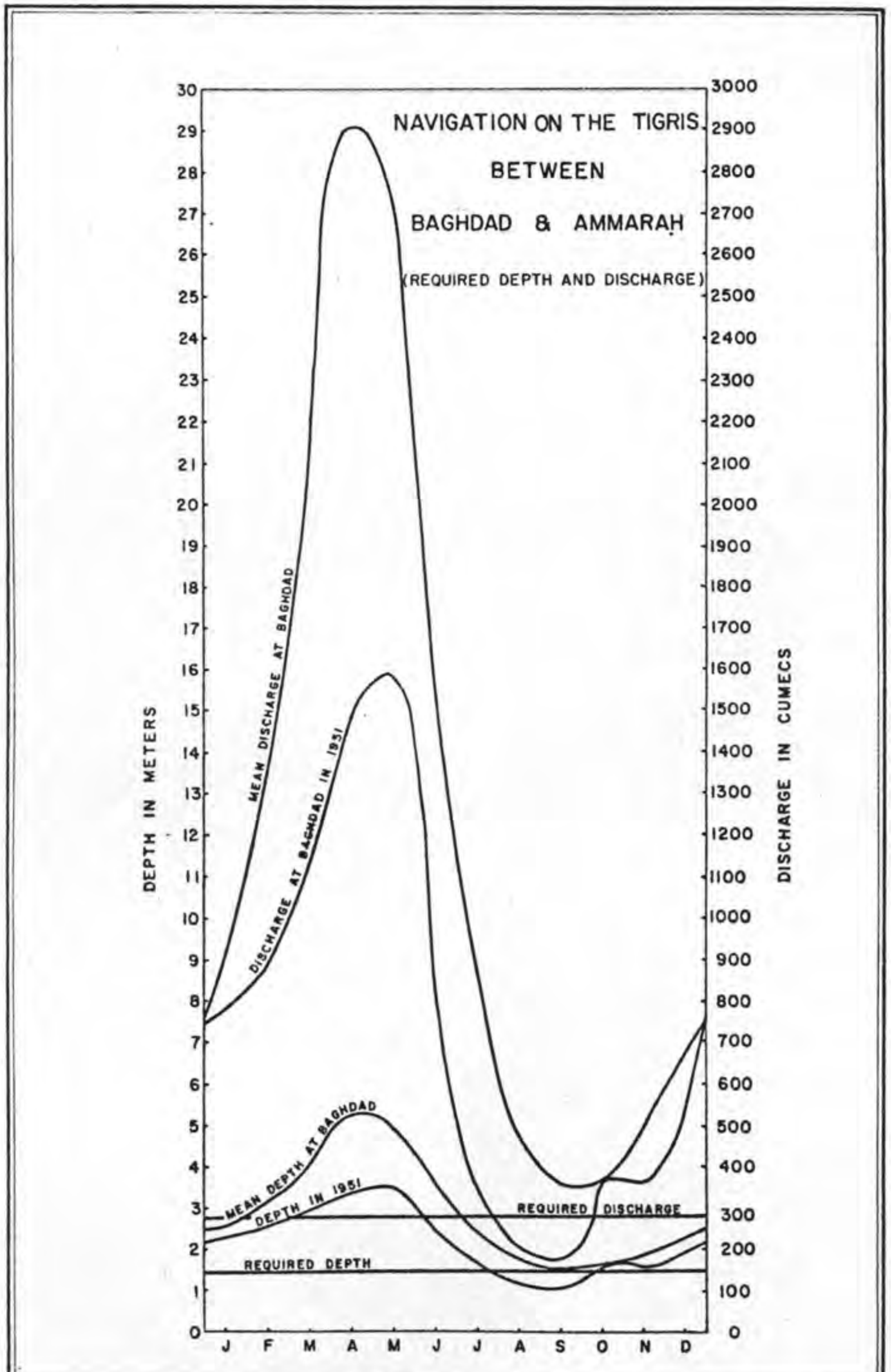

Fig. 16

the last part of July and during all of August and September. The discharge in August amounted to 213 cumecs, while in September it was 177 cumecs, both of them lower than the required discharge of 275 cumecs. In the same year the total tonnage moving downstream decreased from 17,931 tons in August and 14,910 in September of 1950, to 5,925 and 5,537 tons in the corresponding months of 1951.[1] The agricultural communities in both Ammarah and Basrah Liwas (States) were affected seriously, since there were no facilities to ship their fruits and vegetables to the north, mainly to Kot and Baghdad, which constitute the major market for such products.

At Ammarah the mean supply of the river provides a depth of more than the 1.8 meters required for navigation. During 1944, a dry year similar to 1951, the supply was not enough to maintain the necessary depth during September and October, as indicated by Figure 16. However, the depth provided by the mean supply of the dry year supply, does not give a true picture about the navigation conditions below Ammarah. Downstream from Ammarah the discharge and the corresponding depth decreases rapidly, both under the mean and the dry year conditions, to a depth which is inadequate for navigation. As shown in Figure 17, the depth of water in Qualat Saleh, a short distance south of Ammarah, was below the required depth from the end of July to the end of December, under the mean condition of the supply, and for a longer period, from the end of June until the end of March, in the dry year of 1944. It is in this part of the Tigris, south of Ammarah, that all the difficulties of navigation are to be found. A short distance below Ammarah the water of the Tigris is diverted for irrigation. The diversion is carried out through canals located above Qualat Saleh, shown in Figure 15. These canals--Chahalah, Masharah, Majar Kabir and Macheriyah--irrigate an area of 434,520 acres in the vicinity of Ammarah. The flow in the canals is not controlled or regulated because the beds of these canals are lower than that of the Tigris (the Chahalah canal has a bed which is 2 meters lower than that of the Tigris), and because the general tendency among the farmers is to get as much water to the field as possible, a tremendous amount of water from the Tigris River enters these canals. The result is a decrease in the supply of the main river to a level which is inadequate for navigation.

The conflict between irrigation and navigation over the available Tigris River water gradually became more severe as the irrigatio

[1]*Ibid.*, p. 24.

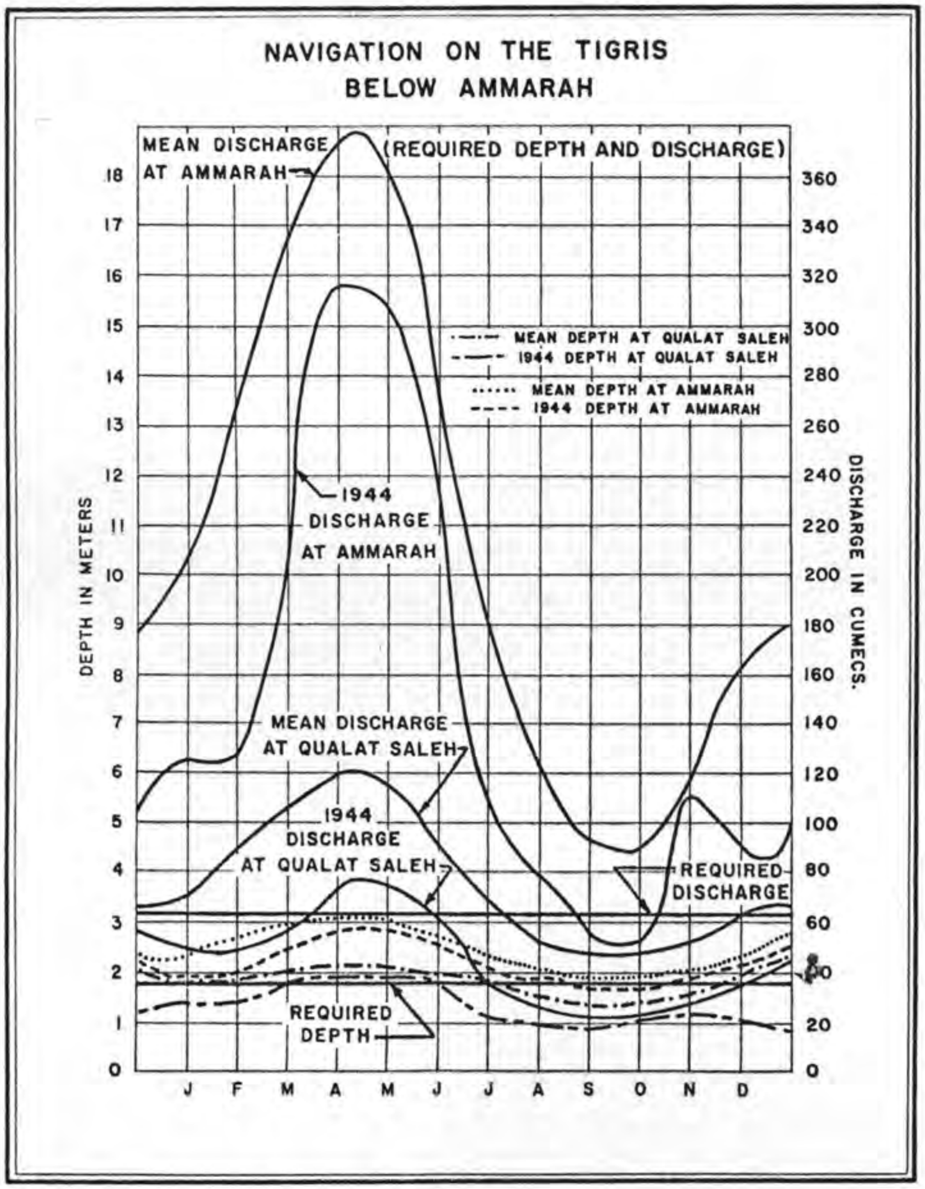

Fig. 17

expanded, until it reached the stage at which the oldest navigation company on the Tigris ceased operation late in 1950. As early as 1917, Sir William Willcocks, referring to the irrigation canals below Ammarah, pointed out that "these canals endanger the navigation of the river and constitute a serious menace to the existence of the river."[1]

The proposed reservoirs on the tributaries of the Tigris--Derbendi Khan, Dokan, and Bekhme--will be operated according to the plan adopted by the government, which seeks to maintain the require depth (1.8 meters) for year-round navigation between Baghdad and Basrah every year.

Water will evaporate from the surface of these reservoirs. The loss through evaporation depends upon the evaporation rate, pre cipitation, and the size of the evaporating surface of the reservoirs. The areas inundated by the waters of the reservoirs are est mated to be about 300 square kilometers. The isarithm of 1,000 mm. of average annual potential evapotranspiration passes, roughly through the areas of the reservoirs (Fig. 7). Similarly, the isarithm of 500 mm. of average annual precipitation passes through the reservoir areas (Fig. 6). Accordingly, the possible amount of wate loss through evaporation would be the difference between potential evapotranspiration and precipitation, 500 mm. (not too different fr the isarithm of annual water deficit passing through the reservoir areas), multiplied by the total evaporating surface of 300 square kilometers or the equivalent of about 150 million cubic meters annu ally. This estimation is based on the assumption that evaporation from the water surface is similar to that of the ground. Actually, evaporation from the water surface is less than from the ground sur face. C. W. Thornthwaite reported that evaporation from inland ground pans, in some of the areas which he investigated, was more than two-and-one-half times that from an inland sea.[2] He also indi cated that in other areas the evaporation from a surface of a lake was 83 per cent as great as the evaporation from a neighboring ground pan.[3] If we assume that the evaporation from the surface

[1] W. Willcocks, Irrigation of Mesopotamia (2d ed.; London, 1917), p. 30.

[2] C. W. Thornthwaite, "Climatology in Arid Zone Research," The Future of Arid Lands, Papers and Recommendations from the Inter national Arid Lands Meetings, Publication No. 43 of the American As sociation for the Advancement of Science (Washington, D.C.: American Association for the Advancement of Science, 1956), p. 72.

[3] Ibid., p. 73.

area of the reservoirs in Iraq is less than that actually indicated on the ground (the 1,000 mm. isarithm of potential evapotranspiration) at least by 20 per cent, the water loss will be about 120 million cubic meters annually--the same magnitude as the estimated residential use of water in Iraq (Table 18).

The previous estimation of water loss through evaporation, based on either 500 mm. or 300 mm. rate of water loss, is far less than the estimate made by Knappen, Tippetts, Abbett, McCarthy Engineers, which is in the magnitude of 2,600 mm. annually.[1] This estimate was not based on actual observations in the proposed reservoir areas, but rather adopted from the available evaporation records of Lake Habbaniyah, as based on inflow-outflow measurements of water in the lake. The lake is located considerably to the south of the reservoir areas, where temperature is higher and precipitation is much lower; consequently, the water loss--according to Knappen, Tippetts, Abbett, McCarthy Engineers' estimates--will amount to about 600 million cubic meters annually: 2,500 mm. (evaporation) minus 500 mm. (precipitation), or 2,000 mm. multiplied by 300 square kilometers. This estimate is twice as much as the estimated water withdrawn for all other water uses in Iraq, except irrigation.

It is evident that a price will be paid for storing the water. This is expressed in the amount of water which will be consumed by evaporation. However, the price is not likely to be as high as that estimated by Knappen, Tippetts, Abbett, McCarthy Engineers, because of the lower temperature in the reservoir areas. But even if we assume that evaporation will probably not exceed 120 million cubic meters, its importance is of the same magnitude as the amount of water consumed for residential purposes in the entire country (Table 18).

This evaporation is a factor that ought to be taken into account if a water budget is to be reckoned.

It is noticed that the estimates of the quantity of the different water uses are made for Iraq only leaving out the upstream areas of the basin--Al-Jazira in Syria and Turkey and the foothills and mountains areas in Turkey and Iran. The lack of essential data --irrigated acreage, types and amount of industries, total and distribution of population, and the number of livestock--make it rather difficult to make such estimates for those areas.

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[1]Knappen, Tippetts, Abbett, McCarthy Engineers, <u>op. cit.</u>, chap. iii, p. 16.

At present irrigation is carried out in the Syrian part of Al-Jazira (Fig. 1, 3a-2). Water is supplied by the Euphrates. Irrigation water consumption is estimated to be about 1,600 million cubic meters annually (Table 7), or equivalent to slightly over 20 per cent of the water consumed by the irrigated crops in Iraq. The other upstream areas have no reported irrigation water withdrawals.

As for the amount of water withdrawn by other water uses--residential, municipal, industrial, and livestock--it may be assumed that it is not too different from that withdrawn for the similar uses in Iraq (Table 18), because of the similarity in culture and level of living between Iraq and those areas. These uses may then be considered relatively insignificant in terms of the amount of water withdrawn by them.

CHAPTER IV

CONCLUSIONS

Southern Iraq, especially the Mesopotamian trough, constitutes the major area of water utilization in the Tigris and Euphrates basin. Water is mainly used for irrigation. Review of the water budget suggests that the present pattern of water utilization in irrigation is not conducive to the attainment of maximum benefits from the land, and is characterized by a great wastage which suggests that improvement of the present utilization may need to be considered as well as an expansion of irrigated areas.

The inevitability of conflict between irrigation and navigation, and the possible conflict among Iraq, Syria, Turkey and Iran, over the available water, indicate the need of international cooperation and coordinated planning for a wiser water utilization.

Auditing the Present Budget

The water supply of the Tigris and Euphrates basin is provided initially by precipitation falling in the mountains and foothills areas in Turkey, Iraq, and Iran. Turkey contributes the largest proportion of the supply, approximately 70 per cent; Iraq contributes 25 per cent; Iran contributes the remaining 5 per cent. Syria and Saudi Arabia do not contribute any significant amount to the initial water supply of the basin. Syria, though mentioned by Cressey as a contributor to the water supply of the basin, contributes nothing. The annual water surplus map (Fig. 9) supports this contention.[1]

During a normal year the water supply of the basin amounts to about 73,000 million cubic meters of water. Of this 65 per cent (47,014 million cubic meters) is supplied by the Tigris Basin. The remaining 35 per cent (about 26,410 million cubic meters) is supplied by the Euphrates. During dry years, the water supply of the basin is about 50,000 million cubic meters per annum.

The greatest proportion of the supply comes during the Spring

[1]G. B. Cressey, "Water in the Desert," loc. cit., p. 114.

season, March through May, in both river basins. Summer--especially September--is characterized by the lowest amount of supply.

At present, three physical areas located in four countries --Turkey, Syria, Iran, and Iraq--are involved in the utilization of the water supply of the basin. Two of these areas are parts of the first three countries, which are located upstream from Iraq: Al-Jazira in Syria and Turkey (Fig. 1, 3a-2 and 3a-3), and upper Khuzistan in Iran. The third area is the Mesopotamian trough (Fig. 1, 3b), which is located entirely in southern Iraq. Both the Al-Jazira and Khuzistan areas withdraw very little of the water supply. The Syrian part of Al-Jazira (Fig. 1, 3a-2), is the largest water withdrawer in the first two regions at the present, and consumes approximately 1,600 million cubic meters of water annually for irrigation (Table 7). Neither the Turkish part of Al-Jazira nor Khuzistan is making any significant water withdrawal at present.

A great part of the water supply is withdrawn and consumed in the Mesopotamian trough. The water is used for irrigational, residential, municipal, industrial, and navigational purposes. These uses in Iraq consume about 64 per cent of the average annual water supply of the Tigris and Euphrates basin. The remaining 35 per cent of the supply, 27,000 million cubic meters of water, flows through Shatt-al-Arab to the Persian Gulf, without being used, where it is dissipated.

In the Tigris Basin, as shown in Table 19, the average annual consumption amounts to about 38,000 million cubic meters. Almost all of it is consumed through irrigation. Other uses are unimportant, inasmuch as they consume only about 128 million cubic meters annually. Navigation requires about 9,000 million cubic meters of water annually to maintain a channel sufficient for floating vessels of drafts ranging between 1 and 1.5 meters. In the Euphrates the average annual consumption, as shown in Table 20, amounts to slightly over 9,000 million cubic meters. Here, too, the greater part is consumed by irrigation.

During the average year the water supply in both river basins adequately provides for the existing consumption. As shown in Figures 18 and 20, the mean supply exceeds the estimated water consumption throughout the year.

During dry years, however, a shortage of water occurs in the Tigris Basin (Fig. 19), whereas in the Euphrates Basin (Fig. 21), the minimum supply is sufficient for the estimated consumption.

TABLE 19

THE PRESENT WATER BUDGET OF THE TIGRIS BASIN[a]
(In Million Cubic Meters)

Use	Consumptive	Non-Consumptive	Total
Withdrawal[b]			
Irrigation	37,940	?[c]	37,940
Residential			
Rural	60	.....	60
Urban) Municipal).... Industrial)	68	.....	68
Non-Withdrawal			
Navigation	Insignificant	8,950	8,950
Total use	38,068	8,950	47,018
Dissipated	.....	.....	8,800
Supply			
Mean			47,014
Minimum			31,000

NOTE: Discrepancy in totals is due to rounding in build-up.

[a]The limited water withdrawals of the Turkish and the Iranian parts of the basin are not included.

[b]The table does not include water consumption by livestock in the country (125 million cubic meters) due to the difficulty of distinguishing the proportion consumed from each river basin. It also does not include the possible evaporation loss from reservoirs for all purposes.

[c]It is estimated by the author that an average ranging between 4,000 and 5,000 million cubic meters of water remains unconsumed in the water table, but it is not possible to distinguish between the proportion which belongs to each river basin. Because no attempt is being made, at present, to use this water, and because it is possible that part of it will evaporate from the surface of the areas having a high water table, after its movement to the surface by capillary attraction, the author has left the non-consumptively used water, of each river basin, tentatively undistinguished from its total consumption.

In dry years, shortage occurs in the Tigris Basin in all months except January and February. Theoretically, the estimated yearly water consumption in the Tigris Basin, 38,000 million cubic meters, exceeds the minimum supply of 31,000 million cubic meters. This gives the impression that during minimum conditions all the water supply of the Tigris will be consumed. Actually, in spite of these conditions, about 1,500 million cubic meters of water is dissipated at Qualat Saleh, in the lower reaches of the Tigris.

TABLE 20

THE PRESENT WATER BUDGET OF THE EUPHRATES BASIN[a]
(In Million Cubic Meters)

Use	Consumptive	Non-Consumptive	Total
Withdrawal			
Irrigation	9,574	.....	9,574
Residential			
Rural	26	.....	26
Urban) Municipal).... Industrial)	7.7	.....	7.7
Non-Withdrawal ..	0	0	0
Total use	9,607.7	.....	9,607.7
Dissipated	.....	.....	16,800
Supply			
Mean			26,410
Minimum			19,000

NOTE: Discrepancy in totals is due to rounding in build-up.

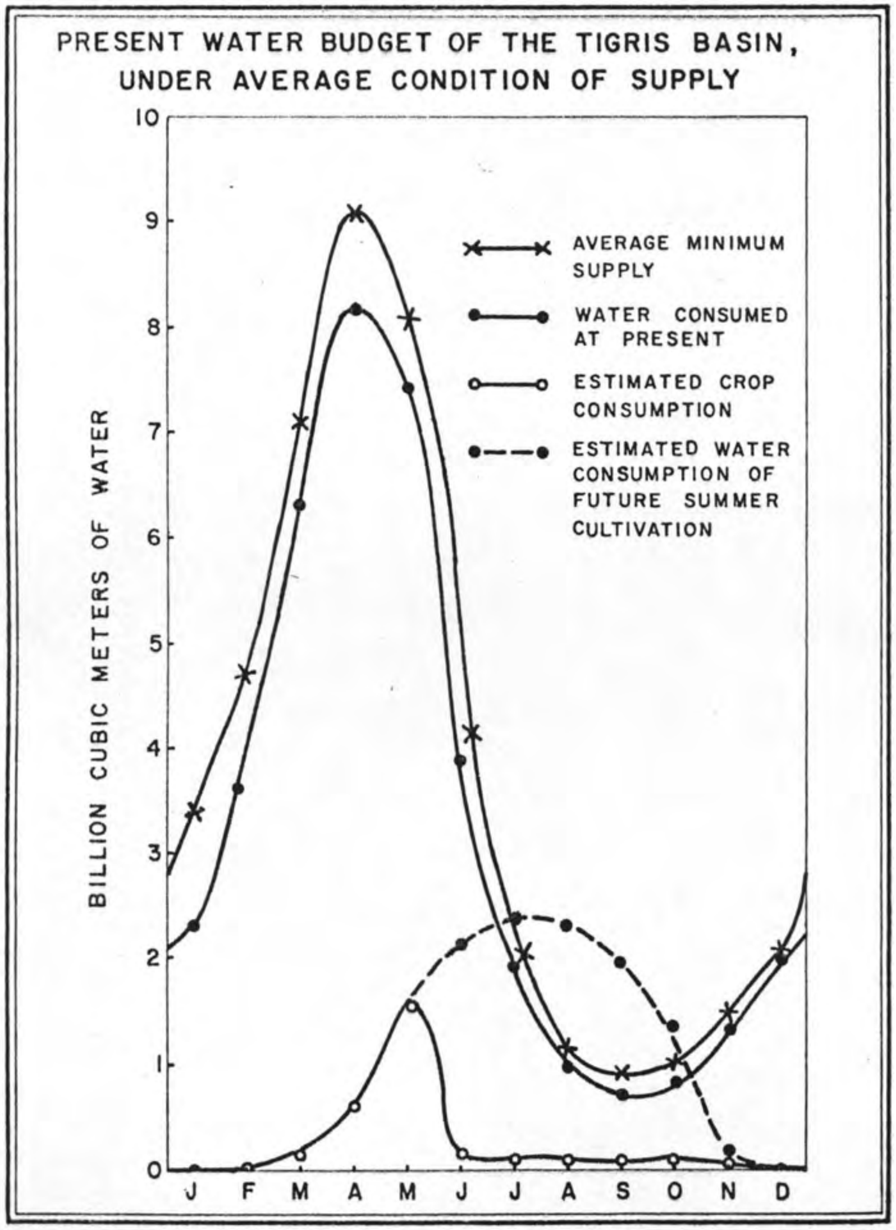
[a]The table includes irrigation water consumption in Al-Jazira, Syria, while the limited other withdrawal uses in the upstream countries are not included.

This can be explained by the fact that during the dry years some of the farmers in the Mesopotamian trough, where most of the water is withdrawn, simply give up the idea of cultivating their fields. This automatically reduces the total consumption.

It is evident that water consumption in the Tigris Basin is greater than in the Euphrates. This indicates that at the present time the Tigris Basin is utilized more than the Euphrates, contrary to some recent estimates.[1]

The characteristic pattern of use in both basins is irrigation which is practiced mainly in the lowlands, primarily in the Mesopotamian trough of Iraq and the Al-Jazira area of Syria.

[1]J. H. G. Lebon, "The New Irrigation Era in Iraq," Economic Geography, XXXI, No. 1 (January, 1955), 53. (Lebon concluded that the total acreage irrigated in the Euphrates, in Iraq, is equivalent to that in the Tigris. This conclusion conflicts with the data in Tables 13, 19, and 20.


PRESENT WATER BUDGET OF THE TIGRIS BASIN, UNDER AVERAGE CONDITION OF SUPPLY
BILLION CUBIC METERS OF WATER
0
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2
3
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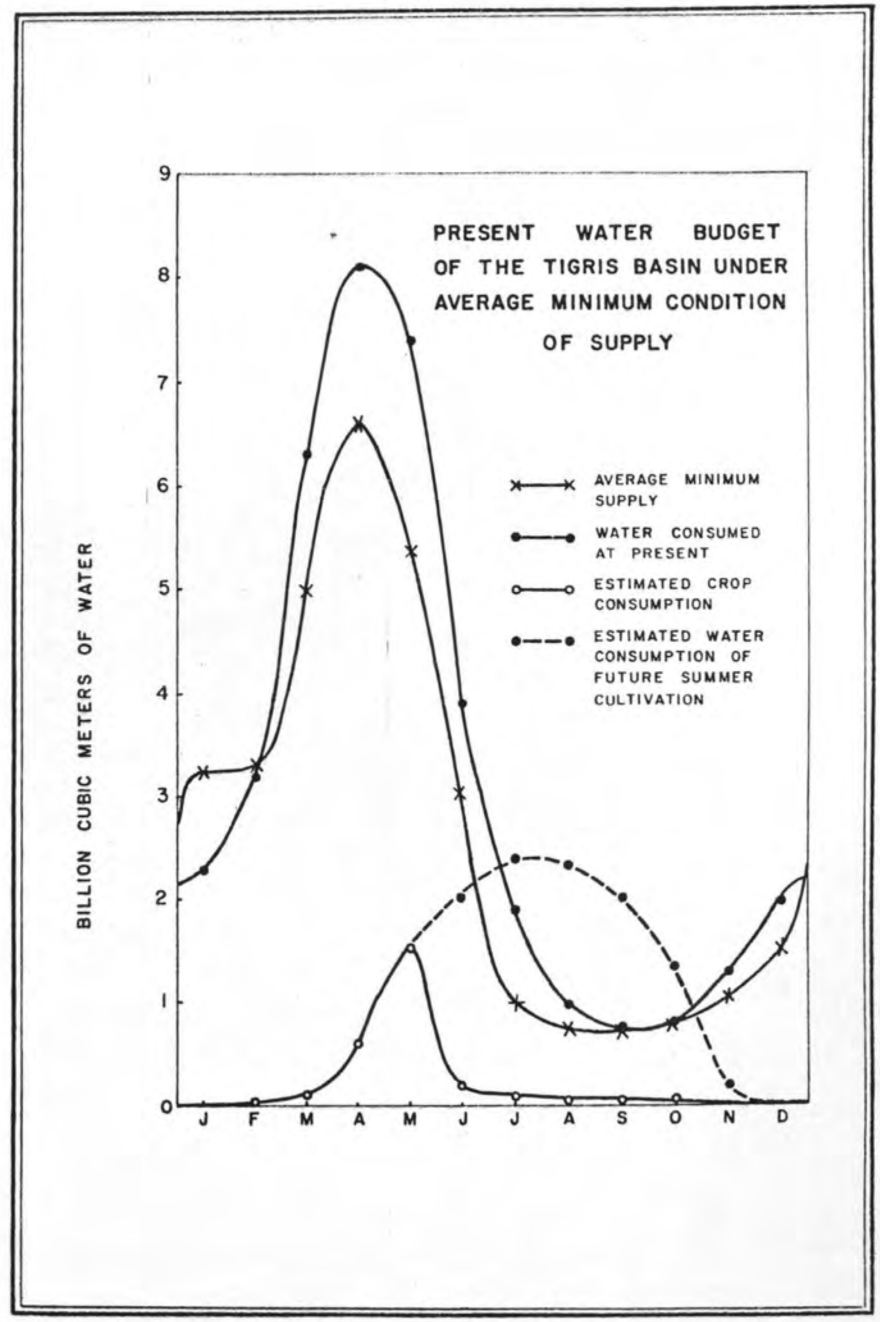
5
6
7
8
9
10
J F M A M J J A S O N D
AVERAGE MINIMUM SUPPLY
WATER CONSUMED AT PRESENT
ESTIMATED CROP CONSUMPTION
ESTIMATED WATER CONSUMPTION OF FUTURE SUMMER CULTIVATION

Fig. 18


PRESENT WATER BUDGET OF THE TIGRIS BASIN UNDER AVERAGE MINIMUM CONDITION OF SUPPLY
BILLION CUBIC METERS OF WATER
0
1
2
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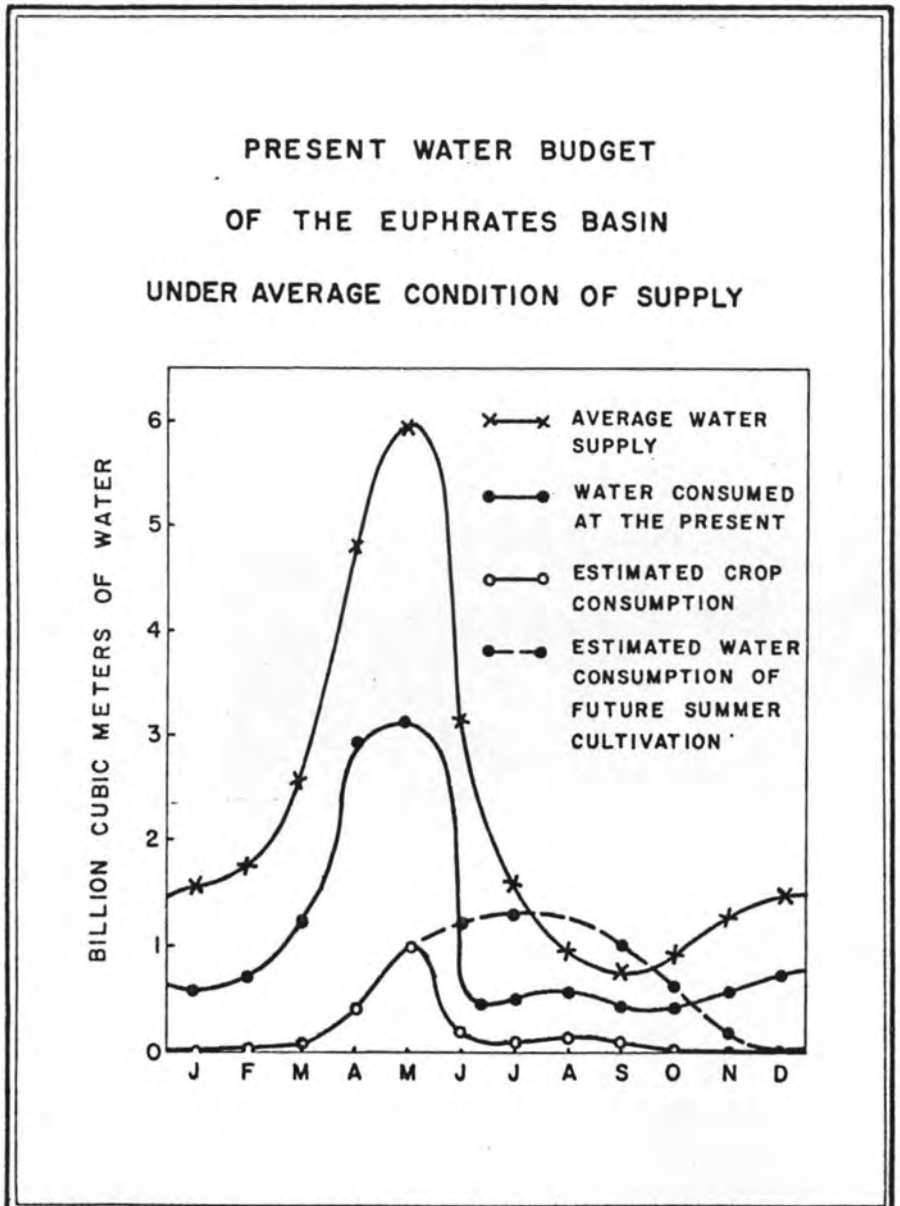
4
5
6
7
8
9
J F M A M J J A S O N D
AVERAGE MINIMUM SUPPLY
WATER CONSUMED AT PRESENT
ESTIMATED CROP CONSUMPTION
ESTIMATED WATER CONSUMPTION OF FUTURE SUMMER CULTIVATION

Fig. 19


PRESENT WATER BUDGET
OF THE EUPHRATES BASIN
UNDER AVERAGE CONDITION OF SUPPLY
AVERAGE WATER SUPPLY
WATER CONSUMED AT THE PRESENT
ESTIMATED CROP CONSUMPTION
ESTIMATED WATER CONSUMPTION OF FUTURE SUMMER CULTIVATION
BILLION CUBIC METERS OF WATER
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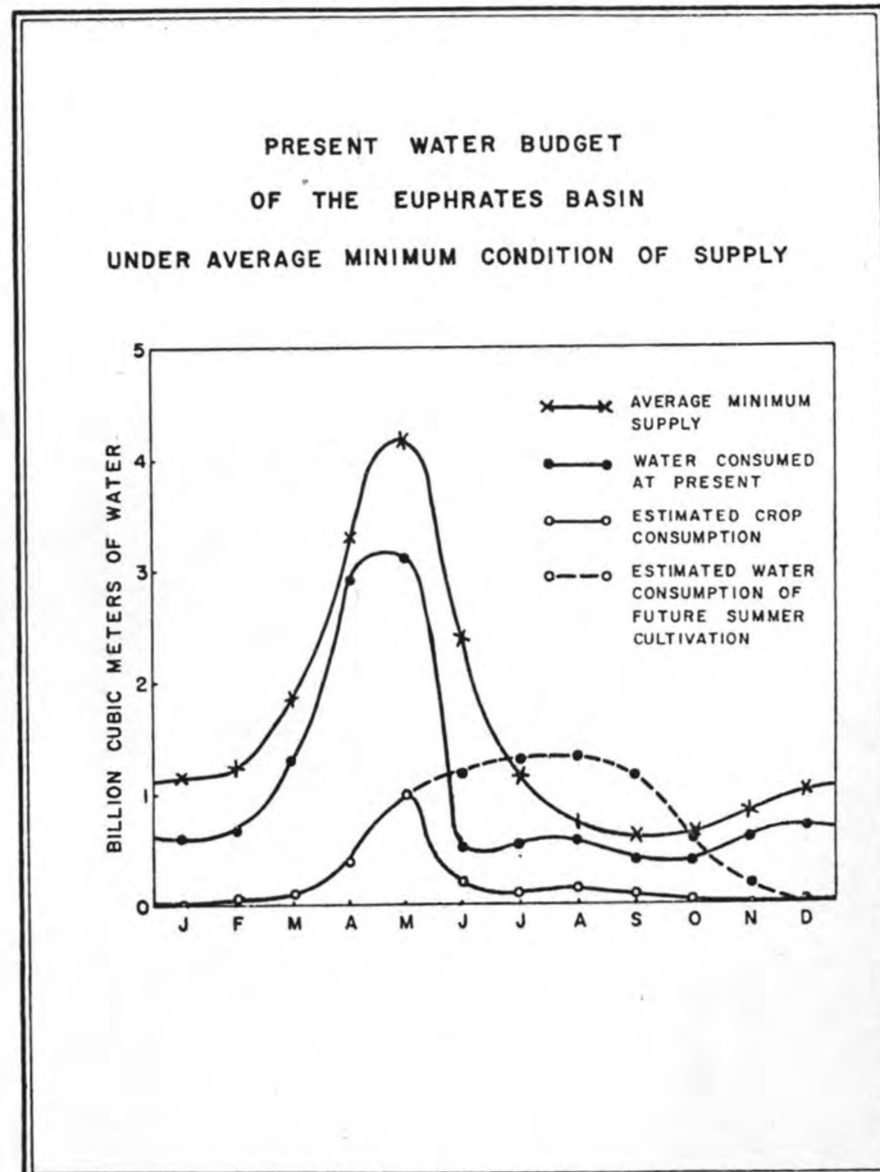
J F M A M J J A S O N D

Fig. 20


PRESENT WATER BUDGET
OF THE EUPHRATES BASIN
UNDER AVERAGE MINIMUM CONDITION OF SUPPLY
AVERAGE MINIMUM SUPPLY
WATER CONSUMED AT PRESENT
ESTIMATED CROP CONSUMPTION
ESTIMATED WATER CONSUMPTION OF FUTURE SUMMER CULTIVATION
BILLION CUBIC METERS OF WATER
0
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4
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J F M A M J J A S O N D

Fig. 21

Evaluation of the Present Budget

An evaluation of the current water uses suggests two respects in which water is now being used at low efficiency, and two points at which conflict is likely to arise in the future, unless effective steps are taken to improve the present methods of utilization, and to prevent the heightening of international problems.

Iraq, at present, does not obtain the maximum benefits from her water resources. A great proportion of the supply is being wasted by the prevailing inefficient methods of utilization. The various demands for water appear irreconcilable due to lack of planning. In addition, the present utilization is complicated by the possible rise of international conflict between Iraq and the upstream countries over the available water.

Unequal Distribution of the Supply

The distribution of the water supply during the year has an important influence upon the present pattern of water utilization in irrigation. The nature of distribution is not conducive to obtaining the maximum benefits from the irrigated land. More than 70 per cent of the water supply of both river basins comes during the Winter and Spring, providing an abundance of water for irrigation. On the other hand, the Summer and Autumn supply is low. During the Winter a farmer can cultivate only a limited acreage of his land (about 14 acres) due to lack of machinery and limited labor in the family. During the Summer cultivation is practiced in small acreage only, along the river banks, because of limited water. The rest of the irrigable land, the farmers and their machinery (if any) remain idle for almost half a year, throughout the Summer and part of the Autumn. As a result, a tremendous range between the amount of acreage cultivated during the Winter, 4 million acres, and that cultivated during the Summer, 0.7 million acres, appear--as shown in Table 13. Accordingly, the farmers depend, mainly, upon the Winter crop for their income, which generally does not exceed I.D. 20 ($56) annually.[1]

Inefficient Methods of Water Utilization

Irrigation is the greatest water consumer at present. The water consumption of the irrigated crops amounts to approximately

[1]International Bank for Reconstruction and Development, The Economic Development of Iraq, p. 133.

6,000 million cubic meters annually (Table 15). Conversely, the amount of water applied to the irrigated land through irrigation canals totals about 46,000 million cubic meters. Thus a waste of about 40,000 million cubic meters of water occurs every year.

The wasted water is designated as the excess withdrawn water which is not consumed by the crops. However, in irrigation practices a certain amount of wasted water is entailed through deep percolation and seepage. This can be deemed economically justifiable, considering the current methods of irrigation, to assure that the amount of water which is delivered to the crops is at least sufficient for consumption requirements of the crops. The amount of justifiable waste in irrigation in Iraq is estimated, by Knappen, Tippetts, Abbett, and McCarthy Engineers (based on samples of farm deliveries), to be about 35 per cent of the amount of diversion requirement for irrigation.[1] Diversion requirement equals consumption requirements of crops divided by 0.65. (DR = CR + JW, or DR = 6,000 + 35% of DR. Thus, 6,000 = 65% of DR, or $\frac{6,000}{.65} = 9,231$ million cubic meters. In order to make the computations easier, the resulting figure is rounded to 10,000 million cubic meters.) The justifiable waste, then, is the diversion requirement minus the consumptive requirements, or about 4,000 million cubic meters annually. The remaining 36,000 million cubic meters is an unjustifiable waste (total waste 40,000 million cubic meters minus 4,000 million cubic meters of justifiable waste), since it is neither consumed by the crops nor needed to assure the arrival of the consumption requirements to the crops.

The justifiable waste cannot be prevented under the present methods of utilization. The possibility of reducing this amount, however, lies in the extent of the improvements in the current methods of conveying and applying the water to the irrigated land, as for example, by lining the irrigation canals in order to reduce seepage and reducing water percolation in the fields, and by applying the irrigation water through controlled ditches instead of the existing uncontrolled flooding method. But even if the justifiable waste is reduced to half of its present amount, or even if it is eliminated, Iraq will save only a small amount of water as compared with what she can save through preventing the unjustifiable waste.

The unjustifiable waste, at present, raises the water table or works its way as surface or sub-surface flow to the swamps. The

[1]Knappen, Tippetts, Abbett, McCarthy Engineers, op. cit., chap. v, p. 39.

swamps are located either at the end of the irrigation canals or adjacent to the irrigated areas (Fig. 13). Most of the underground water comes from the irrigation canals and deep percolation from the irrigated fields. The unlined canals and the flood irrigation practices tend to magnify seepage and deep percolation. This water eventually is evaporated into the atmosphere or returns to stream flow. However, it creates certain problems in that process. The water which seeps to underground storage from irrigation canals and from the fields through deep percolation may raise the water table. The rising water table, through capillary action, brings moisture to the surface of the irrigated lands, where it evaporates, leaving behind such chemicals as sodium chloride, gypsum, and calcium carbonate. Although the extent of fluctuation of the water table is not known due to lack of published data, definite rises in the water table are demonstrated by the fact that areas have become saline. The total acreage affected by salt is not known, but the Iraqi delegate to the Near East Regional Meeting on Irrigation and Drainage practices reported that a considerable amount of land has been abandoned in southern Iraq because of the progressive increase in the concentration of salt in the soil.[1] In 1955, the investigations of the International Bank for Reconstruction and Development revealed that some of the saline areas, although still being cultivated, produce very low yields per acre.[2]

Saltation also became serious in newly settled areas after irrigation was initiated. This can be illustrated by the newly developed Dujaila project which is located south of Baghdad. It is a pilot land settlement project and the first of its kind in the Arab Middle East. The project covers an area of about 29,520 acres and accommodates a population of between 10,000 and 15,000 people. The project is completely supervised by the government. Settlement of the area began in 1946, and until about 195[illegible] the harvest was good. However, salt concentrations accumulated on the surface of some of the irrigated areas to such an extent that those

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[1]United Nations, Food and Agriculture Organization, Report of Proceedings, Near East Regional Meeting on Irrigation and Drainage Practices, Teheran, Iran, 6-13 of November, 1954 (Rome: Agricultural Division, Food and Agriculture Organization of the United Nations, 1954), p. 25.

[2]International Bank for Reconstruction and Development, The Economic Development of Iraq, p. 25.

parts of the project were abandoned.[1] The total abandoned acreage is not known at this time. Drainage works have been started in most of the remaining parts of the project to reduce the danger of salinization. Here, as in many other irrigated areas, the need for extensive drainage is a symptom of over-application of water.

The swamps, where most of the wasted water goes, constitut a source of many epidemic diseases which affect the people living in the nearby irrigated areas. Approximately 93 per cent of the Bilharzia cases, 80 per cent of the Ankylostomiasis cases, and slightly over 50 per cent of the Malaria cases in Iraq are found among the people living within the areas south of Baghdad, where most of the swamps are located.[2]

If the irrigation water wastage is stopped, a gradual, aut matic reclamation of the swamps will occur. Besides saving the wasted water at this time (36,000 million cubic meters), the swamp will eventually become additional land available for cultivation i stead of remaining a source of various diseases. Use of the save water would depend in part upon its quality: some might well be ur suitable for irrigation use. Attempts to reclaim the swamps have not been started in Iraq as yet. The possibility of reclaiming th swamps lies in the control and improvement of the diversion and ap plication of the water to the irrigated land. If we assume that these steps will be taken, a natural reclamation of the swamps wil occur through the evaporation of the present water to the atmosphe Since the average depth of the swamps, in most cases, does not exceed 2 meters, the evaporation of their water, at an average rate of 1.3 meters (Fig. 8), will take approximately two years or sli ly longer, but in the same magnitude. Additional time will be required for the evaporation of water from the exposed saturated so and with possible correction of the emerging salinized soils, Ira will be able to gain about 8 million acres (the present area of t swamps), twice as much as the area irrigated at the present time. But such reclamation is based on the assumption that more wasted ter will not come to the swamps during the estimated period of re lamation.

If the wastage of water in irrigation were to be stopped, Iraq would be able to save about 36,000 million cubic meters of w

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[1]B. Fisk, "Dujaila: Iraq's Pilot Project for Land Settlem Economic Geography, XXVIII, No. 4 (October, 1952), 343-54.

[2]Government of Iraq, Ministry of Economics, Principal Bur of Statistics, op. cit., pp. 315-16.

annually. With the reclamation of the swamps and the utilization of the wasted water for irrigation, Iraq would need to use only part of this water (about 20,000 million cubic meters) in order to irrigate all the swamp areas (the present irrigated acreage of 4.7 million acres uses only 10,000 million cubic meters annually). If we assume that the present pattern of cultivation were also to be used in cultivating the reclaimed swamps, the estimated gross income of the reclaimed cultivated swamps would amount to about I.D. 120 millions ($340 millions) annually, twice as much as the gross income of the irrigated areas at present.[1]

Since uncontrolled diversion is the primary cause of wasted water, the initial step to reduce or prevent wastage is to control the diversion canals. Theoretically, the government of Iraq, through the General Directorate of Irrigation, is supposed to supervise and control the amount and distribution of water in irrigation. The irrigation law of 1923 declared that irrigation engineers shall determine the dimension of irrigation canals, and the areas which may be irrigated from them (Article 5). The distribution of irrigation water is carried out by the irrigation department (Article 8).[2] In reality, the practice is quite different. The attitude of the farmers and landlords toward the laws and regulations is one of indifference and irresponsibility. The farmer diverts greater amounts of water, supported by influential landlords and assisted by the ease of diversion, through breaks in the river's banks. He is also encouraged by the false belief that a greater water application will bring a greater yield. To enlighten the farmers to the dangers involved in such practices, the government has established an agricultural extension station in each state. These stations have been trying, since 1923, to guide the farmer in obtaining the maximum possible benefits from the land and in the most economical use of water. However, their success in this direction has been meager and discouraging. Its lack of success is due to the fact that the farmer does not cooperate in most cases because he either does not believe in such guidance, or is afraid of government officials, who are all thought of as tax collectors. Also, in most cases, the guid-

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[1]Knappen, Tippetts, Abbett, McCarthy Engineers, op. cit., chap. v, p. 56.

[2]Dante A. Caponera, Water Laws in Moslem Countries, United Nations Food and Agriculture Organization, Development Paper No. 43 (Rome: Food and Agriculture Organization of the United Nations, 1954), pp. 129-37.

ance programs of the government must meet with the acceptance of the influential landlord, who owns the land and hires the farmers to work it. The landlord primarily objects to any program which will either cost him money for improvements or somehow modify his authority among his farmers. The task of enlightening the farmers, through such programs, will continue to encounter difficulties because the aforementioned factors still exist.

It is evident that controlling water diversion and distribu tion in Iraq involves basic social and political changes as well as the necessary laws and regulations.

Because some of the wasted water moves to the swamps throug seepage from irrigation canals, there is a possibility of reducing such wastage by lining the canals. Inasmuch as there is no availab data concerning the length and width of these irrigation canals, es mation of the possible cost of lining is difficult to assess. However, it is safe to say that if the present diversion is controlled and the canals are lined, Iraq will save water which is being waste in irrigation (40,000 million cubic meters annually). If the control of diversion and the reduction of seepage were to reduce the wastage to about half of its present size (20,000 million cubic meters), and assuming suitable quality, this amount were to be used f irrigation in the same areas where wastage is occurring (in souther Iraq), yields worth at least I.D. 120 millions ($340 millions) migh be obtained annually.

Furthermore, by reducing the amount of water wastage Iraq will be able to reduce the present high expenditure on drainage wor --the present development plan accounts for spending about $63 millions for drainage works in the presently irrigated areas.

Conflict of Water Uses

The present pattern of water utilization reveals a conflict between navigation and irrigation. Other possible conflicts betwee residential, municipal, industrial, and wildlife uses of water seem unimportant.

The conflict between navigation and irrigation appears in t lower part of the Tigris, between Baghdad and Basrah (Fig. 15). In the upper half of the navigated Tigris, between Baghdad and Ammarah conflict occurs during dry years only; late Summer and early Autumn (Fig. 16). Below Ammarah the conflict occurs every year and lasts longer; from late Spring until the end of Autumn (Fig. 17).

In order to eliminate such conflict the government has considered a plan for operating the proposed storage reservoirs, on the tributaries of the Tigris, so as to provide the required depth (1.8 meters) to operate the vessels used presently for year-round navigation under all conditions of supply.

The possibility of eliminating or reducing the conflict between navigation and irrigation will depend either upon the control of the irrigation diversion canals, in the lower reaches of the Tigris, or upon reducing the demand for navigation facilities.

Possible Future International Conflicts

Feelings of insecurity are expressed at times among water-users of Iraq regarding possible conflict with the upstream countries over the waters of the Tigris and Euphrates rivers. Various incidents with the surrounding countries justify such insecurity.

It has been reported that the agricultural communities of the Diyalah River basin, in eastern Iraq, and near the Iranian border, have been threatened many times with the loss of their water supply from the Diyalah River. This water was dammed and diverted within Iran and in each case caused tension and ill feelings between the two countries.[1] Furthermore, agricultural expansion is being currently planned in Khuzistan, southwestern Iran, adjacent to Iraq. The expansion program will depend upon the Karon River for irrigation.[2] The success of this expansion may encourage further expansion to the north of Khuzistan. In this case, the waters of the Diyalah and Lesser Zab may be subject to use by Iran.

There are no guarantees that such incidents with Iran will not happen again, inasmuch as no measures have yet been taken to settle the basic problems of allocation of available supply.

Groups in Iraq have also been disturbed by the recently proposed irrigation plans by the Syrian part of the United Arab Republic to utilize part of the water supply of the Euphrates. The Syrian plans expect to double the present irrigated areas in the Al-Jazira (Fig. 1, 3a-2) from 1 to 2 million acres by storing about 2,000 million cubic meters of water in Youssef Pasha reservoir on

[1]J. M. Khalaf, op. cit., p. 206.

[2]United Nations, Food and Agriculture Organization, Expanded Technical Assistance Program, The Development of Land and Water Resources in Khuzistan, Report to the Government of Iran, FAO Report No. 553 (Rome: Food and Agriculture Organization of the United Nations, 1956), pp. 181-87.

the Euphrates.[1] If and when these plans are realized, the total acreage in the Syrian part of the United Arab Republic which is irrigated by the Euphrates River will be more than that in Iraq supported by waters of the same river. Additional plans may be formulated by Syria as a result of the recent agreement between the two parts of the United Arab Republic, Syria and Egypt, for a migration of two million Egyptian farmers to Syria.[2] It is logical to assume that these people will be settled within the Euphrates part of Syria, which, according to the evaluation of the International Bank for Reconstruction and Development, in 1955, has the greatest potentialities of irrigation expansion in Syria in both availability of water and suitability of land. If we further assume that each farmer will have as much as two acres of irrigated land (about the average amount of cultivated land per capita in Iraq), then the irrigated areas in Syria will increase from two to six million acres. To irrigate such areas in Syria at least an aver age of 0.9 cubic meters of water would be applied annually (see Fig 8). Accordingly, a total of about 25,000 million cubic meters would be required annually. This is as much as the mean total unregulated supply of the Euphrates (Table 10). In those circumstances, a conflict between Iraq and the United Arab Republic will definitely occur unless necessary steps for agreement in water allocation are taken.

Although Turkey does not utilize the waters of the Tigris and Euphrates for other than livestock and domestic purposes in the foothills region and the Al-Jazira section (Fig. 1, 3a-3) at present, this does not exclude the possibility of future utilization. Plans have been initiated to utilize the waters of the Euphrates for hydroelectric power in Keban, with a capacity of 400,000 Kw. and in Elazig with a capacity of between 4,000 and 7,000 Kw.[3] This will require a certain amount of water storage but only such consumptive use as would come from reservoir evaporation losses. Data concerning the amount of water storage for hydroelectric power are not avai able. However, a rough estimation can be made by considering the amount of storage in one of the reservoirs in Iraq in order to gen-

[1]International Bank for Reconstruction and Development, The Economic Development of Syria, pp. 41-48.

[2]New York Times, February 2, 1958, sec. 4, p. 7.

[3]International Bank for Reconstruction and Development, The Economy of Turkey, pp. 143-44.

erate hydroelectric power, almost equivalent to that expected to be generated in both Keban and Elazig. In the proposed Bekhme Reservoir on the Greater Zab River in Iraq a storage of about 8,300 million cubic meters of water is expected to generate an amount of electric power almost similar to that of Keban and Elazig.[1] If the same amount is needed for storage in Turkey, it will hold about one-third of the mean unregulated water supply of the Euphrates River. If and when those plans are realized, a definite conflict may be expected to arise between Turkey, the United Arab Republic, and Iraq as to the operating schedule for the various regulating reservoirs.

The Al-Jazira section in Turkey is quite similar to the Al-Jazira section of the United Arab Republic in climate, topography, and population density. Since this area is considered, by the recent surveys of the International Bank for Reconstruction and Development, the area of greatest potential development in the Syrian part of the United Arab Republic, it is likely that Turkey, though having no plans at present, may also develop her part of the area in the future by irrigation.

Although the potential use of the waters of the Tigris and the Euphrates Basin by the upstream countries is not as great and as immediate as that in Iraq, these countries may be expected to increase their use of the waters of the basin in the future. Meanwhile, the present government plan of Iraq for utilizing water resources is based on the assumption that all the waters of the Tigris and Euphrates basin will be available in Iraq. Such discrepancy may well result, in the not too distant future, in a conflict over water rights between Iraq and the upstream countries. Conflict now seems more apt to develop at an earlier time with the United Arab Republic than either with Turkey or Iran; because expansion is more obvious in Syria than in the other two countries.

Early cooperation among the countries in the Tigris and Euphrates basin may well be necessary to avoid conflict. Examples of the partial success of international cooperation in finding solutions for international water problems may be observed in the activities of the International Joint Commission of the United States and Canada under the Treaty of 1909 between the United States and Great Britain, and of the International Boundary and Water Commission set

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[1]Government of Iraq, Development Board and Ministry of Development, Major Irrigation Projects (Baghdad: Al-Ani Press, 1956), p. 14.

up by the United States and Mexico for regulating and utilizing the waters of the Rio Grande and Colorado Rivers.[1]

Another example of the success of international cooperation on a limited scale is illustrated by the spirit of cooperation which prevailed between Great Britain and Italy in solving the dispute between Sudan and Eritrea concerning the Gash River irrigation claims. One of the clauses of the agreement was that if profit on the sale of cotton in the Sudan scheme exceeded a certain figure, Eritrea would be paid a percentage of this excess, thus sharing in benefits from water flowing out of that country.[2]

Cooperation among Iraq, Turkey, the United Arab Republic, and Iran could be used to provide better understanding of the water resources of the Tigris and Euphrates basin. Together they could gather and exchange the essential, but lacking data, such as precipitation, temperature, evaporation, streamflow, groundwater, soil moisture, topographic, geologic, vegetation, and soil information. Cooperation could also be used in a thorough assessment of needs for water by the different countries; not only for existing uses, but for possible future expansion of the present uses. Such assessments if realized by these countries, could be used as a basis for water allocation to prevent conflicts which may result from continued uncoordinated planning of water utilization.

Improvement or Expansion

The meager benefits which the farming communities get from the land, the conflict of uses for irrigation and navigation, and possible future international conflicts are not due to a shortage of water but rather to inefficiencies in the utilization of the water supply. It may be asked, if increased benefits are sought from the nation's water resources, whether improvement of the present conditions of water use should not receive greater attention than expansion of new irrigation acreage.

In the present adopted government plan, which will eventually completely control and regulate the amount of the available supply through the proposed storage reservoirs--five storage reservoirs on the Tigris and three storage reservoirs on the Euphrates--

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[1]United Nations, Department of Economic and Social Affairs, Integrated River Basin Development, Report by a Panel of Experts (New York: United Nations Department of Economic and Social Affairs, 1958), p. 37.

[2]Ibid.

benefits are sought from expansion of lands under irrigation rather than from improvement in the efficiency of water utilization.

In order to improve the economic conditions of the country and raise the level of living among the farming communities, the present government has adopted the idea of expanding the present irrigated areas from 4.7 million acres to about 8 million acres. The additional new acreage is intended to provide land for landless farmers and increase the irrigated acreage of the present farming communities. This expansion will increase the gross agricultural production as a result of the increase in the irrigated acreage, and of a more efficient crop rotation plan in the proposed areas of expansion. According to this plan, the income of the farmer is expected to increase from slightly over I.D. 20 ($56) to about I.D. 60 ($168) annually.[1]

Lord Salter recommended that, in a small country such as Iraq, agricultural development should, from the beginning, include the improvement of production from existing cultivation rather than establishing new settlements, since the presently cultivated land is not used to the best advantage.[2]

The author also feels that if the expansion of the presently irrigated areas is aimed at increasing the gross income from agriculture, and thereby raising the income of the farmer, there is a possibility of accomplishing the same aim by improving the method of cultivation of the presently irrigated areas. If the presently Winter-cropped areas (4 million acres) are cropped again during the Summer, the total crop acreage during a year will amount to 8 million acres. This is as much as that expected to be obtained from the present plan of expansion. If the income of the farmer, which is based primarily on one Winter crop, amounts to slightly over I.D. 20, then Summer crops may raise his income to about I.D. 50; not too different from the expected income increase from the plan.

If all the present-day Winter-cultivated areas are cultivated during the Summer, the water consumed by the Summer acreage will amount to about 15,000 million cubic meters in the Tigris Basin (Figs. 18 and 19) and about 9,000 million cubic meters in the Euphrates Basin (Figs. 20 and 21). This estimation of water consumption is based on the assumption that 35 per cent of the water

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[1]Knappen, Tippetts, Abbett, McCarthy Engineers, op. cit., chap. v, p. 56.

[2]J. A. Salter, op. cit., pp. 53-54.

diverted for irrigation is a justifiable waste. Total water consumed for Summer cultivation in both river basins then would amount to about 24,000 million cubic meters annually; about 66 per cent of the amount of water unjustifiably wasted at the present. Thus, besides reclaiming the swamps, the prevention of present irrigation wastage would offer the possibility of using such water, insofar as it may be of suitable quality, for Summer cultivation.

The irrigation of 8 million crop acres in the basin will require about 34,000 million cubic meters of water annually (10,000 is used at present plus 24,000 for the suggested Summer cultivation). Of this, 21,000 million will be used in the Tigris, and the remaining 13,000 million in the Euphrates. This amount of water can be provided by each river basin, even during the minimum conditions of the supply (the Tigris minimum supply is 31,000 million cubic meters, and the Euphrates minimum supply is 19,000 million cubic meters). However, it can be noticed from Figures 18, 19, 20, and 21, that if the assumed Summer cultivation is carried out, a shortage of at least 8,000 million cubic meters in the Tigris Basin, and almost 6,000 million cubic meters in the Euphrates, will occur. The presently planned reservoirs will provide this amount of water under both mean and minimum conditions of supply.

An obvious benefit of such recommended improvement is in not investing all the capital in land development but rather in using more efficiently the amount of land which is presently under cultivation.

It also may be possible that such improvement could be carried on in the rainfall-cultivated areas of northern Iraq, in the foothills, and Al-Jazira regions (Fig. 1). In this part of Iraq cultivation is practiced at present on about 2.3 million acres during the Winter. This depends exclusively upon rainfall, and is left idle during the Summer because of lack of water. Irrigating such areas during the Summer would require about 7,000 million cubic meters (estimated from annual Water Deficit Map, Fig. 8). The farmer would probably welcome such improvement because of the possible increase in his income, since it would give him something to work with during the Summer, usually his idle time. Summer crops, which are grown on a very limited scale--cotton, vegetables, sesame, and fruits--can be expanded. Although this aspect of development has never been tried in Iraq, its consideration should not be excluded. Further research may be initiated in this respect to show the possible required changes in farm system, if this idea were adopted. Investigations could start on pilot schemes, in Al-Jazira or in the foothill regions in Iraq, similar to the Dujaila pilot scheme, which was initiated in the south. The cost of installing new irrigation systems in the rainfall-cultivated areas may be high, but the possible benefits justify such expenditure. If we assume that a sprinkler irrigation system were to be tried in these areas of northern Iraq, the average cost of installation would be approximately $50 to $100 per acre.[1] For an average of $75 per acre, the total cost of installing sprinkler systems for all the rainfall-cultivated area (2.3 million acres) would amount to about $172 million. If we assume that the value of products per unit area in the rainfall-cultivated acreage, at present, is similar to the value obtained in the irrigated acreage in the south--such assumption may be considered justifiable for a rough estimation since they have similar cultivation practices, similar crops, and Winter cultivation predominates in both of them--then the value of products of the rainfall-cultivation amounts to approximately I.D. 31 ($85) millions. Present irrigated acreage in the south--4.7 million acres--has a total value of products of about I.D. 62 ($170) million. Let us further assume that the value of products of the suggested Summer cultivation will be similar to that of present Winter cultivation. Then, the installation cost of the suggested sprinkler irrigation systems would be a half or a third of annual gross product from the land. The author feels, however, that any judgment of the feasibility of such a development requires further research to show the proportional costs and benefits as based on more precise estimates of installation and maintenance costs of such systems, and the possible needed changes in the farm systems and crop rotations.

Let us assume that in the future Iraq will expand its irrigated areas. The expansion is more likely to be carried out in places where irrigation already is established or planned. But, the question arises: Where is the use of water likely to yield the maximum benefit? In terms of water use the foothills and Al-Jazira parts of northern Iraq may be better suited for expansion than the southern parts of Iraq. One of the immediate benefits which would result from expansion in the north is the saving of water. In order to irrigate a square meter of land in the south, an average of 1.2

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[1]Information was obtained through an interview with the experts of the "Champion Corp. of Irrigation Equipments," in July, 1958.

cubic meters of water is consumed, while an average of about 0.7 meters is consumed in irrigating a similar square meter in the north (Fig. 8). Thus, to irrigate 1 million acres in the south, about 5,000 million cubic meters of water are consumed annually. A similar amount of acreage in the north would consume 3,000 million cubic meters. To the estimated water consumption, by crops, an allowance of 35 per cent of the diversion requirement may be made for the justifiable waste, conveyance and application, which will increase the water required to irrigate a million acres to about 7,000 million cubic meters in the south and about 5,000 million in the north. Therefore, for irrigating every million acres of land in the north, 2,000 million cubic meters of water can be saved. If Iraq were to develop 4 million acres in the north the amount of water required would be approximately 20,000 million cub meters annually. Developing the same amount of acreage in the sou as already planned, would require 28,000 million cubic meters.

The estimated cost for installing irrigation systems for t proposed 4 million acres in the south is about I.D. 120 ($337) mil lion.[1] Meanwhile, the cost for installing sprinkler irrigation sy tems for 4 million acres in the north, based on an average cost of $50 to $100 per acre, would be between $300 to $350 million, not t different from the estimated cost of the new installations in the south.

If the suggested expansion is carried out in the north, th return flow, from the water diverted for irrigation, may possibly be used in the lower parts of Iraq, depending upon its quality. This is an advantage which may not occur if the development is car ried out in the south, where most of the return flow will appear a the lower parts of the irrigated areas to be dissipated, through Shatt-al-Arab, to the Persian Gulf, without being used.

The value of water in the northern part of Iraq is much greater than in the south. At present, each cubic meter of water consumed by crops in the irrigated areas yield products worth 10 Fils (equivalent to $.028). If this cubic meter is used in the north, it will yield products which would be worth about 33 Fils ($.10). This is assuming that a similar pattern of irrigation wi be used and that similar crops will be grown, in the north.[2]

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[1]Knappen, Tippetts, Abbett, McCarthy Engineers, op. cit., chap. i, pp. 15-17.

[2]At present the total water consumed by crops is 6,000,000, cubic meters (Table 15). The total value of the products is I.D. 61,000,000 or 61,000,000,000 Fils (each I.D. = 1,000 Fils), annu-

If the utilization of the presently irrigated areas were improved through reduction of uneconomic waste of water and year-round cultivation, and if area expansion of irrigation were carried out in northern Iraq, certain favorable results would be achieved. These would be expressed in an increase in the amount of water consumption, a higher return per unit of water used, and concomitant increase in agricultural production. The farmer of the south would have at least two harvests--Winter and Summer--every year. This would increase his gross income to approximately twice its present size. Another possibility would be an increase in the land available for cultivation through reduction of the size of the swamps, at the same time reducing the existing epidemic diseases. The farmer, in the north, would depend upon two harvests--Winter and Summer --for his income, which would be undoubtedly increased. Furthermore, an increase in Summer cultivation would promote the introduction of more valuable and profitable crops such as vegetables, sesame, cotton, and fruits, which are cultivated now on only a very small scale. However, the pattern of Summer cultivation, as to the extent of acreage which could be devoted to each one of these crops, would be influenced by the market situation. It would be helpful for the agricultural economists to do research in that direction.

Concerning navigation: the government plan for storage reservoirs on the tributaries of the Tigris will provide water for year-round navigation for the different types of vessels used at present. However, it would be worth while to consider a cost-

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ally. The value of products of each cubic meter of water will equal, then, 61,000,000,000/6,000,000,000, or approximately 10 Fils (about $.028). The water is used primarily for Winter cultivation, to irrigate about 4.7 million acres, or about 19,000,000,000 square meters (each acre equals about 4,000 square meters). Each irrigated square meter of crops consumes 6,000,000,000/19,000,000,000, or about .3 cubic meters of water. This amount of water is similar to the average Winter water deficit of the present irrigated areas, as expressed by the average Winter water deficit of Nasiriyah, Kut El-Hai, and Baghdad, which are .37, .34, and .28 cubic meters respectively. Thus, one cubic meter of water is consumed by 1/.3 square meters of irrigated crops, or, approximately 3 square meters of irrigated crops, to yield products worth 10 Fils ($.028). Meanwhile, in both Al-Jazira and the foothill region of northern Iraq, the average Winter water deficit does not exceed .1 cubic meters, as expressed in the Winter deficit of Mosul and Kirkuk. Thus, one cubic meter of water in these two areas will irrigate 1/.1, or about 10 square meters of irrigated crops. If we assume that the value of products in the north will be similar to that in the south, 10 Fils for each 3 square meters of irrigated crops, then 10 square meters of irrigated crops in the north will be worth about 33 Fils (about $0.10). Therefore, every cubic meter of water, if used in those areas of northern Iraq, could have a value of 300 per cent more than its existing value in southern Iraq.

benefit study to find which is more beneficial; constructing a road to the south of Baghdad, along the Tigris, or utilizing the water which will be used by navigation, for irrigation. On land, the distance between Baghdad and Basrah is about 460 kilometers. According to Salter, the average cost of constructing a road is about $61,416 per kilometer.[1] Thus, the total cost of constructing such a road between Baghdad and Basrah would be about $28,000,000. To this cost would have to be added the costs of operating and maintaining road transport, the cost of the unused investment in river transport equipment, and, with data on probable tonnage movements, it then would be possible to compare the benefits and costs involved in providing all-year river transport with those involved in substituting land transport and using the liberated water for irrigation. The released water might be used to yield products which would have a gross value of about $170,000,000, if the water were used in the south, or about $500,000,000 if it were used in the north.

The lack of required data for the comparison makes the author hesitant to draw any definite conclusions at present, but he would recommend further research in this respect, since the tremendous range between the figures indicates the possibility that the more beneficial use of the water may be for irrigation.

Thus, if greater benefits are desired from water and land resources in Iraq, a good case can be made to investigate the possibility of concentrating both effort and capital toward the improvement of the prevailing methods of utilization in order to obtain the maximum benefit from the current investment in these two resources.

If expansion of the present use of water for irrigation is to be carried out, then it might be more beneficial to carry out such an expansion in places where the water would give greater yields. The northern parts of Iraq, both in Al-Jazira and the foothills regions, are well suited for expansion; a situation which was emphasized by Salter in 1954.[2]

Existing and potential water developments in certain areas, upstream from Iraq, indicate that the upstream countries may require part of the water supply of the Tigris and Euphrates rivers. Consequently, any development plan for expansion of water use in Iraq should be based on the premise that all the water of the Tigri

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[1] J. A. Salter, op. cit., p. 139. [2] Ibid., pp. 54-55.

and Euphrates rivers will not be available for use in Iraq, a situation which was considered in the plan formulated by Knappen, Tippetts, Abbett, and McCarthy Engineers, and overlooked by Salter.

BIBLIOGRAPHY

Akim Neticleri. 1954 Su Yili. Ankara: Guzel Istanbul Natbaas, 1955.

Al-Shalash, A. H. "The Climate of Iraq." Unpublished A.M. Thesis, Department of Geography, The University of Maryland, 1957.

Ahmed Sousa. Irrigation in Iraq. Baghdad: New Publishers, 1945.

Boesch, H. "El-Iraq," Economic Geography, XV, No. 4, October, 19

Butler, S. S. Engineering Hydrology. Englewood Cliffs, New Jerse Prentice Hall, 1957.

Carter, D. B. The Water Balance of the Mediterranean and the Blac Seas. Publication in Climatology. Vol. IX, No. 3. Cente ton, New Jersey, 1956.

________. "Maps of Water Requirements for Southwest Asia." Unpub lished Manuscript, 1957.

________. "The Relation of Irrigation Efficiency to the Potentia Development of Irrigation Agriculture in the Pacific North west." Unpublished Ph.D. dissertation, Department of Geog raphy, The University of Washington, Seattle, 1957.

Cressey, G. B. "Water in the Desert," Annals of the Association American Geographers, Vol. XLVII, No. 2, June, 1957.

Cwiller, R. C., and Peterson, H. V. Effects of Stock Reservoirs o Runoff in the Cheyenne River Basin Above Angostura Dam. Geological Survey Circular 223. Washington: U.S. Governm Printing Office, 1953.

Dante, A. Caponera. Water Laws in Moslem Countries. United Nati Foods and Agriculture Organization, Development Paper No. Rome: Food and Agriculture Organization of the United Nations, 1954.

Davies, D. H. "Observations on Land Use in Iraq," Economic Geography, Vol. XXXIII, No. 2, April, 1957.

Directorate of Water Supply of Baghdad. Annual Report. No. XXVI April, 1953. Baghdad: Ar-Rabbita Press, 1956.

El-Kholy, F. H. Hydrology of River Tigris. Baghdad: Ar-Rabbita Press, 1952.

Fisher, W. B. The Middle East: Physical, Social, and Regional Ge raphy. London: Methuen and Company, 1956.

Fisk, W. B. "Dujaila: Iraq's Pilot Project for Land Settlement," Economic Geography, Vol. XXVIII, No. 4, October, 1952.

Friel, Francis S. "How To Estimate the Future Water Supply Needs for a Growing Community," Water Works Engineering, Vol. C December, 1956.

Ginsberg, N. (ed.) The Pattern of Asia. Englewood Cliffs, New Jersey, 1958.

Government of Iraq, Irrigation Directorate General. Rivers and C nals Discharge Observations for 1954. Baghdad: Governmen Press, 1956.

Government of Iraq, Ministry of Economics, Principal Bureau of Statistics. Statistical Abstract, 1955. Baghdad: Zahra' Press, 1956.

Government of Iraq, Ministry of Communication Meteorological Service. Rainfall in Iraq. Baghdad: Government Press, 1946.

Government of Iraq, Development Board and Ministry of Development. Major Irrigation Projects. Baghdad: Al-Ani Press, 1956.

Graham, Jack B., and Burrill, Meredith F. (eds.) Water for Industry. A Symposium Presented on December 29, 1953, at the Boston Meeting of the American Association for the Advancement of Science, Publication No. 45. Washington, D.C.: American Association for the Advancement of Science, 1956.

Haigh, F. F. Iraq Irrigation Commission. The Control of the Rivers of Iraq and the Utilization of Their Water. Baghdad: Baghdad Press, 1951.

Hasted, Gordon. The Physical Background of Iraq. Translated into Arabic by J. M. Khalaf. Baghdad: Arabian Press, 1948.

Himadeh, Said B. Al-Nizam Al Iktisadi fi Al-Iraq. Beirut: The American Press, 1938.

Houk, I. E. Irrigation Engineering. New York: John Wiley and Sons, 1951.

International Bank for Reconstruction and Development. The Economic Development of Iraq. Baltimore: The Johns Hopkins Press, 1955.

________. The Economic Development of Syria. Baltimore: The Johns Hopkins Press, 1955.

________. The Economy of Turkey. Baltimore: The Johns Hopkins Press, 1951.

Ionides, M. G. The Regime of the Rivers Euphrates and Tigris. London: E. and F. N. Spons Company, 1937.

Jordan, Harry E. "Industrial Requirements for Water," American Water Works Association, Vol. XXXVIII, 1946.

Khalaf, J. M. The Water Resources of the Lower Colorado River Basin. Ph.D. dissertation, Department of Geography, University of Chicago, December, 1951.

Knappen, Tippetts, Abbett, McCarthy Engineers. The Development of the Tigris and Euphrates River System, Iraq. Baghdad: Development Board, 1955.

Lebon, J. H. G. "Population Distribution and the Agricultural Regions of Iraq," Geographical Review, Vol. XLII, No. 2, April, 1953.

________. "The New Irrigation Era in Iraq," Economic Geography, Vol. XXXI, No. 1, January, 1955.

Lowry, R. L., and Johnson, A. F. "Consumptive Use of Water for Irrigation," Transactions of American Society of Civil Engineers, No. CVII, 1942.

National Association of Manufacturers and the Conservation Foundation. Water in Industry. New York, December, 1950.

New York Times. February 2, 1958.

Normand, C. W. B. Climate and Weather of Iraq. Baghdad: Government Press, 1919.

Salter, J. A. The Development of Iraq: A Plan of Action. Baghdad: The Development Board, 1955.

Sirri, Ernic. "The Climate of Turkey According to Thornthwaite's Classification," Annals of the Association of American Geographers, Vol. XXXIX, No. 1, March, 1949.

Subrahmanyan, V. P. "The Water Balance of India According to Thorr thwaite's Concept of Potential Evapotranspiration," Annals of the Association of American Geographers, Vol. XLVI, No. March, 1956.

Thornthwaite, C. W. "Report of the Committee on Transpiration, 19 1944," Transactions of American Geophysical Union, Vol. XX 1944.

Thornthwaite, C. W., and Mather, J. R. The Water Balance. Public tion in Climatology. Vol. VIII, No. 1, Laboratory of Clim tology. Centerton, New Jersey, 1955.

United Nations, Economic Commission for Asia and Far East. Water Resources Developments in Burma, India, and Pakistan. Mul tiple Purpose River Basin Development, Part 2. Bangkok: United Nations Publication, 1956.

United Nations, Department of Economic and Social Affairs. Integrated River Basin Development. Report by a Panel of Experts. New York: United Nations, Department of Economic and Social Affairs, 1958.

United Nations, Food and Agriculture Organization. Report of Proceedings. Near East Regional Meeting on Irrigation and Drainage Practices, Tehran, Iran, November 6-13, 1954. Rome: Agricultural Division, Food and Agriculture Organiza tion of the United Nations, 1954.

United Nations, Food and Agriculture Organization, Expanded Techni cal Assistance Program. The Development of Land and Water Resources in Khuzistan. Report to the Government of Iran, FAO Report No. 553. Rome: Food and Agriculture Organization of the United Nations, 1956.

Urban Land Institute. Water for Industry. Technical Bulletin No. 17. Washington, D.C.: Urban Land Institute, November, 1951.

U.S. Department of Agriculture. Water. A Yearbook of Agriculture Washington, D.C.: Government Printing Office, 1955.

Walter, Ernst. "Die Wasserversorgung Alleppos," Gas und Wasser Warme, Bd. XI, 2, 1957.

Warriner, D. Land Reform and Development in the Middle East. A Study of Egypt, Syria, and Iraq. London: Oxford Universit Press, 1957.

White, Gilbert F. "The Facts About Our Water," Harvard Business view, Vol. XXXVI, No. 2, March-April, 1958.

________. (ed.) The Future of Arid Lands. Washington, D.C.: Am ican Association for the Advancement of Science, 1956.

Willcocks, William. Irrigation of Mesopotamia. 2nd ed. London: E. and F. N. Spon, Ltd., 1917.