DRAFT REPORT
PHYSICAL CHARACTERISTICS OF MESOPOTAMIAN MARSHLANDS OF SOUTHERN IRAQ

Background Material Prepared for the
Technical Advisory Panel
Eden Again Project

Prepared by
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TABLE OF CONTENTS

INTRODUCTION..... 3
Preparers..... 3
Acknowledgements..... 3
BACKGROUND 4
Climate..... 5
Physiography..... 7
Surrounding Land Use 9
THE MARSHLANDS..... 12
Hammar Marsh..... 12
Central Marshes..... 13
Haweizeh Marsh..... 14
Evolution of the Marshes..... 14
WATER SOURCES..... 17
Tigris and Euphrates Rivers 17
Karkeh River..... 19
Stream flow..... 19
Groundwater..... 25
WATER CHARACTERISTICS 27
Salinity 27
Temperature..... 27
Turbidity and Transparency..... 27
pH..... 29
Major Ions..... 29
Dissolved Oxygen..... 29
Nutrients..... 30
Water Pollution..... 31
GEOLOGIC CHARACTERISTICS..... 33
Geology..... 33
Sediments..... 33
Soils 34
Salinization..... 35
HYDROENGINEERING STRUCTURES 37
Beneficial Use Structures..... 38
Desiccation Structures..... 41
Effect of Water-Control Structures on Marshes..... 44

INTRODUCTION

PREPARERS

This background report was prepared under the auspices of the Iraq Foundation, which is a non-profit, 501(C)3 corporation, working for democracy and human rights in Iraq, and for a better international understanding of Iraq's potential as a contributor to political stability and economic progress in the Middle East. The Foundation, established in 1991, is non-partisan, non-sectarian and non-ethnic, and is not affiliated with any other organization or political party or government.

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ACKNOWLEDGEMENTS

We would like to express our deepest thanks to the preparers of previous reports on the marshlands, including the Amar Appeal International Charitable Fund, the United Nations Environmental Program, unpublished data from the Exeter Wetlands Hydrology Group (now at Royal Holloway College under the direction of Dr. Edward Maltby), and from Dr. Mike Evans. Numerous other researchers' data have been incorporated within, including original graphics, which we have scanned in for illustrative purposes. Our deepest gratitude goes to all these and the future researchers of the marshlands.

BACKGROUND

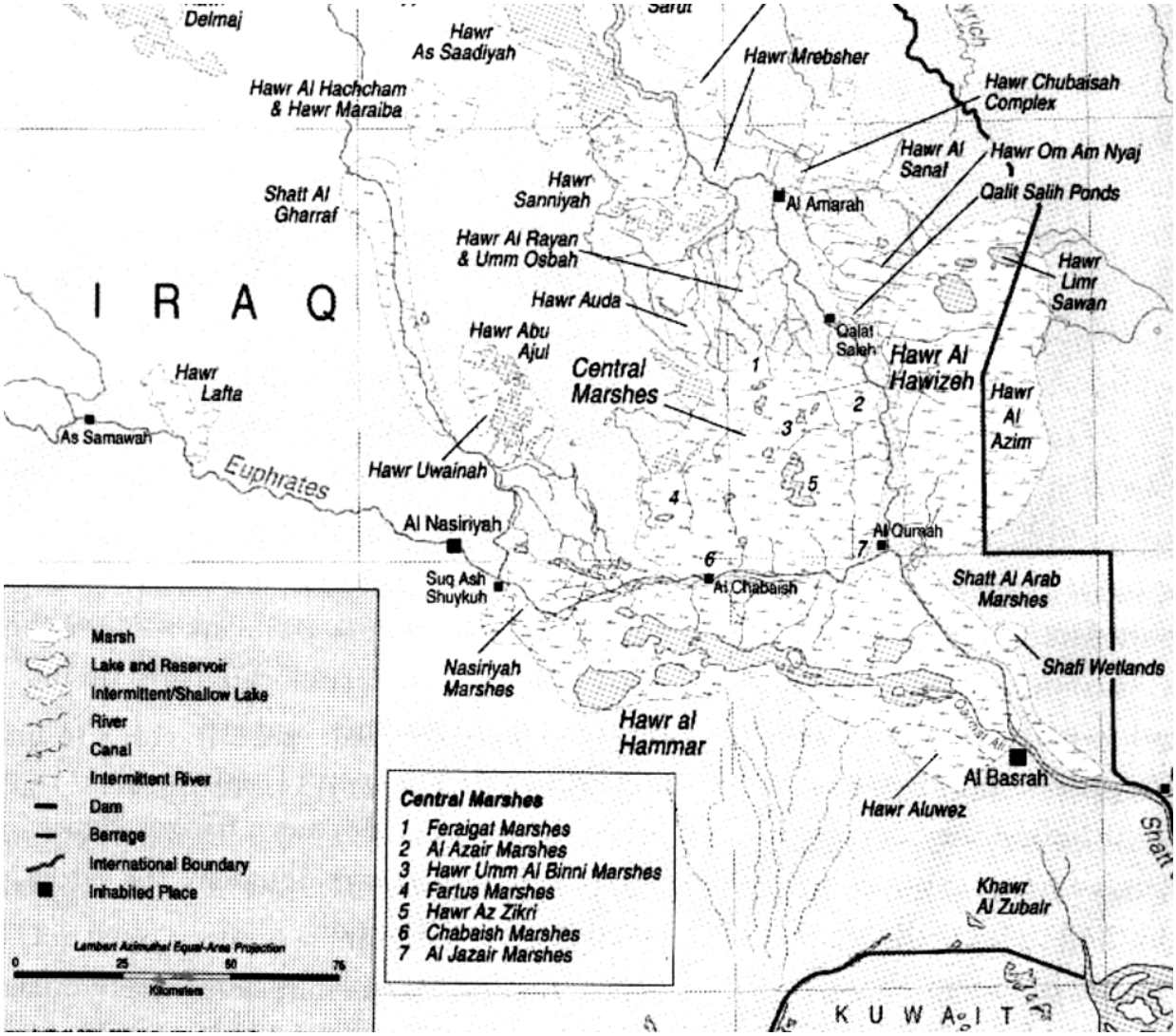
The extensive marshlands of Mesopotamia represent a unique component of our global heritage and resources. The seas of reed beds were home to ancient communities rooted in the dawn of human history. The wetlands are the locale in which human civilization began with the Sumerian culture more than 4,000 years ago. Biblical scholars regard the marshes as the site of the legendary "Garden of Eden," the "Great Flood," and the birthplace of the patriarch Abraham. On the shores of the marshes, the legendary Epic of Gilgamesh was enacted. World-renowned archaeological sites on the fringes of the marshes include Ur, Uruk, Eridu, Larsa, Lagash and Nina.

The current marsh-dwellers, the Ma'dan, are our only link with this rich cultural past. Following the end of the Gulf War in 1991, the Ma'dan were important elements in the uprising against Saddam Hussein's regime. To end the rebellion and punish the freedom fighters, the regime implemented an intensive system of drainage and water diversion structures that have desiccated over 90% of the Hammar and Central Marshes (Partow, 2001). The reed beds were also burned and poison introduced to the waters (Mitchell, 2001). The majority of the marshes are now wastelands.

In addition to destroying the reed beds upon which the Ma'dan culture depended, the regime of Saddam Hussein has systematically destroyed their villages and killed their people. It is estimated that more than 500,000 Ma'dan have been displaced, 95,000 of them to Iran (Nicholson, 2001), 300,000 internally displaced, and the remainder to other countries.

The marshlands historically comprised the largest wetland ecosystem of Western Eurasia. A rare aquatic landscape in the desert, they also provided habitat for important populations of wildlife, including endemic and endangered species. The key role played by the marshlands in the intercontinental flyway of migratory birds, and in supporting coastal fisheries of the Persian Gulf, endows them with a truly global dimension. The impacts of marshland desiccation on wildlife have been devastating (UNEP, 2001; Evans, 2001). Several endemic species of mammals, birds, and fishes have become extinct or are seriously threatened. The marshlands' disappearance as a key wintering and staging site in the intercontinental migration of birds has placed an estimated forty species of avians at risk and caused significant reductions in their populations. Coastal fisheries in the Persian Gulf, dependent on the marshland habitat for spawning migrations and nursery grounds, have also experienced significant reductions. Ecosystem damage has extended to the Shatt al-Arab, with significant seawater intrusion.

Figure 1. Location Map of Mesopotamian Marshlands. From Partow 2001

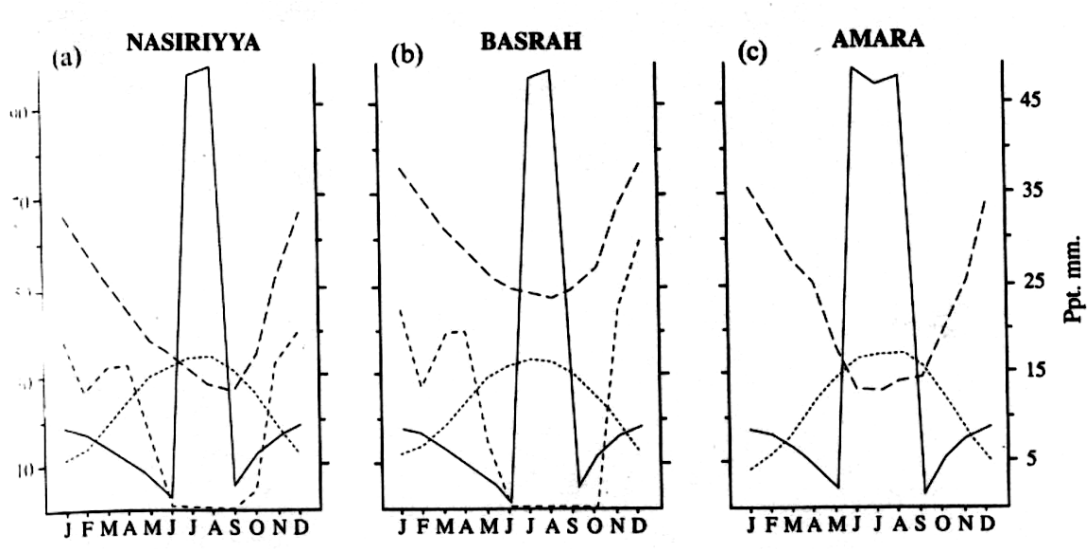


CLIMATE

The climate of Iraq is mainly of the continental, subtropical arid type. The mean temperature measured at Basrah is 24°C (76°F), with the coldest monthly average in January (11°C or 52°F) and the hottest monthly average in July (35°C or 96°F) (Holwerda, 1958). The lowest mean minimum temperature is 8°C (46°F) in January, with the lowest temperatures at –4°C (24°F), so frost and night frost can occur on the surface. The highest mean maximum is 41°C (106°F) in August, with peaks reaching up to 49°C (120°F). The transitional seasons (spring and autumn) are very short (Pons et al 2002).

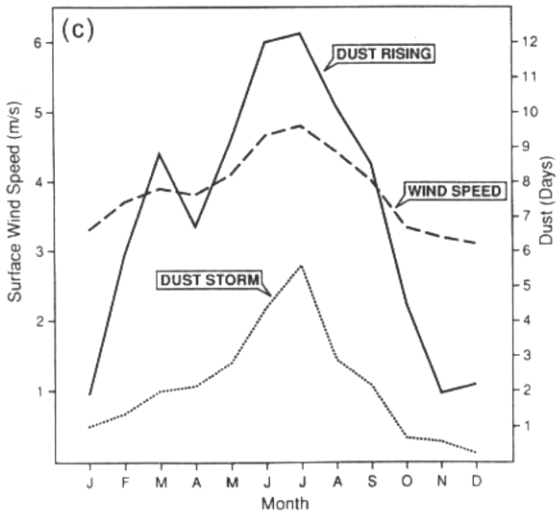
The mean annual precipitation at Basrah is 171 mm, with monthly inputs ranging from virtually zero for the period from June through October, to 22-34 mm per month in the period November through April, with peak rainfalls in January and March (Holwerda, 1958). Yearly averages can range from 70 to 302 mm (Pons et al 2002). Relative air humidity is low throughout most of the country (12-15%) but is considerably higher near the marshes at an annual average of 59% , ranging from 47% in August to 90% in January (Holwerda, 1958).

Figure 2. Meteorological Data from Aqrawi and Evans 1994.
Solid line = pressure, dashed line = relative humidity, dotted line = temperature



The rate of evapotranspiration is very high; figures are quoted up to 3,426 mm/year in Baghdad (Sanlaville, 2002) but probably have an average annual rate of 2,500 mm near the marshes (Pons et al 2002) due to higher relative humidity. Evaporation rates of this magnitude encourage formation of mineral crusts on the surface in areas where the groundwater depths are shallow and the capillary fringe reaches the surface; such crusts occur over large areas on the Mesopotamian Plain.

During the summer (June through September), the prevailing wind, called the *Shamal*, is from the north and northwest; this is a very dry, steady wind but the breeze has some cooling effect (Sanlaville 2002). The *Sharqi*, a dry dusty wind often accompanied by violent dust storms, occurs occasionally during the spring and fall. Typical wind velocity may range from 7 to 18 knots (Saad and Antoine 1978). The dust fall-out from these winds has been calculated to supply sufficient material to allow an accumulation of about 0.8 mm per year of sediment over the area (Al-Aqrawi, 1994).



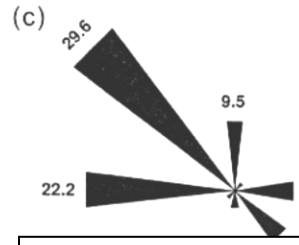


Figure 4. Wind speed and direction from Aqrawi and Evans 1994.

PHYSIOGRAPHY

Iraq consists essentially of a flat, low-lying plain which rises gently to the southwestern plateau reaching elevations of 940 m, and the northeast to the Zagros Mountains, which rise to elevations up to 3,000 m. Elevations on the almost featureless plain characteristic of most of the country vary from a few meters below sea level to about 400 meters above. The widest portion of the plain is 200 km, but it narrows towards Basra to less than 45 km.

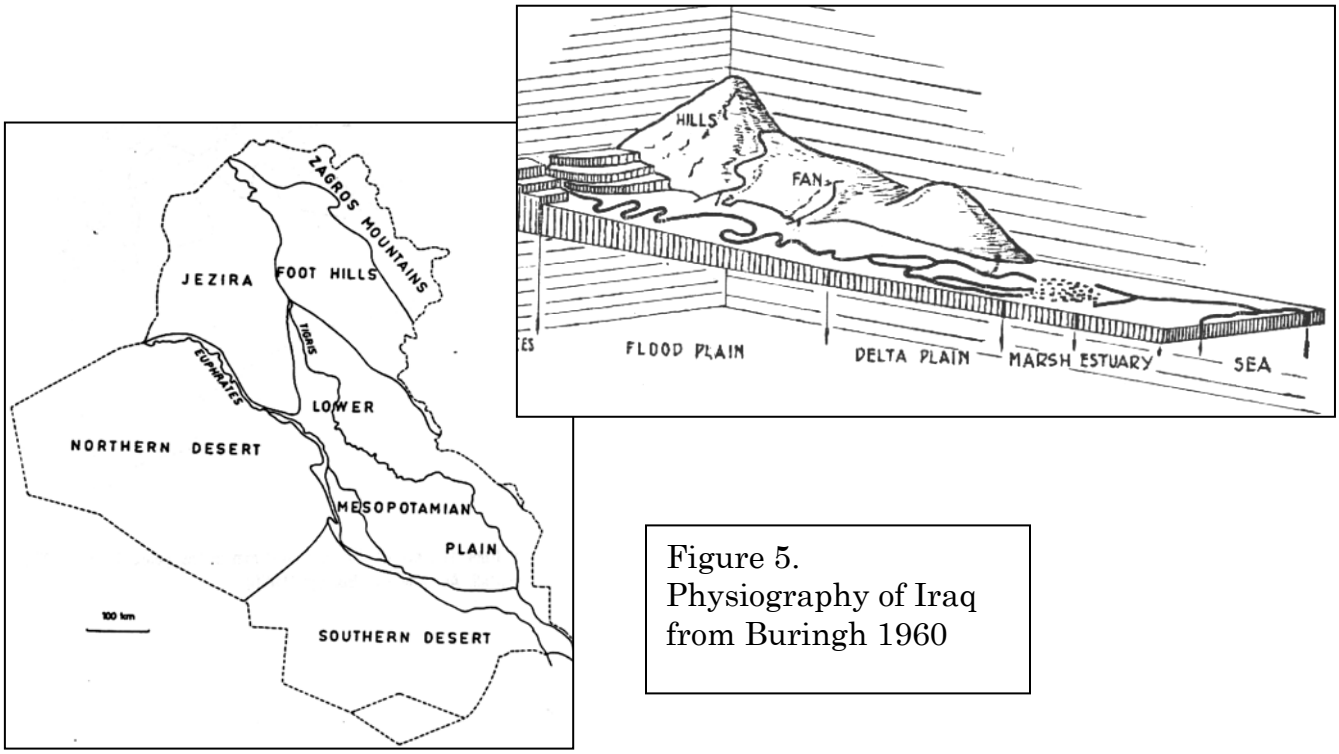


Figure 5. Physiography of Iraq from Buringh 1960

The lower portion of the plain can be divided into four regions: the upper River Plain between Baghdad and Kut; the Interior Delta between Kut and al-Hindiya, the Marsh and Lake area, and the Estuary south of Basrah (Sanlaville, 2002).

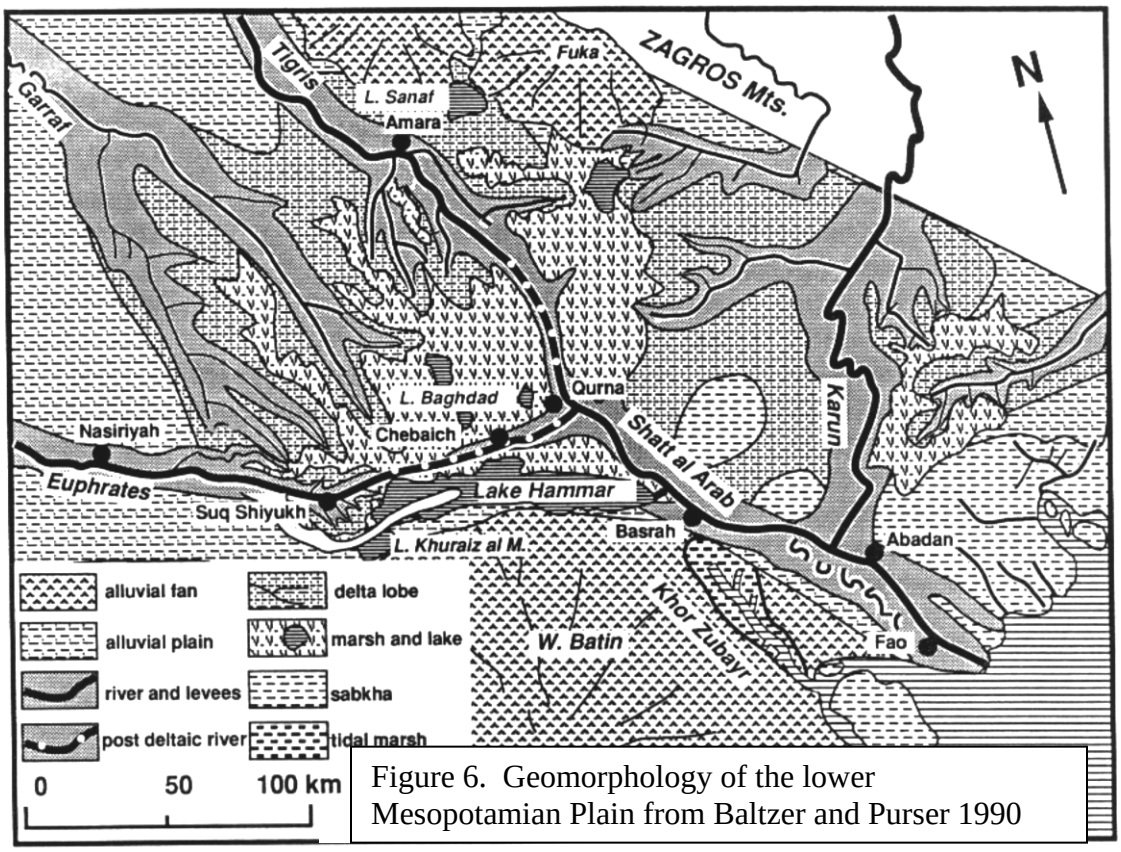


Figure 6. Geomorphology of the lower Mesopotamian Plain from Baltzer and Purser 1990

In the River Plain, the slope is only 0.07%; therefore, the rivers meander and shift position greatly. Levees are generally 1-3 km wide and 2-3 meters high. During high flow conditions, the water within the river rose higher than the levees and the plain was flooded over a large area. Coarser sediment was deposited on the levees, and finer sediment in depressions.

Downstream of Kut, the slope decreases even further to 0.03% (Sanlaville, 2002). The Tigris and the Euphrates split into many branches and form an Interior Delta. The branches into split into smaller distributaries, and meander and shift. The levees are smaller and lower than in the River Plain, the groundwater is closer to the surface and depressions between the channels become marshy. This is the main sedimentation area of the rivers. The Euphrates forms a delta around the Suq-ash-Shuykh area, which has a fern-frond shape with numerous distributaries bordered by levees and flood plains. The Euphrates actually disappears at this point, reforming northeast of the delta. The Tigris delta is located south of Amarah. At this point, the Tigris trends to the east, while the deltaic distributaries trend southward. These deltaic environments have historically been the areas of intensive rice cultivation. A third, inactive delta is associated with the Gharraf River, a distributary of the Tigris flowing southward from Kut.

Past the delta environment, the waters flow into the marsh and onto lake areas, where the land is essentially flat. The groundwater table intersects the ground surface. The last suspended sediments are trapped within the marshes and lakes. The far extremities of the marsh and lake environment (south of Hammar Marsh) grade into saline dry lakes, sabkhas, and desert.

Past the marshes, the Euphrates and Tigris Rivers join together near Qurnah to form the Shatt al-Arab. The Karun River, flowing from the Zagros Mountains of Iran, joins the Shatt al-Arab south of Basrah. The Shatt-al Arab runs through a narrow passageway formed due to the formation of a large alluvial fan associated with the Karun River flowing in from the northeast, and another large alluvial fan associated with the Wadi Batin flowing in from the southwest. The Shatt al-Arab is a shallow, well-mixed estuary flowing into a shallow arm of the Indian Ocean known variously as the Persian or Arabian Gulf; this water body will be referred to herein as the Gulf). The Gulf is a shallow sea, with an average depth of 50 m, with water depths near the Iraqi coast usually only a few meters deep.

West of the Shatt al-Arab along the Gulf Coast is a tidal marsh, the Khor Zubayr. This is a semi-restricted marine environment with wide deep subtidal channels with salinity similar to the Gulf, and hypersalinity in some tidal channels. It is covered by an extensive, branching network of intertidal channels, which drain large tidal flats. Khor Zubayr has also been affected by the local desiccation structures in southern Iraq, as a result of freshwater flowing in from the Mother of Battles River, through the Shatt al-Basrah.

SURROUNDING LAND USE

Basra, a port city located on the Shatt al-Arab, is the largest in southern Iraq with a population of almost one million. Secondary cities (populations around 250,000) include Nasiriyah, on the Euphrates River at the eastern end of Hammar Marsh; Amarah, on the Tigris River at the northern end of the Central Marshes; and Qurnah, at the confluence of the Tigris and Euphrates Rivers. Most of the population is centered along the rivers, with scattered villages within the marshes themselves.

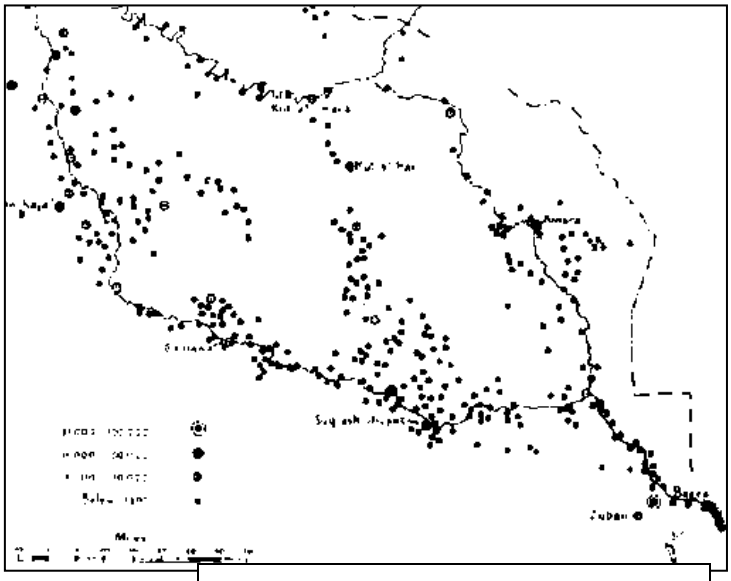
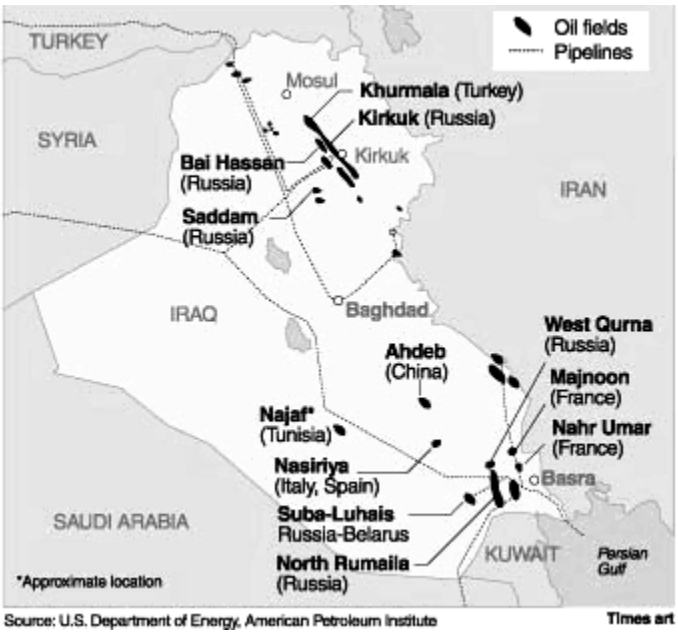


Figure 7. Modern Human Settlements from Rzoska 1980

Agriculture: Agricultural production has historically dominated the areas outside of the marshlands. Rice is cultivated in the distributaries of the Interior Delta regions at the eastern and northern ends of Hammar Marsh, and at the northern end of the Central Marshes. Further north and west, barley and wheat are cultivated by flood irrigation methods. Dates and vegetables are cultivated by tidal-influenced flood irrigation along the banks of the Shatt al-Arab. Smaller areas of dates and vegetables are cultivated elsewhere in the region and to a limited extent within the marshes. The primary economic activities within the marshes are harvesting of reeds to feed water buffalo for the production of milk and dairy products; weaving of reed mats; and fishing. Some marsh dwellers migrate to rice fields and date fields as agricultural laborers.

Petroleum: Southern Iraq is home to perhaps 5% of the world's total oil reserves. The largest oilfields in southern Iraq include Rumayllah, North Rumayllah, West Qurnah (all located within or adjacent to the Hammar Marsh), and Majnoon (located within the Haweizeh Marsh). Iraq has signed contracts with Russian oil companies to develop the Rumayllah, North Rumayllah, and West Qurnah fields. Iraq has signed contracts with French oil companies to develop the Majnoon Fields. Development of these fields cannot proceed until United Nations sanctions have been lifted. Smaller oilfields near the marshes include Bin Umar, Suba-Luhais, Nasiriyah, Tuba, Ratawi, Amarah, and Gharraf. We have not been able to determine the precise location of these oilfields; published maps, even from reputable sources, indicate widely varying locations.



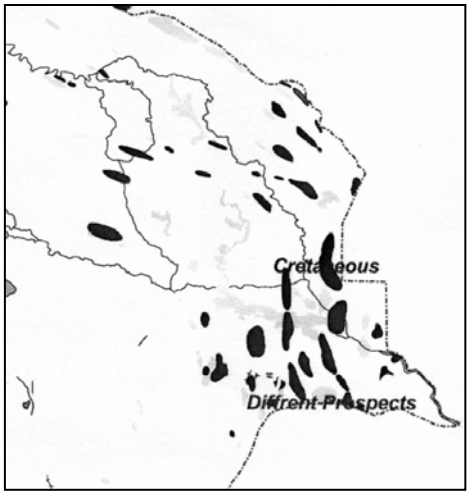


Figure 8. Southern Iraq Oilfields

ARCHEOLOGICAL RESOURCES

Most of the known major archaeological resources are outside the marshes, with the exception of some within the Central Marshes. However, extensive undiscovered archaeological remains are present as slight mounds within the marshes themselves.

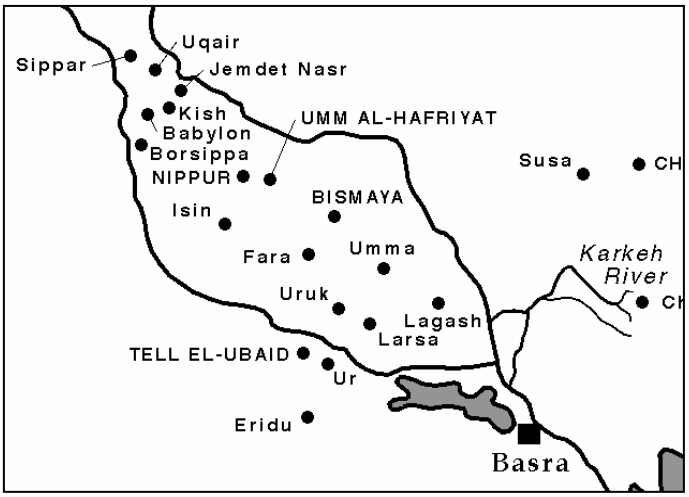


Figure 9. Known Major Archaeological Sites in Southern Iraq. From The Oriental Institute

THE MARSHLANDS

The marshlands lie along the confluence of the Tigris and Euphrates Rivers. Mesopotamia, or the land between the rivers, encompasses this region. The lower Mesopotamian valley is distinguished by an extremely flat alluvial plain. The Euphrates falls only 4 cm/kilometer over the last 300 km, while the Tigris has a slope of 8 cm/km. As a result of the level terrain, both rivers deviate from a straight course, meandering in sinuous loops and eventually dividing into distributaries that disperse into a vast inland delta. This is particularly true of the Euphrates, whose velocity rapidly diminishes as it lacks tributaries along its lengthy course within Iraq. Immediately south of Nasiriyah, the Euphrates' main channel dissolves into the marshes, only to re-emerge shortly before its confluence with the Tigris at Qurnah. The Tigris, which is joined along its eastern flank by several tributaries from the Zagros Mountains, has a relatively stronger hydraulic head, enabling it to maintain a more stable course. Nevertheless, in its lower reaches around Amarah, the Tigris also rapidly begins to lose its velocity and flares out into multiple distributary channels feeding directly into the marshes.

Historically, the marshlands constitute a chain of almost interconnected marsh and lake complexes that flow into another (Maltby, 1994). During periods of high floods, large tracts of desert are under water. Consequently, some of the formerly separate marsh units merge together, forming larger wetland complexes. The wetlands themselves are made up of a mosaic of permanent and seasonal marshes, shallow and deep-water lakes, and mudflats that are regularly inundated during periods of elevated water levels. The highly graded ecotonal environment has given rise to an array of diverse habitats and environmental conditions.

The core of the marshes is centered in the area around the confluence of the Tigris and Euphrates. It is typically divided into the three major areas: the Hammar, south of the Euphrates; the Central Marshes between the twin rivers; and the Haweizah Marshes east of the Tigris River. **The following discussion of the nature and extent of the marshes is based upon conditions existing prior to 1990.**

HAMMAR MARSH

The Hammar Marsh is situated south of the Euphrates, extending from near Nasiriyah in the west to the outskirts of Basra on Shatt al-Arab in the east. To the south, saline lakes, sabkhas, and the sand dune belt of the Southern Desert borders the marshes. The marsh area comprises 2,800 square kilometers of permanent marsh and lake, expanding to over 4,500 square kilometers during periods of seasonal and temporary inundation. Hammar Lake, which dominates the marshes, is the largest water body in the lower Euphrates. It is approximately 120 km long and 25 km wide. Maximum water depth in the lake ranges from 1.8 to 3 meters.

The lake is oxygen-deprived and brackish. Sediments within the lake are gray calcareous silts. During the summer, large parts of the shoreline dry out, and banks

and islands emerge. The lake is surrounded on the north and northeast by freshwater marshes characterized by more terrigenous and organic-rich sediment and extensive reed beds.

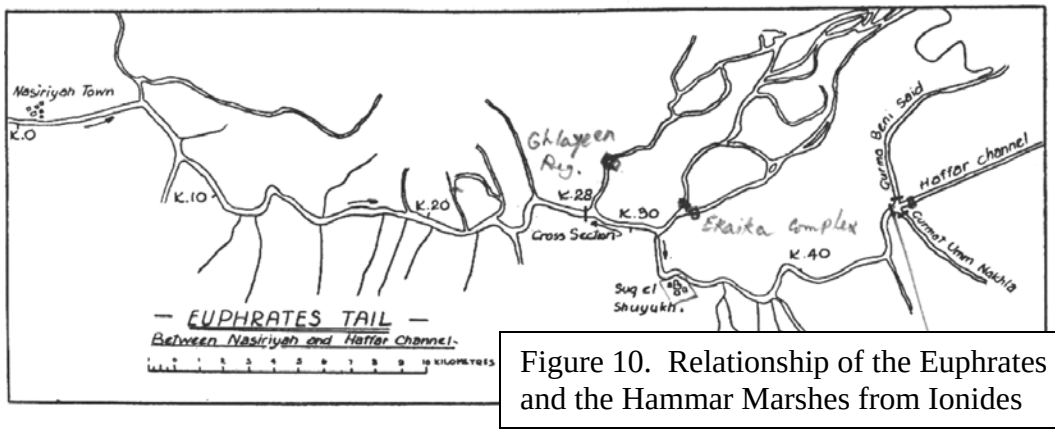
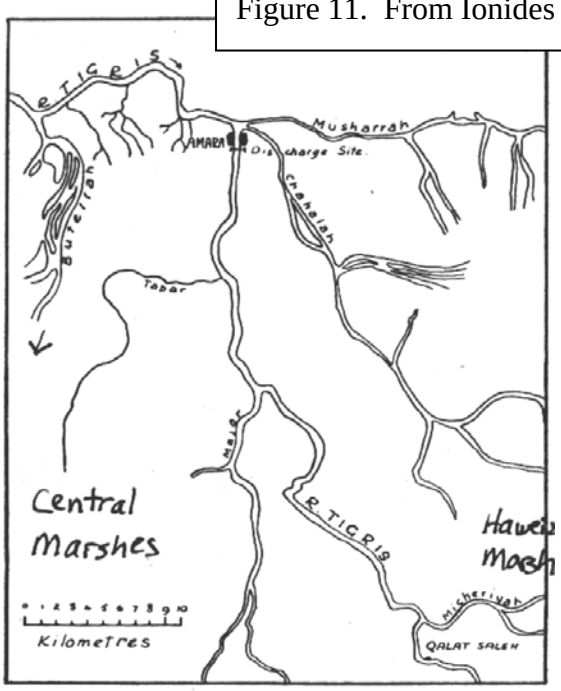


Figure 10. Relationship of the Euphrates and the Hammar Marshes from Ionides

Hammar Marsh is fed primarily by flooding and tributaries of the Euphrates River. A considerable amount of water from the Tigris River, overflowing from the Central Marsh, also nourishes the Hammar Marsh. Groundwater recharge is another source of replenishment.

CENTRAL MARSHES

Figure 11. From Ionides



Bounded by the Tigris River to the east and the Euphrates River to the south, the area is roughly delimited by a triangle between Nasiriyah, Qalat Saleh and Qurnah, covering an area of about 3,000 square kilometers. The Central Marsh receives water influx mainly from Tigris distributaries branching southward from Amarah, including Shatt al-Lumina. The marsh complex is densely covered with tall reed beds, interspersed with several large open-water bodies. Al-Zikri and Hawr Umm Al-Binni are some of the notable permanent lakes located around the center of the marsh, and are approximately 3 m deep and average 1 km in diameter. These are freshwater lakes, with chemical precipitation of calcareous sediment along with terrigenous material. The waters of the marshes are clear. Along the marsh's northern fringes, dense networks of distributary deltas are the sites of extensive rice cultivation.

HAWEIZEH MARSH

The Haweizeh Marsh lies to the east of the Tigris River, straddling the Iran-Iraq border. The Iranian section of the marshes is known as Hawr Al-Azim, where it is fed primarily by the Karkeh River. In Iraq, this marsh is largely fed by two main distributaries departing from the Tigris River near Amarahh, known as al-Musharah and Al-Zahla. During spring flooding the Tigris may directly overflow into the marshes. Extending for about 80 km from north to south, and 30 km from east to west, the marshes cover an approximate area of 3,000 square kilometers. The northern and central parts of the marshes are permanent, but towards the southern sections they become increasingly seasonal in nature. The permanent marshes have moderately dense vegetation, alternating with open stretches of water. Large permanent lakes up to 6 m deep are found in the northern parts of the marshes.

PHYSICAL EVOLUTION OF THE MARSHLANDS

When did the marshlands originate? About 18,000 years ago, the global sea level was about 130 m lower than the present time and the Gulf would have been completely dry. At that time, rivers draining lower Mesopotamia would have been downcutting and no marshes would likely have existed (Sanlaville, 2002). Sea level began to rise from 14,000 until about 4,000 years ago. Some researchers claim that at about 5,000 to 4,000 BC, the marshlands were covered by a lagoonal marine environment, likely having brackish waters (Sanlaville, 2002). Others disagree with this claim (Pons et al 2002). With rising sea level, the rivers began to deposit sediment and create vast aggradational deltas, which caused the shoreline to prograde to its present location, possibly between 3,000 and 1,000 BC (Sanlaville, 2002). The present fresh to brackish-water environment has been dated to have been established around 3,000 years before present (1,000 BC) (al-Aqrawi and Evans, 1994). Prior to that time, the area may have been saltwater marsh with similar characteristics and functions.

The courses of the rivers and their lakes and marshes have changed greatly through time, as evidenced by maps during the past few centuries, and other verbal accounts. Lake Hammar is though to be formed as recently as 600 A.D. (Rzoska, 1980). At times, the Euphrates River actually disappears into the Hammar, and the Hammar discharges directly to the Shatt al-Arab. The Gharraf River is thought to be an ancient channel of the Tigris River.

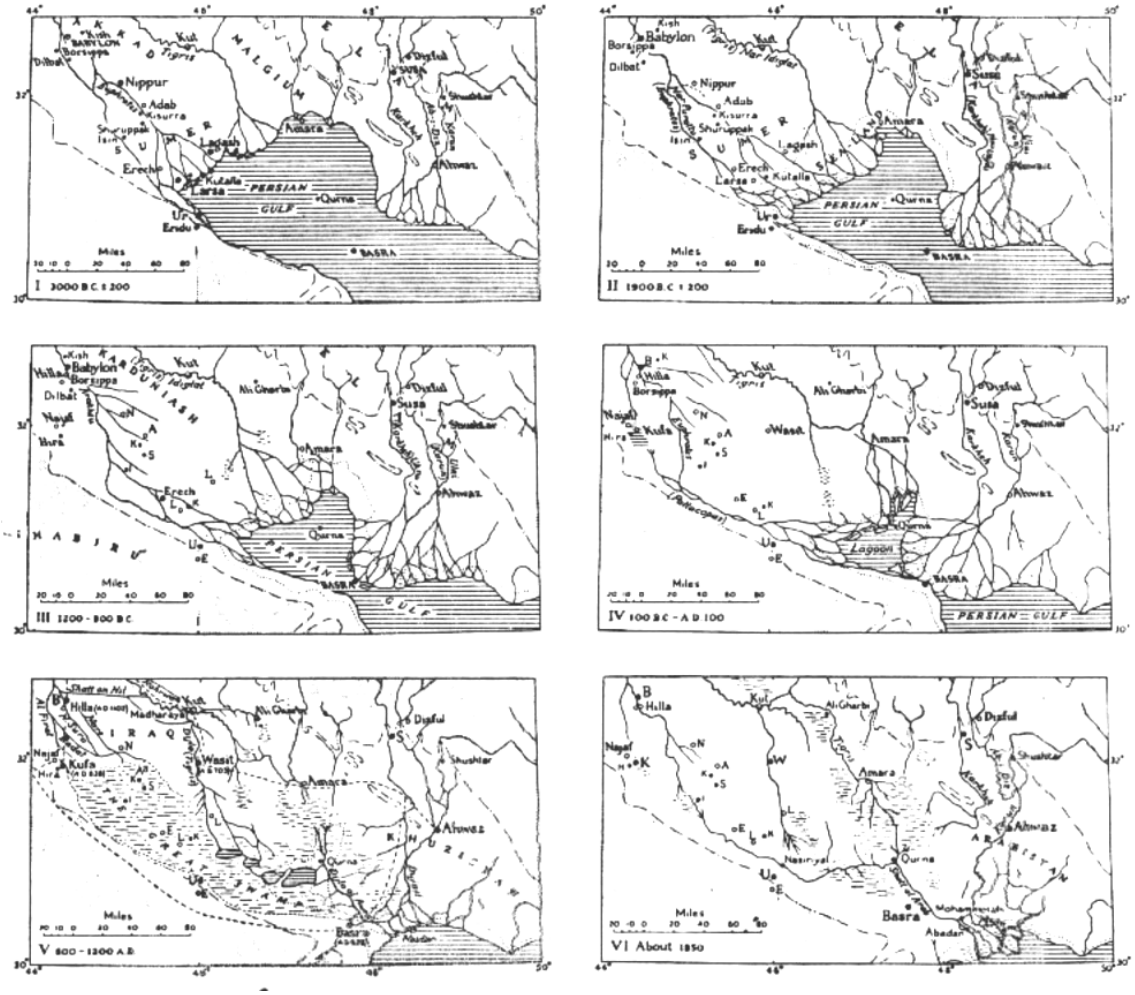


Figure 12. Evolution of the Marshlands. From Rzoska 1980

AGRICULTURAL IMPACT

Agriculture has been undertaken in Iraq for over 6,000 years and has had an impact on the physiography, soils, and area of the marshlands. The earliest type of irrigation in southern Iraq is thought to have been in the estuary area, where the tidal influence was utilized (Schilstra 1962). During flood tide, the rising river water is made to flow into the numerous ditches dug in the low levees bordering the river and the creeks branching off from it. At ebb tide the water flows back again. Thus an easy irrigation and drainage is ensured. This type of irrigation is still used on the fringes of the Shatt al-Arab for date cultivation.

The interior delta was the next area utilized for cultivation using the method of "wild irrigation"(Schilstra 1962). This utilizes natural areas of inundation in the deltaic distributaries and floodplains. As soon as land emerged, seedbeds were prepared, and sowing would keep pace with the falling water surface. Gaps were made in river levees at smallest and lowest spots, thus increasing the presence of meandering river branches, building up their own small levees. As time passed, these wild-irrigation streams would become choked by river sediment and shift their courses. Few areas in southern Iraq continue to utilize this method.

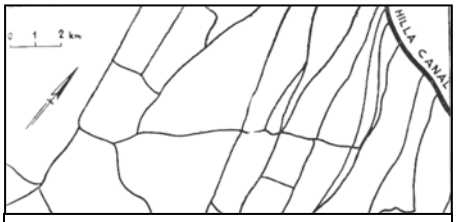
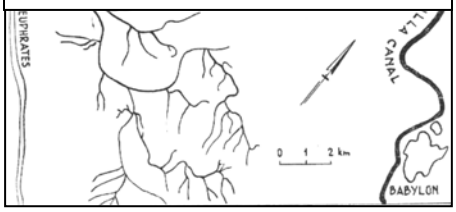


Figure 13: Controlled irrigation (above) vs. wild irrigation (below) from Schlistra 1962



Increased production needs led to the development of controlled irrigation, involving the installation of primitive dams, sluices, water wheels, and extensive systems of dug canals (Schilstra 1962). These canals were more geometric in pattern compared to the wild irrigation (see adjacent figure). The canals allowed for more agricultural development further above the deltaic areas. Eventually, almost the entire river valley was divided into numerous, small artificial basins bounded by the banks of the canals. Wheat and barley fields were characterized by more rectangular patterns, and rice production is more characterized by a fish-bone pattern, where a main canal has many laterals which branch off slantingly. The rectangular pattern was more subject to choking by silt; cleaning out the canals led to the development of huge ridges formed on either side of the canals, or a new canal would be dug out next to the former canal.

As the canals ended in marshes, these also silted up and were found to be suitable for rice cultivation; therefore, most marsh fringes are being cultivated for rice. When the rice land is silted up and has to be abandoned, new rice land is reclaimed towards the end of the canal at the border of the marshes (Pons). The abandoned rice land can be used for millet, which is not irrigated, or barley. Some higher banks may be used for date palm cultivation.

WATER SOURCES

The primary sources of water to the marshlands is flow from the Tigris and Euphrates Rivers, with the Karkeh River supplying some water to the Haweizeh Marshes, and some supply from groundwater. Local rainfall supplies very little water to the marshlands.

TIGRIS AND EUPHRATES RIVERS

The Tigris and Euphrates Rivers supply the majority of the water into the Mesopotamian marshes. The Euphrates traverses a distance of 2,700 kilometers, of which some 40 percent is in Turkey, 25 percent in Syria, and 35 percent in Iraq. Its twin, the Tigris, has a total length of 1,900 kilometers, of which about 20 percent lies in Turkey, 78 percent in Iraq, and only 2 percent in Syria.

Both rivers originate in the highlands of eastern Anatolia at elevations ranging up to 3,000 meters above sea level, where they flow as swift mountain streams cascading tumultuously through steep gorges. The rivers then flow tranquilly through the plateaus of northern Syria and Iraq, where they cut deep courses in the relatively soft bedrock so that their route remains relatively stable. In this section they descend from elevations of about 400 meters to little over 50 meters above sea level where they enter the alluvial plain. In that vast plain, the once-swift mountain rivers snake their way sluggishly as lazy, braided streams.

This great alluvium-filled depression (physiographically, an extension of the Persian Gulf), having a length of 800 kilometers and an average width of 200 kilometers, constitutes the combined inland delta of the twin rivers. Here the surface of the land is so flat—its average slope towards the sea being only 5 centimeters per kilometer – that it greatly impedes the natural drainage of the area.

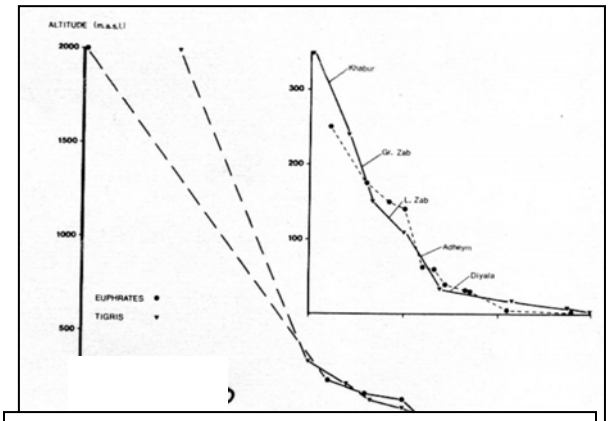


Figure 14. Gradients of the Tigris (upper right) and Euphrates Rivers. From Rzoska 1980

From the head of the plain to the gulf, the rivers meander slowly. The loss of velocity and turbulence causes the rivers to deposit their silt and thereby to build up their beds and banks above the level of the plain, a characteristic that makes these rivers prone to overflow their banks seasonally and to change course capriciously. Throughout history, the twin rivers have bifurcated and altered their beds on numerous occasions and it is believed that some of the deeper portions of the Marshes (lakes) were essentially former paths of the two rivers that have died as the rivers change course in the up stream areas.

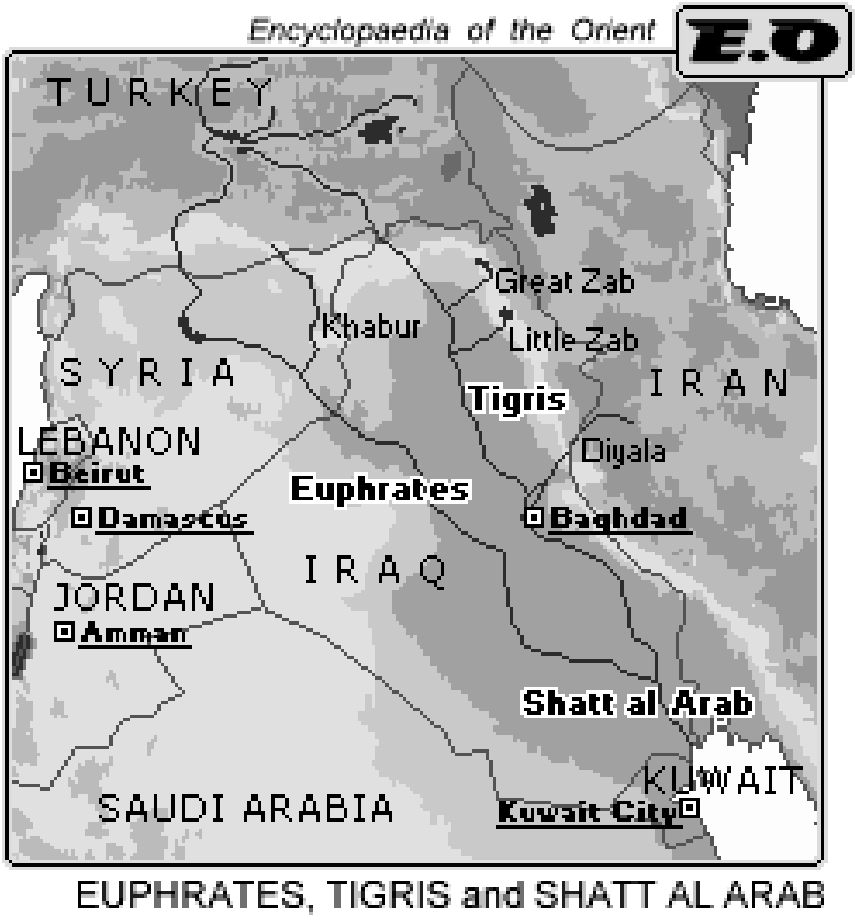


Figure 15. The Tigris and Euphrates Rivers. From Harza

The widths of the rivers vary with discharge and gradually decrease downstream. The width of the Euphrates ranges from 100-200 m, and the Tigris from 350 to 150 in the area of the marshes (Rzoska, 1980). The flow depths of the rivers are generally 5 to 15 meters, and sudden rises of 3-6 meters can occur in a few days during flooding. Levees surrounding the rivers are typically 1-3 meters high, and 1-2 km wide. Both riverbeds are raised above the alluvial plain.

THE KARKEH RIVER

The Karkeh River originates in the mountains of Iran, and discharges into the Haweizeh Marshlands. No data on discharge or other stream flow data could be found. In 2001, Iran completed a large dam on the river, which has halted water flow to the marshlands. Plans are underway to transfer water from the Karkeh reservoir to Kuwait via a 540-km pipeline, supplying Kuwait with 200 million gallons of freshwater per day (Partow 2001).

STREAMFLOW

Because of the low rainfall and high evaporation within the marsh area, restoration of the marshes is highly dependent upon the supply of water from the Tigris and Euphrates River. Therefore, knowledge of the amount of stream flow available to restore the marshlands is essential. It has been estimated that the Hammar Marsh has historically required a water flow of 3.6 billion cubic meters per year (bcm/yr) to maintain a level sufficient for the needs of fishing and rural life (Naff, 2001). A greater amount would be initially required to completely re-flood the marshes, accounting for seepage into the ground and for a greater rate of evapotranspiration over the dry marshlands compared to the fully flooded marshlands. The larger Central Marsh may require a larger water flow, up to 9 bcm per year, to sustain it.

Water is supplied to these rivers primarily by precipitation and snowmelt within the catchment basins of their upper reaches. Downstream, water is removed through the natural processes of evaporation and infiltration and diversion for the purposes of irrigation and municipal use. Flow through these streams has significantly decreased over the past several decades as a result of engineering projects, including many large dams in Turkey, Syria, Iran, and Iraq.

Data on stream flow within Iraq, particularly in the areas of the marshes, is scarce; however, estimates can be made using the existing database and engineering judgment. Several comprehensive reports (Ionides, 1937; Sousa, 1944; Haigh, 1951; van der Leeden, 1975; Badry, Mehdi & Khawar 1979; Hillel, 1990; Kolars & Mitchell, 1991; van der Leeden et al., 1991; Juhmani, 1999, Partow 2001; Aqrawi and Evans 1994) were located that provide data on flow within both rivers at numerous points within Iraq.

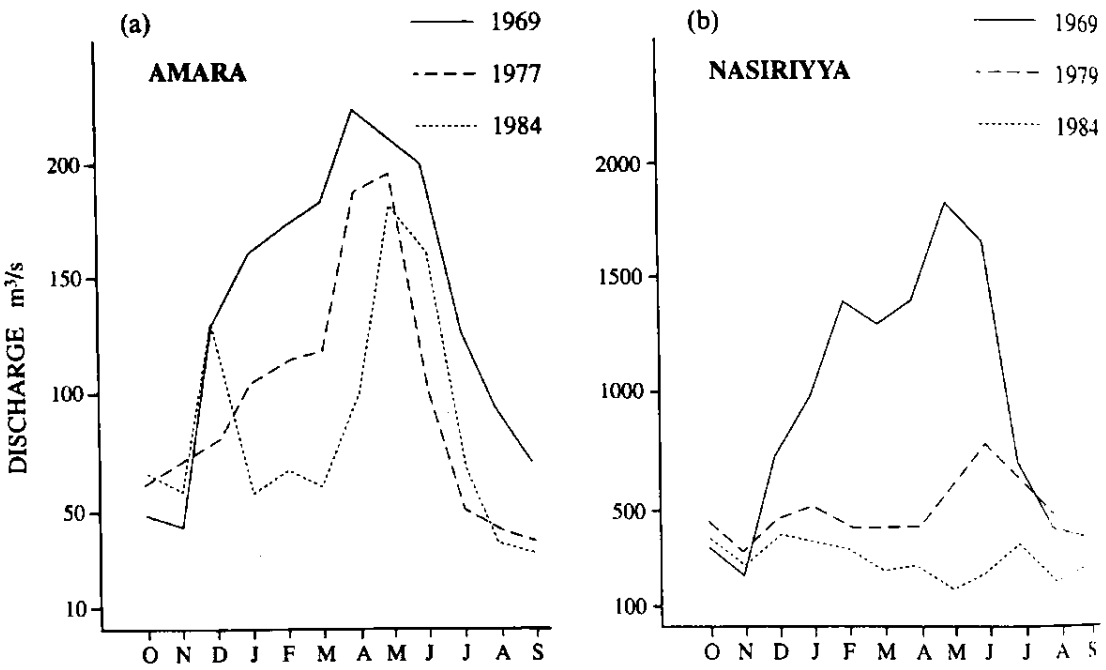


Figure 16. Hydrographs for the Tigris (a) and Euphrates Rivers (b). The dashed line represents 1977, an average year for the time period 1969-1990; the dotted line represents 1984, a dry year for that period; and the solid line represents 1969, a flood year. From Aqrawi and Evans 1994

Euphrates River. The Euphrates collects 84% of its flow in Turkey and 13% in Syria. It obtains no flow inputs within Iraq (Table 1). Usage of Euphrates water within Iraq includes agricultural irrigation and municipal water supply; most of these discharges are upstream of Nasiriyah. The mean natural flow of the Euphrates into Iraq was historically 32 bcm/yr. Between 1928 and 1946, the average stream flow of the Euphrates as it entered Iraq was 27 bcm/yr; this flow was reduced to an average of 14 bcm/yr by the time the Euphrates reaches Nasiriyah. The mean annual discharge of the Euphrates at Nasiriyah between the years 1969 and 1990 was approximately 15 bcm; in 1984 it was approximately 7.5 bcm (Aqrawi and Evans 1994).

During the period 1974-1998, the average flow of the Euphrates into Iraq was 23 bcm/yr. The current stream flow of the Euphrates into Iraq is estimated to range from 18 to 20 bcm/yr (Naff, 2001), to 16-19 bcm/yr (Janabi, 2001).

A worst-case estimate of the lowest possible flow regime within the Euphrates can be obtained through analysis of the agreement/understanding entered into between Turkey, Syria, and Iraq (Turkish Ministry of Foreign Affairs, 1996). Turkey has pledged to supply a minimum of 16 bcm/yr from the Euphrates to Syria; Syria in turn has pledged to release 58% of this to Iraq (9 bcm/yr). If 38% of this flow were

remaining at Nasiriyah, approximately 3.5 bcm/yr would be available to restore the Hammar marshes.

It should be noted that the annual flow capacity of the Third River is estimated to be on the order of 7.8 bcm/yr (Al Khafaji & Dougrameji, 1995), however, the invert elevation of the Third River requires the damming of the Euphrates River down stream to create the necessary hydraulic gradient for diversion of the water into the Third River. The capacity of the Third River leads the authors to the conclusion that the minimum average flow in the Euphrates at Nasiriyah must be on the order of 7.8 bcm/yr or even more, given the extra capacity provided by the LTL and MOB canals/pipelines, as it would be difficult justifying over expenditure for building the extra flow capacity, given the scarce resources available to the regime at the time these structures were built (1992-1993).

Tigris River. The Tigris collects 43% of its flow in Turkey and 57% of its flow within Iraq from left-bank tributaries including the Greater Zab, Lesser Zab, Adhaim and Diyala Rivers (Table 2). Usage of Tigris water within Iraq includes agricultural irrigation, and municipal water supply; the Tigris also has several water storage facilities for flood control and power generation within Iraq. Between 1928 and 1946, the average stream flow of the Tigris as it entered Iraq was 18 bcm/yr; stream flow in the Tigris increased to 42 bcm/yr past its confluence with the Diyala River; discharges south of this point reduced flow in the Tigris to 37 bcm/yr at Kut. Past Kut, the Tigris supplies water for irrigation and public water supply and also discharges to the Central Marsh. Combined, these discharges reduced its flow to 7 bcm/yr at Amarahh and 3 bcm/yr at Qalat Salih during this same time period.

The average annual discharge of the Tigris River at Amarah was about 2.6 bcm between the years 1969 and 1990 (Aqrawi and Evans 1994).

Current flow figures are not available, as mentioned earlier, but the size and flow capacities of the desiccation structures built by the regime can be used to estimate the flow, again based on the assumption that the Iraqi engineers designed these structures to handle slightly above average flow in the area, based on the data they presumably collected during the 1970s and 1980s. The annual flow capacity of the North-South Canal is demonstrated in a latter section of this report, based on assumed depths of flow and velocities. Assuming an average depth of flow of 1 meter and average flow velocity of 1 km/hr, the flow capacity was determined to be 17.5 bcm/yr. The canal can easily handle twice as much water flow depth, however, there is a bottleneck at the outlet of this canal into the Euphrates west of Qurnah, which causes a backflow problem during peak flows, thus requiring construction of the Medina dam.

Variations in Flow. Considerable variation in stream flow occurs on an annual basis. Most of the water flow within the rivers is generated within the Anatolian and Zagros Highlands, where most of the precipitation occurs during winter as snow. With snowmelt in spring, vast quantities of water are rapidly released, creating periodic flooding downstream. These flood waves are a major driving force in the ecology of the marshlands. The rivers have two distinct surge periods: a

minor rise from November to the end of March, due mainly to rainfall in the highlands; and the main rise in March through June, due mainly to snowmelt. During the latter phase, the rivers may carry a torrent ten times as great as during the low flow period of late summer. Water levels within the marshes respond to this hydrological regime (Salim, 1962 (see Brasington 2002) reports that typical depths within the marshes fluctuate between 0.5-3.5 meters annually. However, engineering controls on the rivers have greatly reduced their seasonality (Partow, 2001). Reservoir filling generally begins in March with the high stream flow event, decreasing the maximum discharge in downstream areas.

Stream flow also varies as a result of rainfall conditions, with lower stream flow during times of drought. For example, between 1923 and 1946, the flow of the Euphrates River as it passed Nasiriyah averaged 14 bcm/yr, but ranged from 5 to 20 bcm. Similarly, the flow of the Tigris at Kut averaged 37 bcm/yr, but ranged from 16 to 59 bcm/yr over the same time period.

Discharge Rates: Discharge rates may also be measured as cubic meters per second (cumecs). The mean discharge between the years of 1942-1946 of the Euphrates River at Nasiriyah was 458 cumecs, with highest discharges in May (averaging 1138) and lowest in September (averaging 117 cumecs). The typical flows between 1969 and 1990 averaged 500 cumecs, varying between 300 to 700 cumecs (Aqrawi and Evans 1994) representing a much-decreased seasonality.

The mean discharge between the years of 1942-1946 of the Tigris River at Amarahh was 218 cumecs, with highest discharges in April (averaging 374) and lowest in October (averaging 91 cumecs). The typical flows between 1969 and 1990 averaged about 120 cumecs, varying between 50 and 180 cumecs, a much more seasonal flow (Aqrawi and Evans 1994).

Current Speed: Currents within the Tigris River have been measured to range between 0.18 m/sec to 1.15 m/sec between Kut and Qalat Salih (Rzoska 1980). Currents within the Euphrates River are typically 0.8 - 1.0 m/s, and during high water maximum velocities at some stretches exceed 5 m/s (Saad and Antoine 1978).

TABLE ONE: EUPHRATES STREAM FLOW DATA

	1928-1946[a] average (range) bcm/yr	**1940-49[b] average (range) bcm/yr**	**1950-59[b] average (range) bcm/yr**	**1960-69[b] average (range) bcm/yr**	**1969-1973[c] average (range) bcm/yr**	**1979[d] average (range) bcm/yr**	**1974-98[e] average (range) bcm/yr**	**1969-1990 average**	**Worst-case Treaty Conditions**
Euphrates stream flow entering Iraq at Hit	27 [a] (9-36) [a]	36 [b]	27 [b]	32 [b]	21[c] (16-28) [c]	30 [d] (10-40) [d]	23 [e]		9
Euphrates stream flow at al-Hindiyah	20 [a] (7-25) [a]	20 [b]	17 [b]	23 [b]					
% of Hit flow remaining at al-Hindiyah	*73% (67-83%)*	*73%*	*63%*	*55%*					
Euphrates stream flow at al-Nasiriyah	14 [a] (5-20) [a]				*8*	10 [d]	*9*	7.5 - 15	3.5
% of Hit flow remaining at al-Nasiriyah	*51% 43-63%*								

Italicized numbers are calculated/estimated
a: Haigh, 1951
b: van der Leeden et al 1975, 1991.
c: Kolars & Mitchell, 1991
d: Badry, Mehdi & Khawar, 1979
e: Partow, 2001

TABLE 2: TIGRIS STREAM FLOW DATA

	1928-1946[a] average (range) bcm/yr	**1940-49[b] average (range) bcm/yr**	**1950-59[b] average (range) bcm/yr**	**1960-69[b] average (range) bcm/yr**	**1969-1990 average**	**early 1980s[c] average bcm/yr**
Tigris stream flow entering Iraq at Mosul	18 (7-28)	22	21	27		
Tigris stream flow at Baghdad	35 (16-48)	43	36	34		
Tigris stream flow at D.S. Diyala	42 (19-64)					
Tigris stream flow at Kut	37 (16-59)	40	31	26		20
Tigris stream flow at al-Amarahh	7 (4-10)					
Tigris stream flow at Qalat Salih	3 (1-4)					

Italicized numbers are calculated/estimated
a: Haigh, 1951
b: van der Leeden et al, 1975, 1991
c: Naff 2001

Tidal Influence: The Tigris and Euphrates Rivers join to form the Shatt al-Arab, which flows into the Gulf and is therefore influenced by tidal action. Tides in the Gulf are semidiurnal. Within the Shatt al-Arab, the tidal range averages 3 m near its mouth to 0.5 m at Basrah (Rzoska 1980) with a maximum range of 5 m (Baltzer and Purser, 1990). Due to the fresh-water discharge of the Karun River into the Shatt al-Arab, the saltwater does not penetrate further than Abadan (about 50 km inland, half-way to Basrah). However, the river water rises and falls as far north as Qurnah due to the dynamic tide influence (Sanlaville, 2002). This area covers the marshlands areas under consideration. This fluctuation of water levels is utilized to irrigate date farms that line the banks of the Shatt al-Arab near Basrah. Reversing flows have been observed in the post-deltaic Euphrates between Suq-ash-Shuykh and Medina (Baltzer and Purser 1990).

The MOD and the Third (Saddam's River) flow into the Shatt al-Basrah, which is also an estuary discharging to the Gulf. A lock is present on Shatt al-Basrah near as-Zubayr to prevent the tidal influence from forcing water up into Hammar marshes. Baltzer and Purser (1990) state that the senile (post-deltaic) Euphrates has reversing waters.

Sediment Load: A feature common to both rivers is the heavy concentration of suspended sediment (silt) that they carry at flood-time: they may transport as much as 3 million tons of eroded soil from the highlands in a single day. The Euphrates River historically carried an average silt content ranging from 130 in September to 1800 grams per cubic meter, and for the Tigris it varied from 170 to 2300 grams per cubic meter (Ionides 1937). Current sediment load is estimated as 50-100 million tonnes per year of suspended sediment in the Tigris and Euphrates (Al-Aqrawi, 1994). Little of this sediment reaches the sea, however. Most of the material settles en route and is responsible for the great deposit of alluvium that fills the Mesopotamian plain. Upstream damming of the rivers has greatly decreased their silt load, however, although recent figures are not available.

Much of this sediment load is deposited within the Interior Delta environment; water flowing into the dense-reed beds of the marshes drops their final load there. Water within the open lakes of the marshlands is clear, and the rivers past the interior deltas also have dramatically clearer water.

GROUNDWATER

The major aquifers in Iraq include Recent and Pleistocene Alluvium, the Bakhtiari formations, Paleocene to Eocene limestones of the desert, possibly the Euphrates limestone, the Upper Fars formation, and the Dibdibba formation, in descending order of importance (Holwerda, 1958). The source of almost all the undesirable constituents in the groundwater of Iraq, including the nitrate ion, is the Fars Formation, which is composed predominantly of evaporates such as gypsum, anhydrite and halite.

Under the Mesopotamian Plain, groundwater occurs within the Recent Alluvium, consisting of clay, silt, fine to coarse sand and occasion pebbly beds. The clay and

silt fractions predominate, and the deposits are commonly lenticular, poorly indurated and nearly flat lying. Water levels average about 5 meters above sea level, and in the marshlands the water table intersects the surface. The water table parallels the ground surface, and slopes to the southeast.

Groundwater recharge occurs from rainfall during the winter periods, and also from the Tigris and Euphrates Rivers. During high flow, both the Tigris and Euphrates are influent (rivers recharging groundwater) and their levels exceed that of the water table. During periods of low flow in the summer, the level of these rivers is below the water table and they become effluent (groundwater discharges to the river).

A line of springs extends along the base of the western plateau west of the marshlands and south of the Euphrates Rivers. Groundwater emanating from the springs probably originates from the Lower Fars formation.

WATER QUALITY CHARACTERISTICS

SALINITY (ALL WATERS)

Water salinity is an increasing problem in Iraq. Salinity increases as the river water flows southward and evaporation, sewage effluent, dissolution of limestone and evaporitic bedrock, and agricultural drainage all increase the salinity. Salinity in the Tigris and Euphrates Rivers near their discharge point at the marshes ranges from 0.5 to 2 parts per thousand. The Shatt al-Arab has relatively low salinities for an estuary (1-1.5 parts per thousand, depending on tides), due to freshwater input from the Karun River.

The marshes are generally more saline than the rivers due to further evaporation and agricultural runoff. Winter and spring floods lower the salinity of the lakes, high evaporation raises salinity during the summer. The Central Marshes are typically fresh water, ranging from 1 up to 2 parts per thousand in the summer. The Hammar marshes are fresher, with increasing salinity during the 1980s up to 1.5-2 parts per thousand. Hammar Lake has even higher salinity, ranging up to 10 to 15 parts per thousand, with salinity increasing to the south and east. South of Hammar Marsh are saline lakes and sabkhas with salinities up to 60 parts per thousand.

Reservoirs have varying salinities. The Derbendikhan, Habbaniya, and Dokan are all relatively fresh (less than 1 part per thousand), while the Tharthar is approximately 1.5 part per thousand and the Abu Dibbis is up to 6 parts per thousand.

Groundwater has become increasingly saline, with salinities under the marshes changing from 3-6 in the 1950s up to 10-60 in the 1980s. Somewhat fresher groundwater may be found beneath the Gharraf due to seepage of irrigation water.

The Gulf is surrounded by desert land masses, causing large evaporative losses from the water (approximately 2 m/year on the average). Consequently, dense water is formed in shallow regions of this sea, with salinities as high as 41 parts per thousand along its Arabian Coast.

Water Temperature: Water temperature in the marshes ranges from around 17-18°C in the winter to 30-31°C in the summer. Water temperature in the rivers also varies with seasons; in the southern Tigris and Euphrates, temperature varies from around 10°C in the winter up to 30°C in the summer, exceeding 20°C for most of the year (Rzoska, 1980). Water temperatures in these rivers decreases very slightly with depth (Saad 1978).

Water Turbidity and Transparency: Turbidity values (suspended sediment concentrations) in the Tigris River may range from 30 mg/L in the summer to 2800 mg/L in the winter; in the Euphrates these values ranged from 46 to 6920 mg/L (Rzoska, 1980).

Table 3. Water Quality Parameters of Selected Water Bodies

WATER BODY	LOCATION DATE	SALINITY parts per thousand	pH	Temperature degree C	Transparency (cm) (1975)
Tigris River	Baghdad 1958	0.190 (May) 0.380 (Nov)		10 (winter) 30 (summer)	
	Amarah 1980	0.8 (spring)			
	Qurnah 1980	1.45 (spring)			50-80
Euphrates River	Samawa 1958	0.180 (Feb) 0.525 (Sept)		10 (winter) 30 (summer)	
	S. Iraq 1980	2.2			60-220
Shatt al-Arab	Qurnah	1.45			
	at Karun	1.02-1.2			
Central Area	Lakes 1969-72	<1 (winter) 1.5-2 (summer)	7-8	13 (winter) 30 (summer)	
Hammar Area	Marshes 1969-1972	0.384 0.640			300
	Marshes 1980	1			
	Marshes 1985	1.5-2.8	7.35-7.91		
	Lake inlet 1990	<5 (winter) >10 (summer)	8-9	14.5 (winter) 31 (summer)	
	Lake outlet 1990	<10 (winter) >15 (summer)	8-9	16.5 (winter) 33 (summer)	
South of Hammar	Saline lakes	30			
	Sabkhas	60			
Groundwater	marsh area 1958	3 – 6			
	under Gharraf 1958	<1			
	marsh area 1980s?	10-60			
Reservoirs	Tharthar 1969-72	1.511			
	Tharthar 1975	1.500			
	Abu Dibbis 1969-72	6.315			
	Habbaniyah 1969-72	0.899			
	Derbendikhan 1969-72	0.222			
	Dokan 1969-72	0.172			

Transparency (measured by Secchi disk)measured near Qurnah was: 50-80 cm in the Tigris; 60-220 cm in the lower Euphrates; and 50 to 140 cm in the Shatt al-Arab; transparency varied seasonally, with the least transparency during the spring and the greatest transparency in the early fall (Saad 1978). In the standing waters of the marshes, transparency may reach 300 cm (Rzoska 1980).

Major Ions: In the rivers, nearly all of the ionic content is contributed by four cations (calcium, magnesium, sodium, potassium) and four anions (bicarbonate, carbonate, chloride, and sulphate). Their absolute concentrations are summarized in the table (Rzoska 1980). In the Tigris and Euphrates Rivers, near their headwaters, calcium, magnesium, and bicarbonate dominate. Downstream, increases occur in sodium, chloride, and sulfate, as a result of traversing carbonate bedrocks. Proportions of calcium, bicarbonate, and carbonate are higher in the flood season, compared with those of magnesium, chloride, and sulfate. In the Shatt al-Arab, sodium and chloride rise to dominance. In the marshes near Lake Hammar, (February 1978) concentrations in milliequivalents per liter: sodium 2.6-10.1, potassium 0.06-0.09, chloride 2.3-7.9, bicarbonate 5.1-6.7.

Table 4. Major Ions of Selected Water Bodies (milliequivalents per liter)

	Na	**K**	**Ca**	**Mg**	**Cl**	**SO4**	**HCO3**	**CO3**
Euphrates Nasriyah	4.1	0.11	3.3	3.3	4.6	3.1	2.8	0.3
Euphrates Qurnah	3.7	0.11	3.7	3.6	3.6	3.3	3.4	0.3
Tigris Amarahh	2.0	0.07	3.4	2.1	2.1	2.4	2.7	0.3
Tigris Qurnah	2.9	0.09	3.8	3.2	3.0	3.1	3.3	0.3
Shatt al-Arab Qurnah	3.1	0.11	2.5	3.5	3.5	3.0	3.4	0.4
Hammar Marshes	2.6 - 10.1	0.06 – 0.09			2.3 – 7.9		5.1 – 6.7	

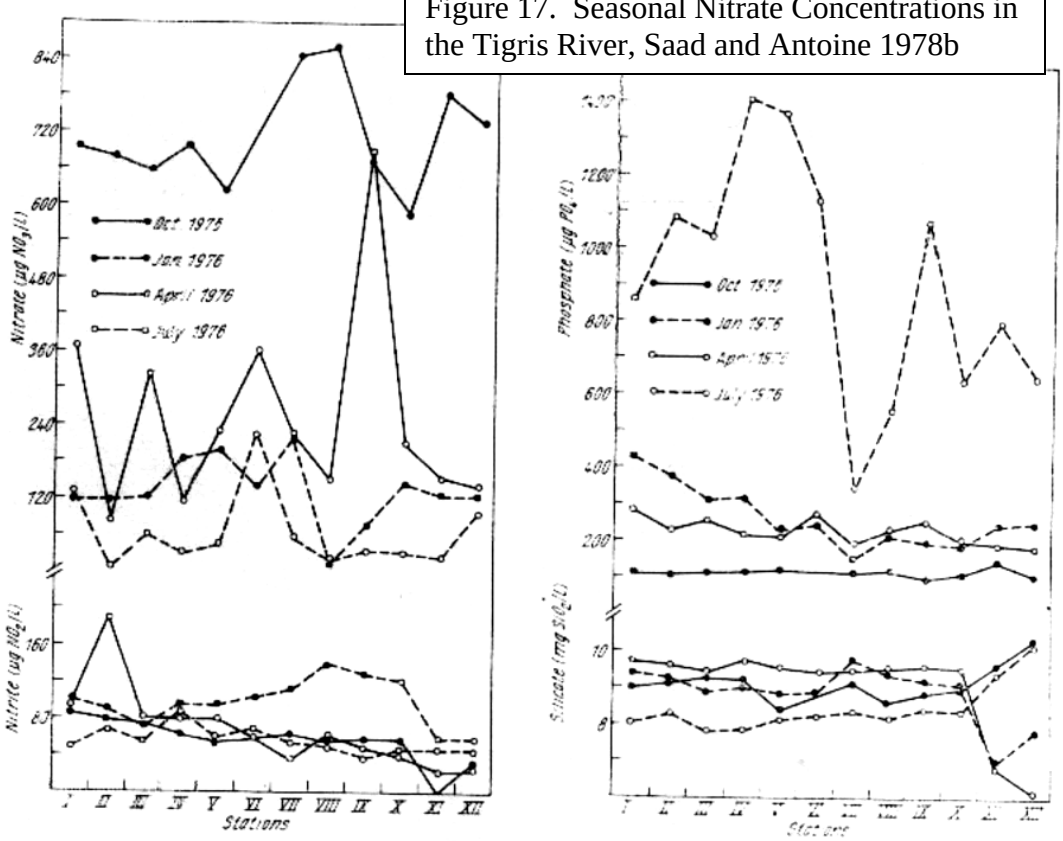
Dissolved Oxygen: In the rivers, oxygen concentrations are typically above 50% saturation (Rzoska 1980). Values in the Tigris and Euphrates Rivers ranged from highest values of 11 mg/L in winter to lowest values of about 5 mg/L in summer (Saad 1978 and Saad and Antoine 1978). The dissolved oxygen content is probably more closely related to physical mixing with the atmosphere than phytoplankton productivity (Saad and Antoine 1978).

pH: Values recorded for most Mesopotamian rivers and lakes is 7-8 (Rzoska 1980). In the Tigris, Euphrates, and Shatt al-Arab, values typically range from 7.5 to 8.5 (Saad 1978 and Saad and Antoine 1978); seasonal variations show the lower values during the winter and spring and higher values in the summer and fall, related to phytoplankton productivity. The pH of water from the lower Hammar Lake was about 8 when measured in January 1974 (Saad 1978).

Nutrients: Samples collected from the Hammar Marshes showed relatively low concentrations of inorganic nitrogen and fairly low nitrogen/phosphate ratios; concentrations of nitrate-nitrogen were around 50-80 micrograms per liter; phosphate-phosphorus around 9-14 micrograms per liter; and silicate-silicon around 1.7-1.8 micrograms per liter in February 1978 (Rzoska 1980).

Water samples from the lower Tigris River were analyzed seasonally in 1975 and 1976 (Saad and Antoine 1978b). The samples had concentrations of nitrate ranging from 80 to 800 with an average of about 200 micrograms per liter, with markedly higher concentrations in the fall, and somewhat higher values in the spring; nitrite ranged from negligible up to 120 micrograms per liter, with slightly higher values in the summer. Phosphate concentrations ranged from 100 to 1,000 and averaged around 200 micrograms per liter, with markedly higher concentrations in the summer. Silicate concentrations ranged from 8 to 10 micrograms per liter, with marked seasonal changes in the lower reaches of the Tigris, having higher concentrations in the summer and fall and lower concentrations in the winter and spring.

Figure 17. Seasonal Nitrate Concentrations in the Tigris River, Saad and Antoine 1978b



Saad and Antoine (1978b) concluded that higher nutrient concentrations were related to agricultural runoff, sewage influx, and release of nitrate from bottom sediments and decaying phytoplankton. Lower concentrations were thought to result from phytoplankton uptake. Evaporation and low discharge during the summer and fall were also thought to increase concentrations of nutrients along with a general increase in salinity.

WATER POLLUTION

Untreated domestic and industrial sewage is being discharged to the Tigris and Euphrates Rivers from upstream locations (Hannoush, 2000). Anticipated pollutants would include components of domestic waste, including excess organic material, nitrogen, phosphorus, enteric organisms and pathogens, trace metals, and dissolved solids. Industrial wastes could include hydrocarbons, heavy metals, and chlorinated hydrocarbons. Industrial wastes from production of weapons of mass destruction may also be present.

Heavy metal concentrations in the Upper Euphrates of Iraq were measured in 1993 (Kassim et al 1997). Cadmium ranged from ND-1.64, lead from 1.6-20.5, nickel from 2-34.2, zinc from 2.6-55.6, manganese from 3-63.2, and copper from 5.2-10.28 micrograms per liter; the concentrations of these metals in the Tigris were reported to be higher (Kassim et al 1997).

Mercury is potentially present in the southern Iraq area (Hannoush, 2000), which is potentially problematic as it is not readily degradable. Mercury concentrations have been detected at high levels in organisms from the Gulf. Concentrations of total mercury in fish from the Gulf have been measured at 72 to 3,923 ppm (al-Majed and Preston 2000). In comparison, the U.S. Food and Drug Administration Action Level for mercury in seafood is 1 ppm.

Organochloride pesticides (dieldrin, endrin, DDE, DDD, and DDT) were found in organisms of Hammar Marsh and Shatt al-Arab. Only the DDT levels are reported herein; for reference, the (United States') National Academy of Sciences recommended levels are 1 ppm, and the U.S. Food and Drug Administration Action Level is 5 ppm DDT. DDT concentrations were found to be 166 ppm in cyprinids from the Hammar marshlands; over 50% of the fish tested in the marshlands contained concentrations of DDT (DouAbul et al 1986). DDT was also found in organisms from the Shatt al-Arab: 21 ppm in cyprinids from the Shatt al-Arab, 2 ppm in shrimp from the Shatt al-Arab, and 163 ppm in Indian Shad from the Shatt al-Arab (DouAbul et al 1986). Sediments in the Shatt al-Arab contained only 5 ppm concentration DDT. This study reported that DDT was applied extensively over the marshlands during the 1950s and 1960s, and concluded that the DDT was transported from the marshlands to the Shatt al-Arab. There are also other sources of DDT and other organochlorine pesticides in the upstream portions of the rivers, both from sewage plants and from agricultural runoff (al-Omar et al 1988).

Toxins Introduced into Marshes. There are reports that the persistent insecticide Chloridin is being used to kill large quantities of fish for sale (Evans 1995). There are also reports that poisons (possibly Rotenone) were introduced into the marshes by the Iraqi military subsequent to the Gulf War.

Impacts of War: Much of the fighting during the Iran-Iraq War took place in and around the Haweizeh Marshes and caused considerable damage. These battles involved extensive burning, heavy bombing and shelling, and widespread use of chemical weapons (Evans 1995). Large areas of the Haweizeh and Central Marshes were destroyed and burned during the Iran-Iraq War and also subsequent to the

Gulf War to search for and control anti-government rebels. There may also be mines of various types present within this area; buried or dispersed weapons of mass destruction may also be present in the marshlands.

Chemical weapon agents (CWAs) are of particular concern in this area. CWAs were utilized by Iraq during the Iran-Iraq war, and may have been released in the area of Haweizeh Marsh. There is no reported usage of CWAs within the Central or Hammar marshes. The CWA of choice in the region is mustard gas (chemical symbol HD). HD is denser than water and if released in liquid form to the marshes or lakes would tend to sink to the bottom. HD is not very soluble in water; however, the material in solution hydrolyzes within minutes to hours. Water could remain contaminated for a long time as the newly released HD is constantly diffusing in small amounts into the water in place of that which has been hydrolyzed (Khordagui and al-Ajmi 1994). Turbulence and heat would increase the dissolution and hydrolysis of the HD. Dissolution and hydrolysis are also enhanced by basic pH, low salinity, and the presence of metal cations in the water. If the HD were to be released to the air above the marshlands, it could be expected that the rate of hydrolysis would be faster, and although there would be great short-term harm, the long-term environmental impacts would be less. If the HD were in canisters the degradation would be effectively nil; leaking canisters of WWII vintage HD are still being encountered in which the bulk of the agent remains as dangerous as it was when dumped (Khordagui and al-Ajmi 1994).

At the end of the Gulf War in 1991, the retreating Iraqi Army sabotaged more than 700 oil wells in Kuwait, leaving them gushing oil and burning. There have been unverified reports that oilfields within Iraq have been mined in preparation for similar sabotage in the case of renewed conflict. Major oilfields (Rumayllah and West Qurnah) are present in the eastern portions of the Hammar marshlands and the Haweizeh marshlands (Majnoon field). The initial impact of the burning of the Kuwaiti oilfields was summarized by Literathy (1992). An estimated 60 million barrels of crude oil created oil lakes covering about 50 square kilometers. Up to 2 cm of black soot was deposited over about 1,000 square kilometers of desert as a result of atmospheric fallout, depositing a total of 320,000 tons of burnt debris (Literathy 1993). The atmospheric fallout was predominantly deposited downwind. PAH concentrations in the samples located 10 km away from the oilfields were greater than those within the oilfield itself; presumably, atmospheric fallout would have higher PAH concentrations due to burning off of the more volatile, less carcinogenic compounds. These compounds appeared to be readily water soluble, thus presenting a potential damage to the groundwater. The atmospheric fallout also was highly acidic.

GEOLOGIC CHARACTERISTICS

GEOLOGY

Iraq structurally is a large northwest-southeast oriented syncline with a steeper northeastern flank. This forms a broad depression filled with eolian, lacustrine, fluviatile, and marine sediments. Along the northeast flank, gentle folds gradually increase in magnitude and form the complex folded and faulted area of the Upper Fold and Nappe Zone (Holwerda, 1958). The southwest flank extends into Saudi Arabia and consists of gently tilted strata. These structures are the result of compressive forces exerted from the northeast, opposed on the southwest by the relatively stable Arabian Plateau. Superimposed on this are local subsidences due to isostatic adjustments and sedimentary compaction, particular in the Mesopotamian Plain. The region is tectonically active today, as the Arabian tectonic plate is forced under the Iranian plate.

Rocks in Iraq range in age from Precambrian to Recent. Calcareous sediments predominate, with minor sandstone, shale, conglomerate, and evaporates. Igneous and metamorphic rocks are restricted to the extreme northeastern portion of the country near the Iranian Border. The marshlands are generally underlain by the Recent Younger Alluvium consisting of alluvial, marine, lacustrine, and playa sediments reaching thicknesses up to 5,000 feet.

SEDIMENTS

Sediments within the rivers are mostly composed of fine sands that become progressively finer as they move southwards (Baltzer and Purser 1990). The river levees generally attain heights of 1 m. The levees are composed of well-bedded silt with thin flaser bedding. The levees separate the rivers from the floodplain deposits, composed of hard brown silty muds, that are massive and heavily bioturbated (Baltzer and Purser, 1990).

The sediments of the marshlands have been studied by al-Aqrawi and Evans (1994). The study was based on 24 cores from the Central and Hammar marshes and lakes; the samples were obtained prior to draining of the marshes. The shallow stratigraphic sequence consisted of three sedimentary units: 1) a surface organic-rich sandy silt layer 0-7 cm thick; 2) a shelly clayey silt with mollusk shells between 7-30 cm depth; and 3) a silty clay or clay from 30 to 100 cm depth characterized by brackish-water and marine microfauna.

The sediments were light greenish grey, becoming darker with depth. Light olive, bluish, and yellowish grey sediments occurred occasionally; in some locations blackish organic rich sediments characterize the surface layers down to about 10 cm depth.

The total organic content generally ranged from 0-2%, up to 20% in the surface layers of freshwater lakes and marshes. Nowhere was peat formation observed in

the marshlands. The carbonate content of the sediments varies between 20-60%; this value includes both authigenic low-magnesium and high-magnesium calcite and dolomite (deposited through evaporation and chemical precipitation in the marshes and lakes) and the shells of microfauna and broken shells of macrofaunal organisms.

The most common sedimentary structure was bioturbation present in every core, and laminations in the clay-rich basal sediments and in the river levee sediments. Grain size analysis revealed generally 62% silt, 21% sand, and 17% clay.

The main non-clay minerals were found to be, in order of abundance: calcite (43%), quartz (21%), dolomite (10%), feldspars (9%), and gypsum, aragonite, and dolomite (5%). The clay minerals were found to contain smectite, illite-smectite, illite, palygorskite, kaolinite, and chlorite. Gypsum is found in the surface sediments as authigenic minerals. The geochemistry of the sediments reflected their high carbonate content (Ca, Mg, and Sr), particularly the shelly horizons of the cores. The latter are generally lower in Al, Ti, K, and V than the other sediments. The values for Fe, Co, Pb, Zn, and Mn are similar to published averages of mudrocks and shales, while those of Cu and P are rather lower. Ni and Cr contents are variable but usually higher than published averages.

Marsh and lake sediments have also been described by Baltzer and Purser (1990). They note that marsh sediments have much more organic material than the lake sediments, which are dominated by chemical precipitation of calcareous sediments. Distributary channels within the marshes are characterized by the accumulation of molluscan shells. They observed that pits dug in recently-drained marshes displayed dark grey or black sediment at the near-surface 20-50 cm thick, grading downwards to a grey or greenish muds. They concluded that the organic material within the marsh sediments is rapidly degraded and is not buried.

Marsh sediments studied by Antoine (1984) were found to average 20% total organic carbon, 66% carbonate, and 12% non-carbonate minerals. The study concluded that most of the carbonate originated from calcareous shells and blue-green algae, the organic carbon originated from decay of plankton and benthic plants and animals. Nutrient concentrations were adequate and varied directly with organic material. Nitrate concentrations were lower than phosphate; phosphate was positively correlated with calcium. Calcium and magnesium were also positively correlated with the calcium. Sodium and potassium concentrations were adequate.

The lacustrine sabkhas along the south side of Lake Hammar are rich in quartz blown in from the adjacent desert, also with carbonate, dolomite, gypsum, and sodium sulphate crystals (Baltzer and Purser).

SOILS

Soils have been described by Buringh (1960) and Pons et al (unpublished report).

Marsh soils These are hydromorphic soils, developed on fluviatile sediments, mostly clay or silty clay, highly calcareous and containing some gypsum, and underlie both temporary and permanent marshlands. Their salinity varies. According to Buringh, these soils are "physically unripe." The upper layers seem to form an "organic" cover of about 30 cm thick, formed by the decaying reed vegetation.

Haur soils These are hydromorphic soils formed on fluviatile and lacustrine clays in depressions, strongly saline. They form shallow lakes during the floods, but dry up completely in the summer, forming heavy salt crusts.

Silted haur and Marsh Soils These are formed on irrigation sediments, covering fluviatile, silt loams to heavy-textured clays. They are saline soils dominated by either calcium and magnesium compounds, or by sodium, sodium-sulphate, potassium-chlorite, and magnesium-sulphate compounds. These were characterized by Pons as Sabakh and Solonchak soils.

Irrigation sediments Soil permeabilities are low and their structure is platy. These likely have a low fertility and poor structure.

Because of the high montmorillonite content and physical softness of the soils, they will likely respond to desiccation through rapid shrinkage. Draining of the marshlands thus would likely have caused considerable cracking and overall subsidence of the soils. The pre-existing topographic contours may not be correct at this time.

The cation-exchange capacity of agricultural soils upstream of the marshes (Diwaniya area) was found to range from 6 me per 100 g for sandy samples to 35 me per 100 g as a maximum for clay samples.

SALINIZATION

Salinization of soils in the lower Mesopotamian plain is a significant problem caused by application of irrigation water and by capillary action of saline groundwater. Calculations have shown that if 1 m of irrigation water is applied, containing 100 parts per million of salt, 1,000 kg of salt per hectare is added (Pons et al). Estimates are that each year irrigation water adds 3 million tons of salt to the irrigated soils of Iraq. In the course of 6,000 years of irrigation, enormous quantities of salt have been added to the soils of the plain. In general, salinity of soils increases southward across Iraq.

Groundwater lies just below the surface of the marshes; when the overlying water is present, the groundwater will have no impact on the surface water. However, when the ground surface is dry, capillary action transports groundwater upwards and evaporation of the water leaves behind salts. A salt crust forms on the surface, sometimes feet thick. When a thick crust has developed, evaporation ceases and soils underneath may still be saturated with groundwater.

“Puffed Solonchak', an externally saline soil in which the greater part of all salt consists of sodium sulphate, may be present in southern Iraq (Delver, 1962). The needle-shaped mirabilite (hydrated sodium sulfate) crystals push fine soil aggregates apart when they are formed. When the temperature rises again during the day, mirabilite is re-converted to water-free thenardite crystals that have the appearance of fine flour.

Sabakh soils may also be present (Delver 1962), dominated by hygroscopic salts such as CaCl2 or $MgCl_2$, and to a lesser extent also NaCl. The resulting `sabakh' soils (`sabakh' is Arabic for morning) are dark-colored and slippery in the morning as a result of moisture absorption during the night. The soils lose their dark color again in the course of the day when the temperature rises and air humidity drops to a low value. Slick spots may also appear due to the presence of a glass-like halite (NaCl) crust, that is so effective in sealing the underlying saline mud from the air that the soil remains wet throughout the dry season.

Desalination of the marshland soil to allow agricultural cultivation would require digging an extensive drainage network, pumping out the groundwater, and flushing the soil with fresh water. When irrigation water is applied for desalinization, salts are washed from the topsoil leaving behind with an absorption complex saturated with high amounts of sodium ions in a low-electrolyte containing environment. This could cause a structural breakdown of the soils. However, the soils here do have significant concentrations of gypsum, which would deliver calcium ions in high concentrations to replace the sodium ions on the absorption complex, giving the soils a relatively stable structure (Pons).

HYDROENGINEERING STRUCTURES

Numerous engineering structures have been built over the past 100 years on the Tigris and Euphrates to control the flow of water for various purposes: 1) for beneficial uses, including maintenance of water flow in irrigation canals, to provide public water supply, and for hydroelectric power generation; and 2) since 1991, numerous engineering structures have been emplaced in southern Iraq for the primary purpose of drying out the marshes. For the sake of clarity in this report, structures within the first category are referred to as "beneficial use structures" whereas structures within the second category of projects are referred to as "desiccation structures."

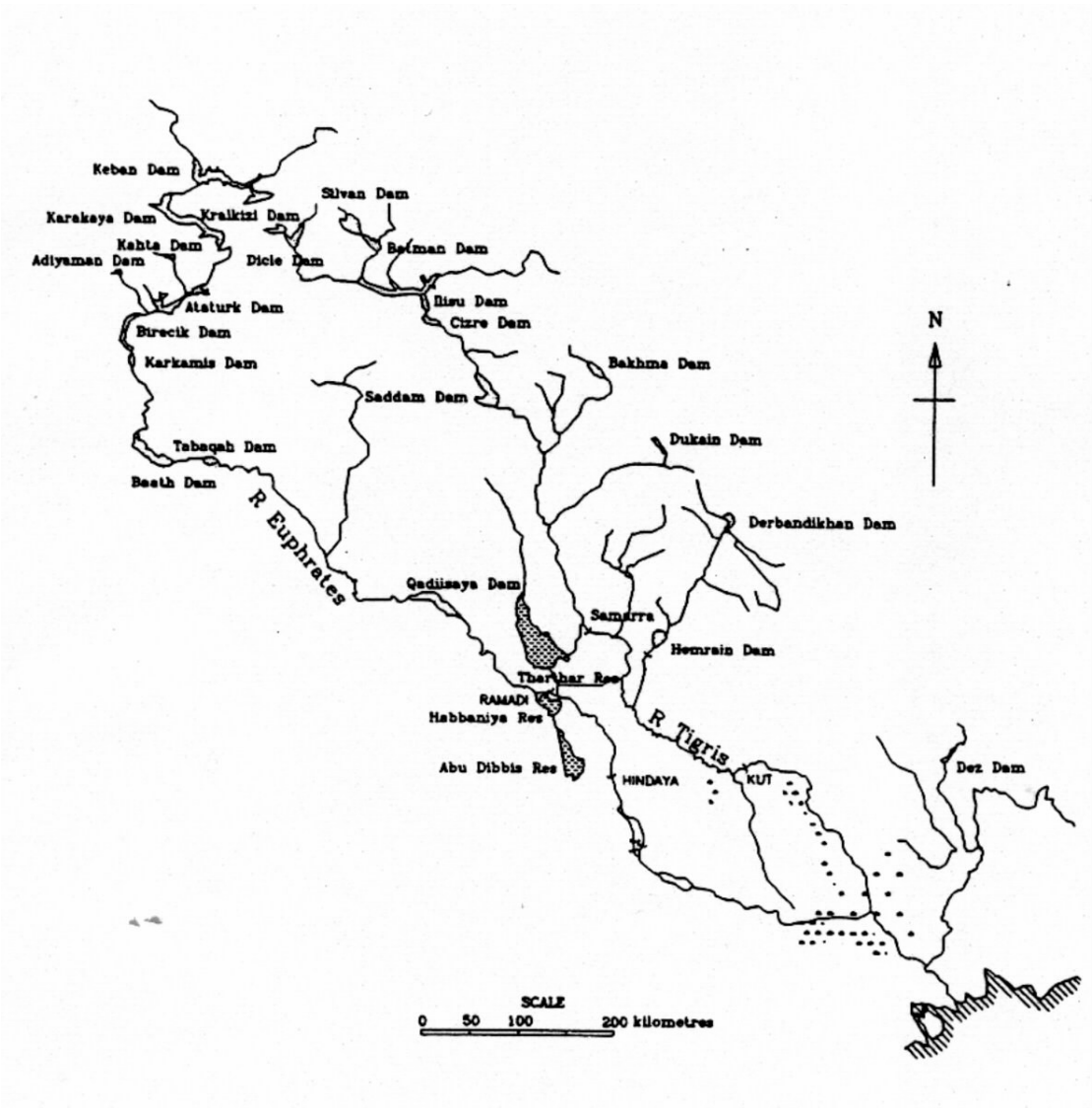


Figure 18. Major Dams on the Tigris and Euphrates Rivers. From Manley (unpublished)

BENEFICIAL-USE STRUCTURES

Beneficial use structures include dams, diversions, barrages, and sluice gates intended to provide public water supply, flood control protection, maintenance of water flow in irrigation canals, and hydroelectric power generation (Ionides, 1937; Harza, 1963; Partow, 2001; Alwash, 2001).

Euphrates Outside Iraq. The Euphrates rises in Turkey, and passes through Syria, where tributaries further increase its stream flow. No tributaries join the river inside Iraq. Major dams include:

- Keban Dam*:* Constructed by Turkey, this structure is mainly used for hydroelectric power generation. The storage capacity of Keban reservoir is 30.6 bcm.

- Karakaya Dam. This dam has a storage capacity of 9.6 bcm for irrigation and hydroelectric power generation.

- Ataturk Dam. This enormous structure has a storage capacity of 48 bcm and is intended to generate electricity and to irrigate lands in Turkey.

- Tabaqa Dam. Built by Syria in 1975 with a reservoir storage capacity of 11.9 bcm. Reportedly, outflow from Tabaqa is such that Iraq is "guaranteed" 9 bcm/yr inflow through the Euphrates.

Euphrates Inside Iraq. The structures on the Euphrates inside Iraq are either intended for flood control or for maintenance of water levels to facilitate irrigation; the only major structure or dam with large storage capacity is the Haditha Dam.

- Haditha Dam*:* Iraq completed Haditha Dam, an earthen dam with an impervious core, in 1985 with a reservoir storage capacity of 6.2 bcm (Alwash, 2001) to 11.3 bcm (Juhmani, 1999). The reservoir is intended to hold water in high flow periods to protect Baghdad from flooding; the stored water is released in low flow periods for down stream use in public water supply and irrigation. The dam also maintains water levels to facilitate gravity flow in irrigation channels north of the reservoir. The dam includes a hydroelectric generation plant.

- Ramadi Barrage*:* This concrete structure is located 3 km north of the town of Ramadi and its main purpose is to regulate the discharge going down stream to the Warrar Regulator which channels water to Habbaniya Lake during periods of high flow/flood. The maximum discharge capacity of the barrage during floods is 3000 m^3/sec.

- Warrar Regulator and the Link Canal*:* The Warrar Regulator is located upstream of the Ramadi Barrage and water flows into it when the Ramadi Barrage restricts the flow of water, causing upstream levels to rise and thus

feed into the Warrar Regulator. The Warrar Regulator directs water into the Habbaniya Lake via a 7 km long Link Canal. The maximum discharge capacity of the Warrar Regulator is 7800 m^3/sec.

- Habbaniya Lake: This lake is located southeast of Ramadi. The lake is a natural depression whose storage capacity was enhanced by the construction of dykes and earthen embankments along the low areas. The lake is used as long-term retention basin, where water is directed into the lake during the flood season and/or high flow times and released back into the Euphrates during low flow periods through the Deban Regulator. The surface area of the Lake is 425 km^2 for a total usable storage capacity of 3 bcm.

- Deban Regulator: This regulator is intended to control the outflow of water from the Habbaniya Lake back into the Euphrates in low flow periods. Maximum outflow from this regulator is 400 m^3/sec.

- Mujjarah Regulator*:* The floodwater that cannot be stored in Habbaniya Lake is directed through the Mujjarah Regulator into Abu-Dibbis Lake via an 8 km link canal.

- Abu-Dibbis/Razzaza Lake. According to published literature and personal communications (Alwash, 2001), this lake is a dead end, however, there are reports that this lake is now connected with the Euphrates (Janabi 2001). Theoretically, inflow of water is during flood periods when water cannot be stored in Habbaniya and cannot be allowed to flow down stream. However, if this lake is truly connected to the Euphrates, it can be used as a storage reservoir, if the salts that have accumulated since the construction of the Mujjarah Regulator are removed through controlled outflow (similar to Tharthar desalinization).

- Tharthar Lake Outlet. To the north of Falluja, the outlet canal from the Tharthar Lake feeds into the Euphrates with a maximum flow capacity of 500 m3/sec. The inlet was constructed in 1975 as a part of larger project designed to utilize the Tharthar depression (which had been used since 1954 as a flood control basin for the Tigris River without an outlet) as a reservoir where flood waters are held during the high flow season and outlet during the summer low flow season for feeding the down stream portions of both the Euphrates and Tigris. A second canal bifurcates from the outlet canal to the Tigris with a flow capacity of 600 m^3/sec.

- Falluja Barrage*:* This barrage, located south of the city of Falluja, raises the water level upstream to allow gravity irrigation of the fertile agricultural lands around Abu Ghraib, Yousifa, Latifa, and Iskanariya. It is noteworthy that these areas are located between the Euphrates and Tigris. The barrage includes a navigation lock.
- Hindiya Barrage*:* This barrage was constructed in 1911-1914 is intended to raise the water level for irrigating upstream areas of land around Hilla, Greater Mussaiyab, Hussainiya, and Beni Hassan. Plans exist for constructing a new barrage with a navigation lock, a small hydroelectric

plant and regulators for irrigation, which draw water from the river upstream of the barrage. It is the understanding of the authors that this new barrage has in fact been built, however, no documentation has been located in the available literature corroborating its existence.

- Regulators for Kifil-Shinafiya*:* Plans exist for constructing five cross regulators on the Kufa and Shamiya branches of the Euphrates to ensure the flow of water to fertile lands in Kifil and Shinafiya.

Tigris River Outside Iraq. The Tigris originates in eastern Turkey. Eight dams are planned as part of the Southeast Anatolia Project and the GAP Project in Turkey, however, the International Monetary Fund (IMF) has made financing the project subject to a treaty between Turkey, Syria and Iraq. Since the treaty has yet to be negotiated, it appears highly unlikely that Turkey will be able to generate enough funds to construct the dams on its own. So far, Turkey appears to have concentrated on constructing the Euphrates part of project and has apparently postponed the construction of the Tigris part of the project to a later date.

Tigris River Inside Iraq. The main tributaries inside Iraq are the Greater Zab and Lesser Zab, which join the river south of Mosul. Two minor tributaries join the Tigris from the Zagros Mountains from the east, the Adhaim and Diyala. South of Baghdad, the Tigris is confined by artificial levees, the overspill from which flows into the marshes. Shat al-Gharraf branches off from the Tigris near Kut. Shatt al-Gharraf feeds agricultural land west of the Tigris, eventually flowing into the Central Marsh. After Amarahh, numerous smaller distributaries branch off from the Tigris, feeding agricultural lands to the east and west of the Tigris. The main body of the river flows southerly and finally meets with the Euphrates, which emerges from the Hammar Marsh at Qurnah. Several major dams and barrages have been built on the Tigris and its tributaries over the past century to control the flow of water for beneficial uses.

- Bakhma Dam: This dam is on the Greater Zab north of Mosul. Construction began in 1987 and the first phase was completed in 1990. The reservoir capacity is 8.3 bcm and is used for hydroelectric power generation and irrigation.

- Mosul Dam*:* This is a concrete dam completed in the late 1980s, and the reservoir was filled in the 1990s. The reservoir capacity is approximately 13.5 bcm. It is used for hydroelectric generation and storage of water during high flow season. The water from this reservoir is intended for eventual use for the irrigation of the land west of Mosul, which are now irrigated by rain. The project is called Al-Jazzera project, which has yet to be built.

- Alfatha Dam: This structure lies midway between Mosul and Baghdad and it is currently under construction.

- Al Adhaim Dam: Work on this dam was started in 1988 and completed in 1998. The dam is constructed of concrete and is used for irrigation,

desalinization of soil, and hydroelectric generation. Its reservoir capacity is 3.5 bcm.

- Dokan Dam*:* This is a concrete dam built in 1961 on the Lesser Zab with an approximate reservoir capacity of 6.8 bcm. It is mainly used for hydroelectric power generation and holding water for release during summer months.

- Derbendikhan Dam: Built in 1962, this is an earthen dam with a clay core on the Diyala River, for hydroelectric power generation and water storage. Its reservoir capacity is 3.5 bcm.

- Dibis Weir: A sunken structure (weir), this dam was constructed in 1965 and is intended mainly for irrigation control with a small storage capacity of 0.01 bcm. Its purpose is to raise water levels upstream to facilitate irrigation using gravity flow of the farms in the vicinity.

- Himreen Dam*:* Built in 1980, on the Diyala downstream of Derbendikhan, this is an earthen dam with a clay core and a reservoir capacity of 3.9 bcm intended for hydroelectric power generation.

- Samarrah Barrage*:* In Samarrah, a barrage was constructed in 1954 to divert water during the flood season into the Tharthar gorge (located between the Tigris and Euphrates), which has a storage capacity of 90 bcm, half of which is recoverable through a canal that connects Tharthar lake to the Euphrates.

- Kut Barrage*:* This structure controls the flow between the Shatt al-Gharraf, Tigris and Nahr Dijail.

The Main Outfall Drain (MOD): Work on this canal was started in 1953 and it is intended to intercept saline water that had been used for irrigation of farmlands to the north. The canal, completed in December 1993 and dubbed the Third River, or Saddam's River, travels south and crosses under the Euphrates, south of Nasiriyah, via a siphon system. In this report, the name MOD is retained. The MOD skirts around the southwestern edge of Hammar Marsh, passing through the desert for 60 km between raised embankments. It then cuts through the southeastern sector of Al- Hammar marsh and connects to the Shatt al-Basra canal which discharges into the Persian Gulf. In 1992, a series of three large pipes with pumps used to push the water flowing from the MOD under the Euphrates into the continuation of the MOD west of the Euphrates was constructed. This part of the MOD and the siphon system were built following the Gulf War.

DESSICATION STRUCTURES

All of the structures discussed above were originally planned and constructed for beneficial purposes. In 1991, the regime of Saddam Hussein initiated construction of drainage and water diversion structures for the specific and intentional purpose of

draining the marshes of water (NIMA, 1991-1998; Economist, 1992; CIA, 1992; Barnes, 1993; North, 1994; CIA, 1994; National Geographic, 1994; al-Khafaji and Dougrameji, 1995; Martone, 1999; Partow, 2001; SCIRI, 2001). These structures are termed desiccation structures in this paper for the purpose of clarity.

Desiccation Structures Affecting Hammar Marsh: The following water-control structures have been found to be draining water away from the Hammar Marsh.

- Al-Qadissiyah River (completed in mid-1993). To reduce the inflow of water into Nasiriyah and prevent water flowing over the dam(s) blocking the way to the marshes, al-Qadissiyah river/canal was built, directing water from the Euphrates upstream of Samawa into a dead end depression called al-Sulaybiyat, via Shatt al-Atshan. Water that is trapped into this depression percolates and/or evaporates leaving salt flats behind.

- Euphrates Levees: According to UNEP and SCIRI, along the right bank (south side) of the Euphrates, a 70 km long artificial levee was reportedly constructed of earthen material to prevent water from the Central Marsh from flowing into the Hammar Marsh. However, it should be noted that NIMA maps reviewed did not show evidence of such a structure.

- Nasiriyah Dam(s). The most devastating drainage program affecting the Hammar Marsh is the diversion of the entire flow of the Euphrates River away from the marshes. This was accomplished through the construction of at least one dam east of Nasiriyah, and potentially three, near where the MOD canal flows under the Euphrates. This dam/sluice gate was built to block the flow of the Euphrates from going into the Hammar Marsh. Canals and pipelines have been constructed past this point to carry the combined flow of the MOD and the Euphrates away from the marshes.

- Mother of Battles River (completed in April 1994). The flow capacity of the MOD was designed to carry the drainage water from the irrigated lands to the north, and proved to not be capable of handling the additional flow from the Euphrates River. To convey the water coming from the Euphrates River, a new canal was built parallel to the MOD. This canal runs for 108 kilometers and discharges into the southeastern portion of Hammar Lake north of the Rumayllah Oil Field. An earthen dyke was constructed to the north of the canal's outlet, parallel to the MOD and extending easterly to Basra, so that water would not flow northward into the main portion of the Hammar Marsh. Earthen dykes also protect the Rumayllah Oil Field from flooding by this water.

- Loyalty to the Leader Canal: Built in 1997, this canal reportedly is intended to carry the water from the vicinity of al-Gharraf, south to Shatt al-Basra canal which discharges into the gulf, bypassing Shatt Al Arab. This canal is reported to run parallel to the MOD and the Mother of Battles River.

The above projects have effectively resulted in drying out over 90% of the Hammar Marsh and Lake Hammar as it diverts all of the Euphrates River, in addition to all

the water draining from irrigation of the rice fields, away from the marshes and discharges it into the Persian Gulf.

Desiccation Structures Affecting the Central Marsh. In order to drain the Central Marsh, Saddam in 1992 undertook a similar program of canals, embankments, flow regulators, and ditches. Following is a description of these structures.

- Earth Embankments & Flow Regulators*:* Earthen embankments ranging from 6 to 18 km in length were built along seven different Tigris irrigation distributaries to prevent overtopping of the embankments. The irrigation canals are: Adel and Wadiyah which bifurcate from Majar Al-Kabir; Keffah and Charamkhiya which bifurcate from Shatt al-Muminah; and the Masbah, Hadam and Um Jaddi which receive their waters from Butayrah, which, in turn, bifurcates from al-Muminah. The headwaters of some of these distributaries are controlled by sluice gates or flow regulators to control the amount of in-flow (Jawad Alwash 2001). No specific documentation was located to identify the exact locations of these sluice gates, however they are presumed to be located under bridges and street crossings over the distributaries close to the headwaters.

- East-West Canal (1993). The outflow of all of the distributaries discharging from the right bank of the Tigris north of Qalat Saleh (around 40) was captured through an east-west canal located along the northern boundary of the Central Marsh. The canal, dubbed the Glory River, is between 1 and 2 km in width and appears to be an excavated structure several meters deep at is eastern end, and a leveed structure close to the headwaters at the terminus of Hadam and Butayrah. Sources indicate that the canal is contained by earthen dykes up to 6 m in height, measuring from 9 m wide at the top to 35 m wide at the base (SCIRI, 2001).

- North-South Canal (1993). Dubbed the Prosperity River, this canal begins at the terminus of the east-west canal approximately 10 km south of Qalat Saleh. The North-South Canal is 2 km wide and approximately 50 km long. The canal appears to be an excavated feature several meters deep with low levees. It is essentially a moat that intercepts whatever water flows over the west bank of the Tigris River. The North-South Canal drains into the Euphrates River west of its confluence with the Tigris just west of Qurnah.

- Medina Dam. The North-South Canal joins the Euphrates River west of its confluence with the Tigris. The elevation of the land near Qurnah is actually slightly higher than the elevation of the dry Hammar Lake – this is what caused the creation of the Hammar Lake. Introduction of this huge water flow from the North-South Canal into the Euphrates at this point would lead to the Euphrates essentially flowing backwards. The westward flow through the Euphrates would continue until the Hammar Lake was refilled, and possibly beyond due to the buildup of water being introduced from the North-South Canal. In 1993, to increase the hydraulic head so that water would flow into the Shatt al-Arab instead of "backing up" into the Hammar Marsh,

a dam/embankment was constructed on the Euphrates River west of its confluence with the North-South Canal. Extensive embankments were also emplaced in the surrounding area to further control water flow. These embankments essentially created a large, flat reservoir behind which water is present at depths potentially up to several meters deep. Additionally, embankments were placed surrounding the village of al-Medina to prevent it from flooding. This village is shown as an island in satellite images from 1993.

- Crown of Battles River, 1993. This canal was excavated on the east side of the Tigris River north of Kumayt to divert water from the Tigris to the north of the Hawizeh Marsh. Apparently drainage of the Hawizeh Marsh was not a priority of the regime of Saddam Hussein in 1993, probably because it acts as a buffer zone between Iran and Iraq; however, subsequent actions of the regime indicates that it is the intention of the regime to use Hawizeh as a "flood control" area where water can be held during peak flow times and then diverted back into the Tigris and Shatt al-Arab, through two canals that apparently were constructed circa 1994 (as shown up on US maps of 1994). Though Hawizeh was initially enlarged in 1993 as a result of the diversion of water from Tigris into the marsh, it has since shrunk as a result of diversion of water back into the Tigris and Shatt al-Arab and the construction of a dam (March 2001) on the Karkeh River in Iran which effectively cuts of water from the Iranian side to Hawizeh Marsh,

Desiccation Structures Affecting the Hawizeh. During 1992 and 1993, the size of Hawizeh Marsh increased as a result of the diversion of water from the Tigris to the marsh in order to allow for the construction of the east-west and north-south canals.

- Crown of Battles River. This canal diverts water from the Tigris to the north of Amarahh into a non-wetland depression, which is connected to the Hawizeh Marsh. The northern portion of the Hawizeh Marsh was initially enlarged in 1993 as a result of the diversion of water from Tigris into the marsh. The northern portion of this flooded area is simply flooded desert, not wetland; in the southern portion of the flooded area, water ponds against a causeway and is drained back into the Tigris between Qalat Saleh and Qurnah.

- Aybas Canal. The southern portion of the Hawizeh Marsh has been desiccated as a result of the Aybas Canal that re-directs the Tigris water from the Hawizeh Marsh into the Shatt al-Arab just past the confluence of the Tigris and Euphrates.

EFFECT OF WATER-CONTROL STRUCTURES ON MARSHES

The scale and speed of land cover changes in the marshes has resulted in effectively destroying over 90 percent of the ecosystem of one of the most important wetlands in the world in less than 10 years (NIMA, 1991-1998; CIA, 1992; CIA, 1994; Munro and

Touron, 1997). The once-extensive marshlands no longer exist and only minor and fragmented parcels remain and those will die out as the ground water levels become lower with reduced recharge. Landsat pictures show salt crusts where extensive lakes used to exist in the Central and Hammar Marshes. Hawizeh Marsh most likely will become as dry over the next several years if not re-charged soon.

Manley (unpublished report) conducted computer modeling to determine the effect of upstream damming projects (beneficial use structures) on the marshlands. Although the study included some aspects of the desiccation structures, it was not clear how these were included, and which were not included; so the following discussion focuses only on the impacts of the beneficial use structures. In Manley's Scenario 3-1 (present water flow conditions) the Central Marshes were reduced by about 50% in area, while the Hammar Marshes were reduced by around 20% with a marked decrease in the seasonal flood pulse, having lower flows in the flood season and higher flows in the dry season compared to traditional times.

Manley's Scenario 4-1 looked at the possibility that all of the planned beneficial-use structures were emplaced. This resulted in an overall reduction of the Central Marsh to less than a third of its original area, but still variation in areas as a result of the seasonal flood pulse. The Hammar Marsh would be reduced to slightly less than half of its original area, with very little seasonal variation in area.

In reality, what has happened is that the Central and Hammar Marshes have been desiccated by nearly 100% of their total area. Less than 10% of the total marsh area remains, mostly in Haweizeh, and that is rapidly disappearing as a result of the Karkeh Dam (Partow 2001, 2002). This extremely rapidly desiccation is the result of the desiccation structures emplaced; therefore, removal of these structures should be an immediate focus of the restoration plan.