ISSN 0097-8078, Water Resources, 2009, Vol. 36, No. 4, pp. 380–395. © Pleiades Publishing, Ltd., 2009.
Original Russian Text © V.A. Isaev, M.V. Mikhailova, 2009, published in Vodnye Resursy, 2009, Vol. 36, No. 4, pp. 402–417.

WATER RESOURCES AND THE REGIME OF WATER BODIES

The Hydrography, Evolution, and Hydrological Regime of the Mouth Area of the Shatt Al-Arab River

V. A. Isaev[a] and M. V. Mikhailova[b]

[a] Moscow State University, Leninskie gory, GSP-1, Moscow, 119991 Russia
[b] Water Problems Institute, Russian Academy of Sciences, ul. Gubkina 3, Moscow, 119333 Russia
Received September 4, 2008

Abstract—The hydrography, evolution, landscapes, and hydrological regime of the mouth area of the Shatt al-Arab River—the terminal part of the channel system of the Euphrates and Tigris rivers—are considered. The effect of natural and anthropogenic changes in the Euphrates and Tigris regime and the regime of the Persian Gulf of the Indian Ocean is evaluated.

DOI: 10.1134/S0097807809040022

INTRODUCTION

The Shatt al-Arab River originates from the confluence of two large Asian rivers—Euphrates and Tigris—and, in essence, is the mouth part of the channel system of these rivers. Moreover, the Shatt al-Arab River is an independent mouth hydrographic feature, which occupies an intermediate position between the river system of the Euphrates and Tigris, on the one hand, and the Persian Gulf of the Indian Ocean, on the other hand.

While the Euphrates and Tigris rivers have received much attention in both domestic and foreign literature, very few studies of the Shatt al-Arab River and its mouth are known. In the domestic scientific literature, this mouth was considered only in a small section in I.V. Samoilov's monograph, published in 1952 [9]. Almost no works on the regime of the Euphrates and Tigris rivers and large water management measures in their basins were published in our country in recent decades.

The objective of this study is to describe the evolution and the present-day state of the Shatt al-Arab River and to analyze the effect of natural and anthropogenic variations of the Euphrates and Tigris runoff on the mouth of the former river. This paper is mostly based on a review of recent foreign publications on the problem.

GEOGRAPHICAL AND HYDROLOGICAL CHARACTERISTIC OF THE EUPHRATES AND TIGRIS RIVER SYSTEM

General Description of the River System of the Basins

The system of the Euphrates and Tigris (Fig. 1) is the largest in Southwestern Asia. The sources of these rivers lie not far from one another in the mountains of the Armenian Highland in the eastern Turkey.

The rivers flow mostly to the southeast. In their upper reaches, they flow far from one another (~400 km, near the Turkey–Syrian border), while in the middle reaches they gradually move closer, flowing around a triangular barren limestone plateau Al Jazira (which means *island* in Arabian). Here, the rivers incise deep channels in rocks, which have only slightly changed from the prehistoric times.

In their lower reaches, the Euphrates and Tigris flow over the Mesopotamian Lowland, which has been formed by the sediments of these rivers. The slopes of water surface here average 4×10^{-5} and 8×10^{-5}, respectively [19]. The Mesopotamian Lowland is separated from the Al Jazira Plateau by a step 60 m high near the city of Hit on the Euphrates and the city of Samarra on the Tigris. The lowland is slightly sloped southward. In the recent geological past, it was occupied by waters of the Persian Gulf, while the Euphrates, Tigris, and the tributaries Diyala and Karun emptied into the bay independently. The hydrogeological and hydrological features of Mesopotamian Lowland (silty soils, the shallow occurrence of underground water, floods on rivers) facilitated the formation of lakes and marshes in its lower part.

The marshy lower part of Mesopotamian Lowland is commonly divided into three regions referred to as marshes: Al Hammar, south of the Euphrates; Central, between the rivers; and Khafeveiseh, east of the Tigris. The first of these, consisting of marshes and lakes has an area of 2800 km^2 during low-water period and 4500 km^2 during floods; the areas of both the second and third marshes are 3000 km^2 [19]. These marshes represent a complex of ancient deltas, which formed on the coast of Persian Gulf between years 3000 B.C. and 500 A.D. [19].

The directions of flows of both rivers south of the cities of Ar Ramady and Samarra have radically changed over millennia, in particular, due to human interventions. The 7000 years of irrigated farming on the alluvial plain have resulted in the formation on the

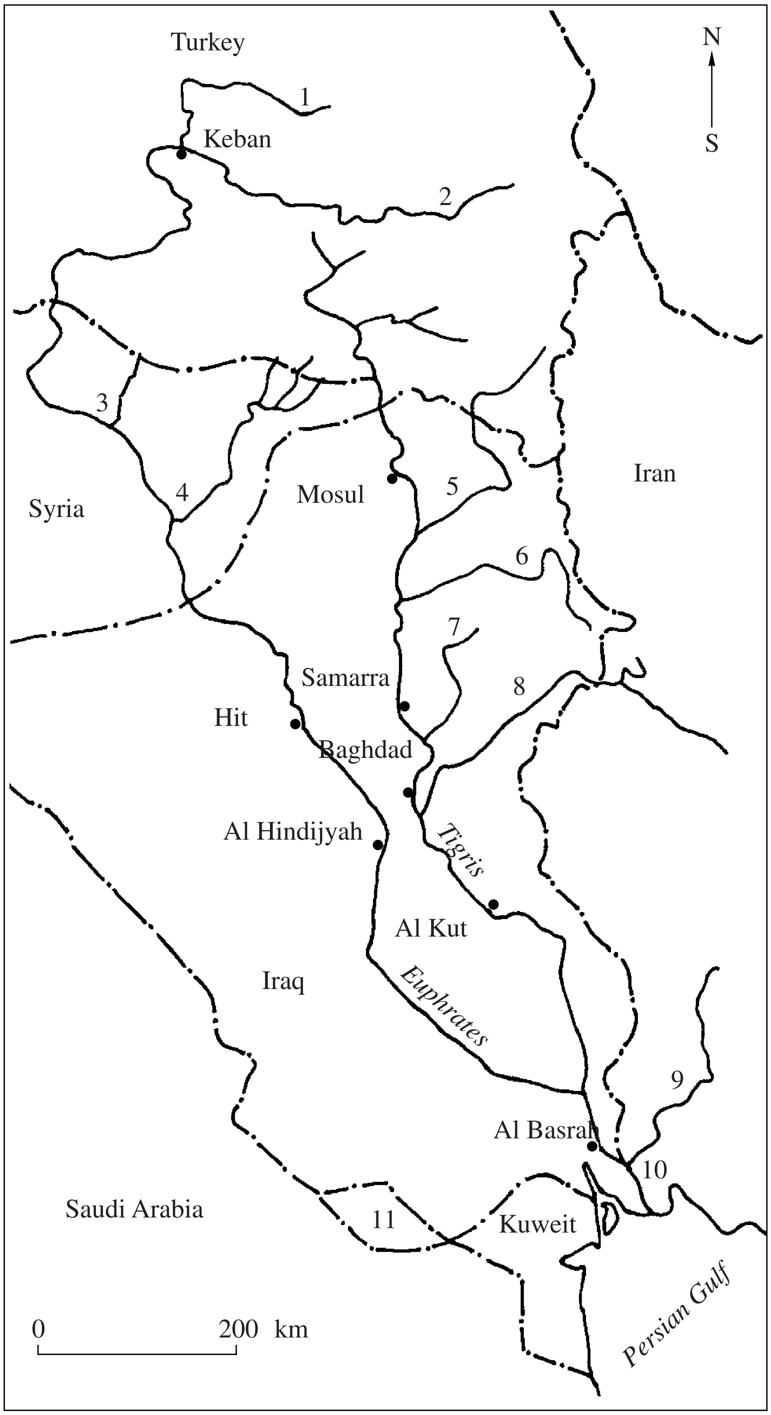

Fig. 1. Schematic map of the basins of the Euphrates, Tigris, and Shatt al-Arab. Tributaries: (1) Karasu, (2) Murat, (3) Balikh, (4) Khabur, (5) Great Zab, (6) Little Zab, (7) Al 'Uzaym (Al Adhaim), (8) Diyala, (9) Karun, (10); Shatt al-Arab River, (11) neutral zone. Dash-and-dot lines are state borders.

alluvial plain of a complex landscape of natural levees, oxbows, abandoned channel systems, and thousands of ancient settlements [24]. Burial mounds, covering ruins of ancient Babylonian and Sumerian towns and settlements, are often found far from the present-day river channels.

The distance between the rivers near Al Fallujah City and the Iraq capital Baghdad is as little as 50 km. Before the introduction of the Euphrates regulation, its water during river floods reached Baghdad on the Tigris River [24]. As early as the III century B.C., a triumph of engineering was the construction of five canals connecting the two rivers in the nearest place: the Isa, Sarsar, Malik, Kutha, and Shatt al-Nil canals [24].

After confluence at the city of Al Qukrna, the Euphrates and the Tigris form the Shatt al-Arab river, emptying into the Persian Gulf.

The Euphrates is too shallow for navigation, though ships with shallow draft navigate up to the city of Hit. The Tigris is navigable for shallow-draft ships up to Baghdad, while ferries navigate up to Mosul City.

The largest cities on the Euphrates (in the downstream direction) are Birecik (Turkey), Ar Raqqah, Dayr-Az-Zawr, Al Mayadin (Syria), Al Haditha, Ar Ramadi, Al Habbaniya, Al Fallujah, Al Kufah, As Samawa, An Nasiriyah (Iraq). The cities on the Tigris include Diyarbakir (Turkey), Mosul, Tikrit, Baghdad, Al Kut, Al Amarakh (Iraq).

The Euphrates and Tigris interfluve is the cradle of ancient civilizations; the states of Assyria, Babylon, and Sumer were situated here. Babylon was situated on the Euphrates bank. Its ruins were found not far from Al Hindiyah Town. Ruins of two capitals of the ancient Assyrian Empire—Nineveh and Calah—can be seen between Mosul and Samarra cities on the left-hand bank of the Tigris, and the ruins of the third capital—Ashur—stand on the right bank near the modern Al Sharqat Town [24].

The northern part of the basins of the Euphrates and Tigris lies in a subtropical climate zone, while their southern part lies in a tropical zone. The climate of the territory features wide variations of air temperatures: the temperature can drop to –35°C in winter within the Armenian Highland and reach 40°C on Al Jazira Plateau in summer.

The most humid in the Euphrates and Tigris basins are the eastern and northeastern parts—the mountain areas of Turkey (Armenian Plateau, Taurus, and the Kurdistan Range), Iraq, and Iran (the Zagros Mountains). In these areas, the annual precipitation varies from 300 to 1000 mm, and rivers receive the major portion of their annual runoff volume (up to 85%). Notably, the most important role belongs to solid precipitation, while snowmelt runoff is of greatest importance for river nourishment. Zones with the densest erosion network also occur here [10].

The Use of Water Resources

Water is of exceptional importance for the populations of the countries in the Euphrates and Tigris basins. Along with minerals, water resources are the major value for these countries. Most important economic sectors in Iraq, Syria, and Turkey, such as agriculture and power production, are based on water use. Water is also required for industry, municipal services, and water transport. The situation is most acute in Iraq: the majority of the population of this agrarian country is concentrated in the valleys of the Tigris and Euphrates and uses water for land irrigation.

Artificial irrigation has been in use in Mesopotamia for over 5000 years. As early as B.C. an irrigation canal network was constructed in the Euphrates basin. These canals also facilitated runoff regulation. Thus, flood waters of the Euphrates are discharged in lakes Al-Habbaniyah and Ar Razzaza (Al Milh). Lake Al-Habbaniyah is connected by a canal with the Tartar Reservoir, which also receives water from the Tigris. The Nimrod dam (Nimeruz) was constructed on the Tigris in the XV–XVI centuries B.C. near the exit of the river into the Mesopotamian Lowland with the aim to supply water to the Nakhravan Canal in low-water period [10].

The main irrigation canals in Iraq are the Shatt al-Hilla (Euphrates) and Shatt al-Gharraf (Tigris). After the construction of a dam near Al Hindiyah, the ancient channel of the Euphrates (Shatt al-Hilla branch) was turned into a canal. The capacity of Shatt al-Hilla branch–canal is 200 m^3/s, and its length is 104 km. Later it separates into three channels through which water enters the irrigation network covering an area of 575 thousand ha. Downstream of Al Hindiyah, the branch with the same name becomes the major channel of the Euphrates. The flow of rivers in this area is slow; the mean slopes are 0.07‰ [10].

The Shatt al-Gharraf Canal is the largest in the Tigris basin; it runs from the right-hand bank of the Tigris almost to the Euphrates valley. The maximum capacity of the head structure of this canal is 622 m^3/s, and its length is over 170 km. Fifty-two canals and 968 irrigation ditches separate from the Shatt al-Gharraf Canal, and the area irrigated by it is 700 thousand ha [10].

A vast network of second-order canals separate from the major irrigation canals. The area of irrigated lands in Iraq in the mid-1970s was 5610 thousand ha (46% of all arable lands in the countries), of which 3000 thousand ha were irrigated every year [11]. The major portion of lands (3825 thousand ha) is located in the Tigris basin [11].

The choice of agricultural crops changed during the history of Mesopotamia. Records of attendants of temples in 3500 B.C. note that the areas of lands under wheat and barley were first equal; however, with an increase in the area of saline soils, the areas under barley, which is more tolerant to salt, also increased [11]. The present-day farmers in Iraq prefer the crops, which are irrigated mostly in winter, such as wheat, barley, flax, peas, and vegetables. They occupy up to 85% of cultivated lands. The crops that are irrigated in summer (rice, cotton, corn, and millet) occupy 11% of the areas. Other 4% of lands are used round the year: these are date-palm plantations [11].

Works for the construction of Main Outfall Drainage Canal started in 1953. This canal was intended for the collection of water with higher mineralization from the irrigated interfluve of the Euphrates and Tigris. The construction of this canal, also called Saddam's River or the Third River, was finished in the late 1993. The canal runs southward from the town of Al Mahmudia, crosses Euphrates south of the city of An Nasiriyah, runs around Al Hammar Lake from the west, and next runs for 60 km between dikes in a desert and confluences with the Shatt al-Basra Canal, emptying into Persian Gulf [19].

The dependable total natural runoff of the Tigris and Euphrates and their tributaries is 45.3 km^3 [11], while the water demand of agriculture in the 1970s was 60 km^3 [11]. The deficit of water resources was ~15 km^3 and has been increasing since then. Turkey and Syria, seeking to increase the irrigated areas, constructed large reservoirs, resulting in an increase in runoff losses.

The need to regulate the runoff of the Euphrates and Tigris, induce governments of the basin to large-scale construction of hydroschemes, such as canals and reservoirs. In the basins of Euphrates and Tigris, 19 and 43 hydrosystems have already been constructed or designed, respectively.

The high water potential of the Euphrates is used for irrigation and power production. In 1975, the first large dam with the Keban Reservoir was constructed on the Euphrates in Turkey under a development project of agricultural Anatolia region (GAP), and a dam and the Karakaya reservoir were constructed in 1987 [33].

In 1992, the construction of Atatürk dam (one of the largest in the World, 184 m in height and 1820 m in length) was completed further downstream on the Euphrates [22]. The reservoir is large enough to contain the entire annual runoff volume of the Euphrates, i.e., it can stop the river. The HPP at Atatürk dam is the most powerful in the Euphrates basin (2400 MW).

In 1973, Syria, with the help of the USSR, constructed Tabaqah dam (or Euphrates dam) 60 m in height and 4.5 km in length on the Euphrates 50 km upstream of the city of Ar Raqqah [24]. The Al Asad Reservoir (or Lake Asad) that formed as the result was filled in 1977; its length is 80 and width is 8 km [24]. The capacity of the HPP is 800 MW [33]. It was planned that this HPP will cover 90% of power consumption in Syria and the water from the reservoir will irrigate 640 thousand ha of lands. However, the site for reservoir construction was poorly chosen: the high gypsum content of soils prevented the full-scale irrigation of lands, and the construction of the Atatürk Reservoir had reduced the river runoff, thus preventing the filling of the entire usable volume of the Al Asad Reservoir. The actual capacity of the HPP is as little as 11% of its design value.

In 1986, a large dam with the Al Haditha HPP and several off-stream reservoirs (Al-Habbania, Ar-Razzaza, etc.) and low-head dams–barrages (Ar Ramady, Al Falluja, Al Hindiya, etc.) were constructed on the Euphrates, allowing water to be supplied into irrigation canals.

The runoff of the Tigris is controlled by the Mosul, Samarra, Al Kut, and other dams. The reservoir at Mosul City (the dam across the Tigris channel is also called Saddam's Dam) is among the largest in Iraq. The HPP constructed here contributes most to the Iraq hydropower engineering: its peak power is 1050 MW [33]. However, more recent data on the power units on this dam suggest another estimate—as little as 320 MW [22]. It was also found that the Mosul Dam is tottery. The major cause of this is the poor choice of the construction site. The bedrocks in the area (limestone, gypsum, anhydrite) are prone to karst formation. A September 2006 report by the United States Army Corps of Engineers [22] noted that Mosul Dam is the most dangerous dam in the world. A sudden collapse of the dam would flood Mosul with the population of 1.7 million within two hours and affect some parts of Baghdad. The injection of 50000 t of grout into the dam basement has not radically improved the situation [22].

In the 1950s, a dam was constructed at the city of Samarra and a canal with the same name was excavated from it to Tharthar depression [10]. Earlier, Tharthar depression was a valley of the Wadi-Tharthar River, which divided into two branches emptying into the Tigris and Euphrates (downstream of the city of Al Fallujah), respectively. Tharthar depression can be divided into two parts: the small Rufai depression with an elevation of 42 m above sea level and the larger Jub Al-Abeid depression, whose bed lies 3 m below sea level. Water from Tharthar depression was not withdrawn for a long time, and all water in it evaporated. Later, Tharthar depression was also connected by a canal with the Euphrates. This project—water transfer from one part of the river system to another—was of great importance for economy [11].

Dams Dokan (on the Little Zab River), Derbendikhan (on the Diyala River), and others were constructed on Tigris tributaries.

Data on the largest reservoirs in the basins of the Euphrates and Tigris rivers are given in Table 1.

The volumes of water consumption in municipal services and industry (though out-of-date) are small compared with the demands of agriculture. The demand for domestic water in 1971 was ~0.678 km^3/year [11]. Water consumption in the industry was very approximately estimated at 0.25 km^3/year [11].

Recently, oil fields, rapidly developing in south Iraq, became large water consumers [19].

Characteristic of Euphrates and Its Water Regime

The Euphrates originates from the confluence of the Karasu and Murat rivers, rising in the mountains of the Armenian Highland in eastern Turkey at an elevation of 3000–3500 above sea level.

The length of the Euphrates from the source of the Murat to the confluence with the Tigris is 3065 km [5], and the length from the confluence of the Murat and the Karasu is estimated at 2330 [30], 2700 [20], and

Table 1. Largest reservoirs and HPPs in the basins of the Euphrates and Tigris according to [1, 10, 16, 26, 33] (here and in Tables 4–6, 8, dash means no data available)

Name of reservoir	River	Country	Year of filling	Reservoir area, km^2	Head at the dam, m	Volume, km^3		Evaporation losses, km^3/year	HPP capacity, MW
						full	usable		
Keban	Euphrates	Turkey	1975	675	190	31	16.3	–	1330
Karakaya	″	″	1987	268	155	9.6	5.6	–	1800
Atatürk	″	″	1992	817	175	48.7	19.3	–	2400
Al Asad	″	Syria	1975	610	60	11.7	7.8	0.99	800
Al Hadita	″	Iraq	1984	500	50	8.2	–	0.98	660
Al Habbaniya	″	″	1958	426	13	3.3	2.7	1.07	No HPP
Ar Razzaza (Abbu-Dibbis)	″	″	1951	1850	15	2.6	–	2.51	The same
Mosul	Tigris	″	1985	371	90	11.1	10.0	0.37	320
Al-Tharthar	″	″	1976	2420	–	85	43.5	2.86	No HPP
Dokan	Little Zab	″	1959	270	511	6.8	6.1	0.419	400
Derbendikhan	Diyala	″	1961	113	485	3.0	2.5	0.17	249

Table 2. The distribution of basin areas F, thousand km^2; lengths L, km; and water runoffs W, km^3/year, between states [27]

River	Characteristic	Turkey	Iraq	Syria	Iran	Total
Euphrates	F	125	177	76	0	378
	L	1230	1060	710	0	3000
	W	32.2	0	0.5	0	32.7
Tigris	F	45	292	1	37	375
	L	400	1418	44	0	1862
	W	33.5	6.8	0	11.2	51.5
Euphrates and Tigris	F	170	469	77	37	753
	W	65.7	6.8	0.5	11.2	84.2

2800 [24] km; the basin area is 233 [30], 289 [4], 444 [12], 673 [5], or 766 [22] thousand km^2. According to most recent data, the length of the Euphrates is 2940 [31] or 3000 [27] km, and the basin area is 378 [27] or 388 [31] thousand km^2.

The Euphrates flows through Turkey, Syria, and Iraq. Small parts of Jordan, Saudi Arabia, and Kuwait lie within the Euphrates basin. Data on the distribution of the Euphrates basin area between different countries (Table 2) show that the shares of Turkey, Iraq, and Syria in the total Euphrates basin are 33, 47, and 20%, respectively.

In its upper reaches, the Euphrates is a mountain river and flows through steep canyons and gorges in the mountains of the Armenian Highlands in Turkey. In the middle reaches, the river turns southeast and flows through a deep wide valley in Syria between the Syrian Desert and Al Jazira Plateau. Here the Euphrates receives major left tributaries—Balikh and Khabur—and further flows in a sinuous channel through Mesopotamian Depression in Iraq. After the city of Hit, the river enters the zone of irrigated farming: irrigation canals separate from it, the river flow slows down, and the runoff disappears in floods and marshes. Before the confluence with the Tigris, the Euphrates divides into several channels. Its water feeds salt marshes, small lakes with slightly saline water, and the large lake of Al Hammar. The alluvial floodplain in this part of Iraq are covered with salt crust.

The Euphrates receives the major nourishment in the mountain part of the basin during snow melting; while the nourishment on the plain is mostly by rainwater. The mean annual precipitation is 800 mm in the northern part of the basin and <100 mm in the southern part. The spring flood on the Euphrates (April–May) carries much water: ~60–70% of the annual runoff passes in this period (Table 3). The autumn low-water period (September–October) features low water abundance. Its slight increase during autumn and winter is due to rains and short-term thaws in the mountains. The proportion of the basin in the mountains in Turkey

Table 3. Annual distribution of water runoff in the Euphrates and Tigris (the top number in m^3/s, the bottom number is the percentage of annual runoff according to [21])

River, gauging station	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Spring flood	Low-flow period
Euphrates, Keban	1937–1972	318 4.0	383 4.8	784 9.8	2060 25.9	1880 23.6	808 10.1	369 4.7	251 3.2	221 2.8	254 3.2	313 3.9	322 4.0	664 100.0	III–VI 69.4	VII–II 30.4
Euphrates, Hit	1964–1972	677 4.9	815 5.9	1100 7.9	1630 11.7	1870 13.4	1570 11.3	1960 14.1	1640 11.9	1020 7.3	542 3.9	493 3.5	591 4.2	1160 100.0	IV–VIII 62.4	IX–III 37.6
Euphrates, Al Hindiya	1968–1972	314 3.8	245 3.0	475 5.8	570 7.0	578 7.1	712 8.7	1350 16.5	1760 21.6	1030 12.6	450 5.5	352 4.3	339 4.1	681 100.0	VII–IX 50.7	X–VI 49.3
Tigris, Mosul	1964–1972	492 5.0	591 6.0	995 10.1	1280 13.0	1140 11.6	1260 12.8	1290 13.1	1170 12.0	530 5.4	306 3.1	329 3.3	453 4.6	820 100.0	III–VIII 72.6	IX–II 27.4
Tigris, Baghdad	1968–1972	475 3.5	533 4.0	914 6.8	913 6.8	1110 8.2	1460 10.9	2280 17.0	2230 16.7	1580 11.7	840 6.2	610 4.5	504 3.7	1120 100.0	VI–IX 56.3	X–V 43.7

Table 4. Long-term variations of mean water runoff of the Euphrates, km^3/year, according to [19]

Point	Years							Minimal admissible runoff
	1928–1946	1940–1949	1950–1959	1960–1969	1969–1973	1979	1974–1998	
Hit	27	36	27	32	21	30	23	9
Al Hindiya	20	20	17	23	–	–	–	–
An Nasiriyah	14	–	–	–	8	10	9	3.5

being <30% of the total basin area, it accounts for 94% of the river water runoff.

Before the beginning of river regulation by a system of reservoirs, the mean annual discharge was 664 m^3/s (20.9 km^3/year) at the Keban gauging station (Turkey), 1160 (36.6) at the Hit gauging station (Iraq), and 681 m^3/s (21.5 km^3/year) in the lower reaches of the river (Al Hindiya gauging station in Iraq) (Table 3). According to [18], the mean annual runoff of the Euphrates at Al Hindiya gauging station is 19 km^3/year and that at the mouth is 21 km^3/year. The maximum Euphrates water discharge over 1937–1972 was 3753 at the Keban gauging station, ~2000 in the middle reaches; the minimum discharge was 200–300 m^3/s [21]. After the beginning of river regulation, the Euphrates water runoff significantly dropped because of the greater water withdrawal for irrigation and losses for evaporation. By the late 1980s, the mean annual discharge at the city of Hit has dropped to 250 m^3/s (7.89 km^3/year), i.e., more than fourfold [26]. Somewhat different data on long-term variations in the Euphrates runoff are given in [19]. In the past, the river's runoff at the boundary with Iraq averaged 32 km^3/year, while in 1928–1946, it dropped to 27 km^3/year (Table 4). In this period, the runoff at An Nasiriyah was 14 km^3/year. Data on the subsequent periods (Table 4) suggest both a farther anthropogenic decrease in river runoff at the boundary of Iraq and a decline in this runoff farther downstream. Recently, river runoff at the An Nasiriyah gauging station averages 7.8 km^3/year [19].

The recent paper [31] gives statistical characteristics of Euphrates runoff before the construction of large water management complexes (up to 1990) and after the construction and commissioning of GAP project in Turkey (after 1990) (Table 5). These data show that the mean runoff in the lower reaches of the Euphrates (Al Hindiya gauging station) dropped from 18.8 to 10.7 km^3/year, the mean maximal discharges decreased from 3690 to 827, and the minimal discharge, conversely, increased from 3 to 60 m^3/s.

River regulation caused a redistribution of Euphrates runoff within the year (Fig. 2a): the runoff accumulates in reservoirs during flood and the accumulated water is discharged in the hottest month, July.

Estimates of the minimal admissible drop in Euphrates runoff are given in [19]. According to an agreement between Turkey, Syria, and Iraq, Turkey will supply to Syria ~16 km^3/year and Syria will supply to Iraq ~ 9 km^3/year (58% of the previous volume). If 38% of this runoff will persist to the city of An Nasiriyah, the volume of water for watering marshes and Lake Al Hammar will be as little as ~3.5 km^3/year.

Table 5. Data on water runoff in the Euphrates and Tigris according to [31]

Period	Characteristic	Points along the Euphrates		Points along the Tigris		
		Hit gauging station	downstream of Al Hindiya gauging station	Baghdad	upstream of Al Kut gauging station	downstream of Al Kut gauging station
Before 1990	Q_{av}, m^3/s	869	597	1078	1147	945
	W, km^3/year	27.4	18.8	34.0	36.2	29.8
	Q_{max}, m^3/s	7510	3690	7640	9206	8700
	Q_{min}, m^3/s	55	3	43	70	0
After 1990	Q_{av}, m^3/s	356	338	666	578	368
	W, km^3/year	11.2	10.7	21.0	18.2	11.6
	Q_{max}, m^3/s	2514	827	1825	1577	1321
	Q_{min}, m^3/s	58	60	155	140	60

Characteristic of the Tigris and Its Water Regime

The Tigris rises in the small mountain Lake Hazar southeast of the city of Elazig in eastern Turkey at the elevation of ~1200 m above sea level, passes by the basalt walls around the city of Diyarbakir and, after Cizre City, flows between Turkey and Syria, forming a natural border between them. Data on the distribution of the Tigris basin area between different countries (Table 2) show that the major portion of the basin lies in Iraq (78%), while the proportions in Turkey and Iran are 12 and 9.8% of the total basin area, respectively.

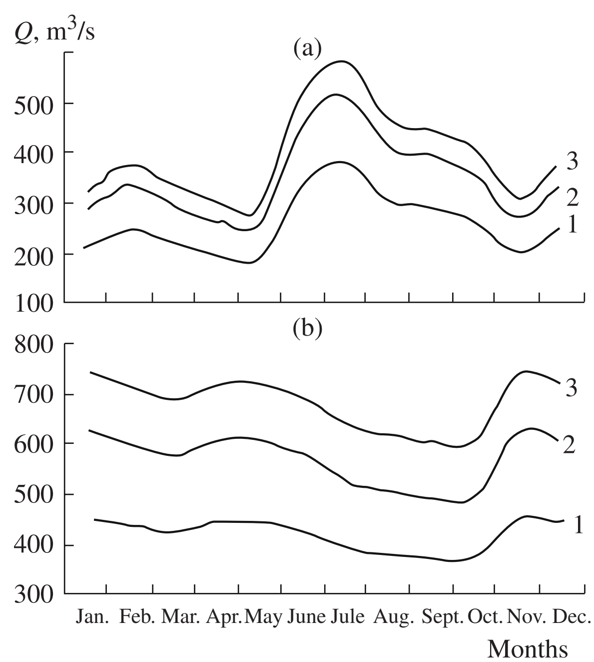

Fig. 2. Annual distribution of water runoff in the (a) Euphrates and (b) Tigris [31]. (1) Low-flow, (2) medium-flow, and (3) high-flow years.

After entering into Iraq, the Tigris receives water from a tributary of the Euphrates—the Khabur River. Farther, the river flows in a generally southeasterly direction through the Al Jazira Plateau. In its middle reaches, between the cities of Mosul and Samarra, the Tigris receives large left-hand tributaries—the Great Zab and the Little Zab (with lengths of 473 and 456 km and the basin areas of 26.2 and 19.4 km^2, respectively [10]). Near the city of Samarra, the Tigris enters the Mesopotamian Lowland, where it receives the Al' Uzaym (Al Adhaim) River and the Diyala River downstream of Bagdhad.

The length of the Tigris to the confluence with the Euphrates is estimated at 1718 [30], 1750 [22], 1850 [5], 1900 [24, 27] km. The basin area is 110 [22], 172 [30], 190 [4], or 375 [5] thousand km^2. According to most recent data of [27] and [31], the length of the Tigris is 1862 and 1900 km and its basin area is 375 and 235 thousand km^2, respectively (Table 2).

The Tigris receives its major nourishment from snow melting in Turkey mountains and from rains in late winter and early spring. The flood in the Tigris (from March or June to August–September) accounts for 56–75% of its annual runoff; and the low-flow water runoff, for 27–44% (Table 3). The most water-abundant month of the year is June. According to [30], the mean annual runoff of the Tigris before the confluence with the Euphrates before the regulation was 48.7 km^3, of which 13.2 were contributed by the Great Zab, 7.2 by the Little Zab, and 5.7 km^3 by the Diyala. The mean water runoff at the city of Mosul was 820 m^3/s (Table 3), corresponding to the mean annual runoff of 25.9 km^3. The mean discharge at Baghdad was 1120 m^3/s (the maximum was ~6110, and the minimum was 158), the mean annual runoff was 35.3 km^3/year, respectively (Table 3). During spring floods, the Great Zab and the Little Zab can double the Tigris runoff; that is why their runoff is regulated by dams.

According to [31], after the beginning of Tigris regulation (since 1990), the mean runoff at the Al Kut

Table 6. Long-term variations of Tigris mean water runoff, km^3/year, according to [19]

Point	Years					
	1928–1946	1940–1949	1950–1959	1960–1969	1969–1990	1980
Mosul	18	22	21	27	–	–
Baghdad	35	43	36	34	–	–
Diyala	42	–	–	–	–	–
Al Kut	37	40	31	26	–	20
Al Amarakh	7	–	–	–	2.6	–
Qalat Salih	3	–	–	–	–	–

Table 7. Water balance componentsof the Euphrates, Tigris, and Shatt al-Arab in the period before runoff regulation [6] (the top number is in mm, the bottom number is in km^3)

River	Basin area, thousand km^2	Precipitation	Runoff at the mouth	Evaporation	Runoff coefficient
Euphrates, Hit gauging station	264	$\frac{410}{108}$	$\frac{110}{29.0}$	$\frac{300}{79}$	0.27
Tigris, Baghdad gauging station	166	$\frac{650}{108}$	$\frac{256}{42.5}$	$\frac{394}{65.5}$	0.39
Shatt al-Arab (Euphrates, Tigris, and Karun rivers)	750	$\frac{382}{286}$	$\frac{61}{46.0}$	$\frac{321}{240}$	0.16

gauging station dropped from 36.2 to 18.2 km^3/year, the mean maximal water discharges decreased from 9206 to 1577 m^3/s, and the mean minimal discharges, conversely, increased from 70 to 140 m^3/s (Table 5). River regulation appreciably leveled the runoff distribution within the year (Fig. 2b).

Coinciding floods on the Tigris and its tributaries in Mesopotamian Lowland cause catastrophic inundations; for protection against them, the Tigris channel is embanked, in particular, in Bagdhad and near it. Part of the flood water is directed via a canal into Lake Al-Tharthar depression (northwest of Baghdad in the Tigris–Euphrates interfluve) and farther, via the Euphrates, into Lake Al-Habbaniyah.

The runoff of the Tigris within Iraq is withdrawn for irrigation and municipal water supply and is lost in swamps in the lower reaches. Mean Tigris runoff at the border with Iraq over period of 1928–1946 was 18 km^3/year (Table 6). After merging with the Diyala River, the Tigris runoff increased to 42 km^3/year. Further downstream, the runoff appreciably dropped because of water withdrawal. Near the towns of Al Amarakh and Qalat Salih, the runoff dropped to 7 and 3 km^3/year, respectively (Table 5). In the subsequent periods, the runoff was found to decrease both over time and along the river (Table 5).

Water Balance

According to [27], the mean natural runoff of the Euphrates (32.7) and Tigris (51.5) km^3/year total 84.2 (Table 2); according to other data, their total is 77.7 km^3/year [11]. The guaranteed natural runoff of these rivers in the formation zone is 45.3, and the maximal runoff is 165.7 km^3/year [11]. The contributions of both rivers to the total runoff are 39 and 61%, respectively. The largest share of the total runoff forms in Turkey (65.7 km^3/year or 78%), while the shares of Iraq and Iran are 6.8 (~8) and 11.2 km^3/year (~13%), respectively.

The only data on the annual water balance of the common basin of the Euphrates, Tigris, and Shatt al-Arab before the regulation are available from [6]. The results of these calculations (Table 7) suggest the large water losses for evaporation and the low value of the runoff coefficient (0.16) for the common basin of the three rivers.

According to [6], notable disagreement was found to exist in the basins of the Euphrates, Tigris, and Shatt al-Arab between the runoff of the rivers in the zone of their formation and at the emptying into the Persian Gulf.

With the mean annual total precipitation of 500–600 mm, the runoff that forms in the Taurus and Zagros mountains is ~3500 m^3/s. Water discharge at the inflow of the Shatt al-Arab into the Persian Gulf is 1450 m^3/s. Therefore, the losses of river water in the basin are

Table 8. Runoff losses in the basins of the Euphrates, Tigris, and Shatt al-Arab in the period before runoff regulation [6], m^3/s

Characteristic	Rivers					Total for the basin
	Euphrates	Tigris	Karkheh	Karun	intermittent watercourses	
Total runoff with no allowance made for losses	918	1540	150	775	120	3500
Runoff losses in Mesopotamian Lowland up to Al Hammar Lake	460	517	50	–	120	1150
Evaporation from Al Hammar Laked	–	–	–	–	–	900
Total losses	–	–	–	–	–	2050

2050 m^3/s or ~60% of the total runoff [6]. Table 8 gives the estimated water losses in the major tributaries of the Shatt al-Arab. The runoff losses of the Euphrates and Tigris were calculated in this case as the difference between water discharges between the Hit gauging station (at the exit of the Euphrates into Mesopotamian Lowland) and the city of An Nasiriyah (the area of river confluence) for the Euphrates and between the Mosul gauging station and the city of Al Kut (the analogous points in the Tigris).

Water losses in the basin are due to its evaporation from the surface of numerous lakes and marshes in Mesopotamian Lowland, which are fed by rivers during floods, to river water discharge into lakes–reservoirs, and water withdrawal for irrigation. Large water intakes, against the background of the wide occurrence of loose alluvial soils cause a rise in groundwater table and an increase in the area of marsh zones in the lowest parts of the depression, which features a generally poor drainage. According to the available approximate estimates [6], up to 13 km^3 of the runoff of the rivers is spent for the replenishment of groundwater reserves. It is likely that later they are to some extent discharged into the sea. The remaining 50 km^3 of water evaporate (including transpiration from vegetation).

The natural water regime of the Shatt al-Arab is similar to the regimes of the Euphrates, Tigris, and Karun rivers. Their characteristic feature was flood period in April–May and low-flow period in October. However, the regime of this river has radically changed in the recent decades because of an increase in anthropogenic impact.

Sediment Runoff

Data on the sediment runoff of the Euphrates, Tigris, and Shatt al-Arab are very contradictory and unreliable. The total sediment runoff of the Euphrates and Tigris according to [28] was 105 million t/year in the past, from which it decreased to 53 million t/year. With the water runoff of 46 km^3/year, the mean turbidity should be ~1.2 kg/m^3. According to [29], the values of the suspended and dissolved matter runoff in the Shatt al-Arab are 100 and 18 million t/year, respectively. According to [10], the mean annual sediment runoff in the Euphrates at the Hit gauging station in 1933–1960 was ~55 million t/year. Measurements of sediment runoff at the Haditha gauging station in the Euphrates in 1974–1982 allowed the mean annual sediment runoff to be estimated at 14 million t/year [12].

The regime of sediment runoff in the Euphrates and Tigris basins up to the 1970s was in general agreement with the water regime of the rivers. The maximum discharges of suspended sediments were recorded annually in April: in this period, the rivers transport ~80% of the annual sediment volume. The considerable saturation of river water with sediments (up to 3.5 kg/m^3 during flood [10]) is due to their upper reaches being situated in mountain areas, where the erosion processes are especially active.

The granulometric composition of sediments varies within the year in accordance with the river nourishment conditions and the transporting capacity of the flow. On the average over the year, the sediment contains ~5% of sand particles (>0.05 mm in size) and 95% of silt and clay (<0.05 mm) [10]. Downstream of Hit, sand particles deposit on the bottom and suspended sediment consists only of silt and clay.

The concentration of sediment in the flow decreases toward the mouth area. Especially large amounts of sediment deposit in the marshy lower reaches of the Tigris and Euphrates.

The construction of reservoirs on the Tigris, Euphrates, and their tributaries appreciably increased the spatial heterogeneity of sediment runoff: sediment accumulation began in the upper pools of reservoirs, while erosion and channel processes became more active in their lower pools. Changes in the water regime also affected the annual distribution of sediment runoff.

GEOGRAPHIC FEATURES OF THE HEAD OF THE PERSIAN GULF

The northwestern, head part of the Persian Gulf, which represents the nearshore zone of the Shatt al-Arab River, is a shallow area composed of thick beds of alluvial–marine deposits [8]. The coastal–delta complex is a large sedimentation system, whose evolution was complicated by modern tectonic processes associated with the subsidence of deposits. The sea shore is

Table 9. Climatic characteristics of the head part of the Persian Gulf [8]

Point	Air temperature, °C				Relative air humidity, %	Total annual precipitation, mm
	maximum		minimum			
	mean	range	mean	range		
Al Basrah	30.6	17.8–40.6	17.8	9.4–27.2	68	185
Bushir	27.8	17.8–36.1	20.6	10.6–28.9	74	274
Bahrein	29.4	20.6–37.2	28.3	15.0–31.1	87	74

represented here by numerous low and marshy accumulative delta islands. These islands are surrounded by silty shallows.

The mean depth of the gulf is ~50 m, while the depth in the near-mouth area is only a few meters [19, 31]. The retreat of its shore during the Holocene transgression of the sea was fast because of the small depth of the gulf.

The climate in the head part of the Persian Gulf is dry and hot (Table 9). The air temperature is high, though winters can be cool [8]. The extreme values of the temperature vary from 0 to 50°C. The coldest month is January (the mean temperature is ~16°C), and the warmest month is July (~35°C) [25]. The precipitation is low and mostly has the form of rare and short heavy showers in the period from November to April.

Water temperature in the gulf is high. In the northwestern part of the bay, it commonly varies from 16 to 32°C. The shallow coastal areas are the warmest. The temperature here can rise to 35°C in summer and drop to 15°C in winter [25].

The low river runoff, small precipitation, and large evaporation facilitate the formation of higher water salinity (up to 38–41‰ in the extreme northwestern part of the gulf [8]).

Tides in the Persian Gulf are irregular and diurnal, their range in the northwestern part of the bay reaches 3.2–3.4 m [8]. The waves in the gulf head are weak.

GEOGRAPHIC CHARACTERISTIC OF THE SHATT AL-ARAB RIVER AND ITS MOUTH AREA

Hydrography

Shatt al-Arab means *the river of Arabs* in Arabic. Indeed, the shores of the Shatt al-Arab are inhabited by Arabs, mostly, the so-called “marsh” Arabs (Shias), originating from the area near the confluence of the Euphrates and the Tigris.

The source of the Shatt al-Arab and the apex of its delta are near the city of Al Qukrna, where the Tigris and Euphrates merge (Fig. 3). The length of the Shatt al-Arab, according to different sources, is 145 [6], 175 [15], 188 (V.I. Kravtsova, MSU), 190 [30], 193 [24], and 195 [31] km. The total area of the Shatt al-Arab basin is ~750 thousand km^2 [6, 27].

The Shatt al-Arab is weakly meandering river and has few branches. Its width is 250–300 m downstream of the confluence of the Euphrates and Tigris and ~700 m near the city of Al Basrah, and the depth varies from 7 to 13 m [19, 31]. The water level drop from Al Basrah to the gulf, over the distance of 63 km, is ~0.67 m (a slope of 1.1×10^{-5}) [31]. The width of the river increases toward the bay to 800 m [24] and more.

The Shatt al-Arab receives the Karun River, flowing from the Zagros Mountains. The Karun (its ancient name is Ulai) is the most copious and the only navigable river in Iran and contributes largely to the formation of water and especially sediment runoff of the Shatt al-Arab. The length of the river was estimated at 820 [5, 31] or 829 [24] km, and the drainage area, at 60 [5] or 63 [31] thousand km^2. The river channel is very sinuous: the linear distance between its source and mouth is as little as 290 km [24]. The Karun has repeatedly changed its channel, and now the coastal parts of some old channels are filled with seawater. The most recent change of the channel took place in 1795 [24].

The mouth area of the Shatt al-Arab can be classified as estuarine–deltaic: the river fills a shallow and narrow part of the gulf with its sediment. The process of filling is accompanied by a slow tectonic subsidence of the area and a transgression of the sea. Abdallah Gulf, which is situated west of the site of the Shatt al-Arab flowing into the Persian Gulf, has a shape resembling an estuary. It is commonly accepted that this gulf has formed as an old channel of the Shatt al-Arab [24]. On the other hand, the processes typical of river mouth areas, including channel branching and the excessive accumulation of sediments, begin in the Tigris–Euphrates system about 500 km upstream of the Shatt al-Arab emptying into the Persian Gulf.

According to V.I. Kravtsova, the delta area is 13460 km^2, the length of the delta coastline is 140 km, the length of the main channel is 188 km, and the number of branch mouths is 10. According to [15], the delta is 18497 km^2 in area.

Immediately at the mouth of the Shatt al-Arab (at the place of its emptying into the gulf) the channel width is 2 km during spring tide and 1 km during ebb tide (Fig. 4). A vast silty shallow, drying up during

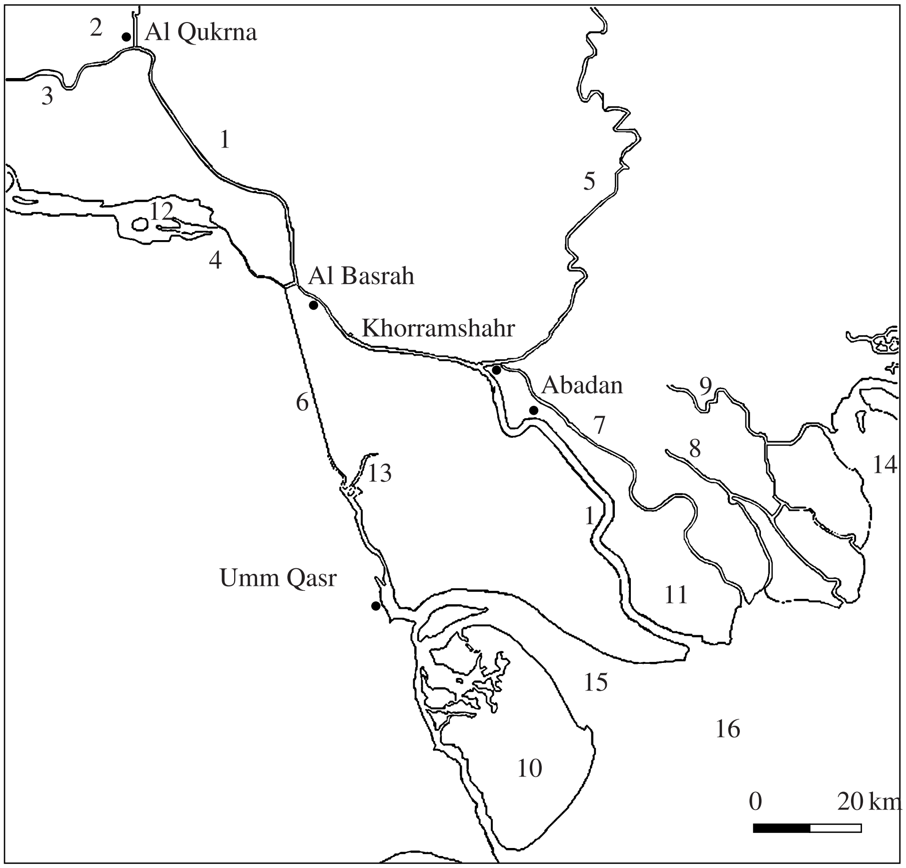

Fig. 3. Schematic map of the Shatt al-Arab mouth area. Rivers: (1) Shatt al-Arab, (2) Tigris, (3, 4) Euphrates, (5) Karun, (6) Shatt al-Arab canal; old channels of the Karun River: (7) Bahmanshir, (8) Shatt al-Ameh, (9) Shatt al-Qadimi; islands: (10) Bubiyan, (11) Abadan, (12) Al Hammar Lake, (13) Az Zubayr Lagoon entrance; bays: (14) Hor-Musa, (15) Hor-Abdullah, (16) Persian.

spring ebb tide, lies near the delta coastline. The foreshore width is 10–15 km. The isobaths of 5 and 10 m in the gulf during spring tide pass at distances of 20–25 and 30–35 km from the delta coastline, respectively. The depth of river channel during flood tide is 9–10 m. Inlets form during flood tides in the northwestern part of Bubiyan Island and even in the delta.

The western bank of the Shatt al-Arab has formed when a low sea island has connected with the main land, after which the depressions in relief were filled with river sediments. A shallow bar formed in the nearshore. The natural depth at the bar was ~2 m [9]. The length of the bar in the 1960s was 35.2 km [10]. The bar can be distinctly seen on space photographs. A navigable canal with a length of ~20 km and a depth of 10–12 m was excavated through the shallow coastal zone [13].

Climate and Landscapes

The averaged climatic characteristics in the middle part of the Shatt al-Arab can be roughly estimated based on data on the city of Al Basrah (Table 9). The air temperature here varies, on the average, from 9 to 41°C. The mean precipitation is 185 mm.

The mean air temperature in the mouth area (Al Basrah) is 24°C, the coldest month is January (11°C), and the hottest month is July (35°C) [19]. The mean temperature in January may drop to –4°C (ground frosts can occur), the maximum temperature in August can be 40–50°C [19].

Strong winds often blow over the Shatt al-Arab delta and the head of the Persian Gulf. Northern and northwestern storm wind (Shamal) is common between mid-June and mid-September and may blow for several days. This wind causes heavy dust storms on the coasts of the gulf. The hot southern and southeastern wind (Sharqi), similar to sirocco, commonly blows in the spring and autumn and delivers much dust and sand from Iranian deserts. In December–April, when cyclones shift from the Mediterranean Sea, squally southeaster wind (Kaus) often appear, bringing cloudy and rainy weather lasting for short (up to 3 days) periods.

According to [2], the mean annual values of precipitation and potential evaporation on the average for the Shatt al-Arab delta are 150 and 1900 mm, respectively.

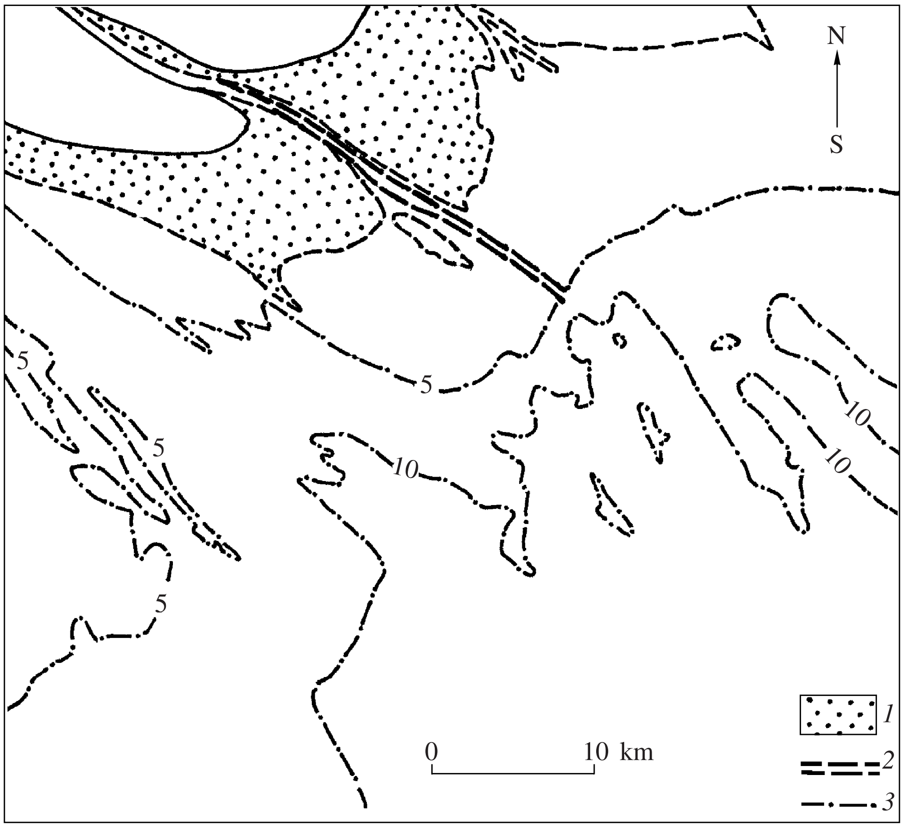

Fig. 4. Schematic map of the exit of the Shatt al-Arab into the Persian Gulf [13]. (*1*) Silty foreshore, which dries up during spring ebb tide, (*2*) navigable canal, (3) isobaths, m.

The amount of precipitation varies within the delta from 100 in its western part to 200 mm on the east. Conversely, the potential evaporation is greater on the west (~2000 mm) than on the east (~1750 mm).

The main landscapes of the Shatt al-Arab delta are low marshy areas covered with grass and reed, lakes, lagoons, delta islands, estuaries (referred to as *hor* by the local population), silty foreshores along the delta coastline, irrigated lands, and date-palm plantations [9]. In its marginal parts, the delta passes into desert.

HYDROLOGICAL PROCESSES IN THE SHATT AL-ARAB MOUTH AREA

The amount of river water received by the Shatt al-Arab mouth area was estimated at 22.2 [11], 46 [29], 62 [15], and 77 [18] km^3 per year. According to the most recent data [19], the total runoff of the Euphrates and Tigris rivers totals ~12 km^3 (Tables 4 and 6). According to [29], the sediment runoff at the mouth is ~100 million t/year, and the dissolved salt runoff is 18 million t/year.

In higher runoff period, part of river water fills delta depressions, marshes, and lakes and is evaporated.

The water balance of the Shatt al-Arab delta is negative. If, following [2], we take the mean precipitation and potential evaporation in the delta equal to 150 and 1900 mm, respectively, the excess of water losses over precipitation will be about 1750 mm per year. The delta area being 13460 km^2, this yields the tentative losses of runoff of 23.6 km^3/year or 38% of river runoff, if we assume it to be 62 km^3/year [15].

The runoff-induced variations in the Shatt al-Arab water level are not large. Considering the closeness to the Persian Gulf, the main cause of level variations in the mouth area is associated with the sea. Wind-induced storm-surge phenomena often occur in the Shatt al-Arab. The strong northwestern wind Shamal causes a negative surge at the delta coastline [8, 9]. Conversely, the southeastern wind Kaus can cause a surge with a height of up to 1 m [8, 9].

The level rise in the Shatt al-Arab also occurs under the effect of tides, which, in the mouth section of the river, amount to 3 m during neap tide (5 m during spring tide). The average tide range at Al Basrah is 0.5 m [19]. The effect of tides (rise or drop of water level) manifests itself upstream of the confluence of the Euphrates and Tigris (195 km from the gulf) and, according to [19] propagates along the Euphrates up to the upper boundary of Al Hammar marshes. Therefore, strictly speaking, the modern mouth area of the Shatt al-Arab has two apexes: upstream of Al Qukrna, in the lower reaches of the Euphrates and Tigris. Back currents during flood tides occur in the Euphrates upstream of the confluence, between the cities of Suq ash Shuyukh and Medina [19]. Flow velocities during tidal level variations can be as large as 2–3 m/s [10]. Because of the large inflow of freshwater from the Karun River, saline water does not penetrate into the Shatt al-Arab upstream of the city of Abadan (50 km from the gulf) [19].

Measurements carried out in the autumn during the flood tide showed [13] that water temperature in the Shatt al-Arab channel near the gulf was nearly constant over the depth (15.6–15.9°C), while water salinity in the river channel increased with depth from 6 to 14‰ at a distance of 15–20 km from the gulf and from 14 to 28‰ near the mouth section. In a neashore navigable canal, the temperature in the water body was 18–20°C, while water salinity increased from 22 on the surface to 38‰ at the bottom.

The appearance of specific tree structures in the erosion network in the southern part of the delta is due to the effect of tides. Lagoon Az Zubayr is a vast foreshore in the zone of tidal water motions. The lagoon is filled with water during flood tide: water rises along a narrow bay with the Umm Qasr port at the mouth; during ebb tide, mud flows form here. The abundance of marshes rules out any economic activity, whereas in the XII century, according to historical documents [10], the local population successfully cultivated plants, as can be seen, in particular, from the abandoned irrigation canals. Ground subsidence and sea transgression have resulted in that, over 800 years, these areas sank deep enough to be in contact with the Persian Gulf water [10].

EVOLUTION OF THE SHATT AL-ARAB MOUTH AREA

The rivers of Tigris, Euphrates, Karun, and some their tributaries are believed [7] to have been emptying into the Persian Gulf independently in the remote past. There also exists an opinion, that the Tigris and Euphrates flowed through a marshy area, now covered by the Persian Gulf water, directly into the Arabian Sea into the zone near the Strait of Hormuz [32]. During the epoch of the most recent glaciation, the Persian Gulf did not exist in its present form.

In the period of the Holocene transgression of the sea, considerable land zones were inundated by waters of the gulf. Within 7000 years, seawater covered the distance of 1000 km (from the Strait of Hormuz to the lower part of the modern Mesopotamia). The mean speed of land retreat was 140 m/year; whereas about 11500–12000 and 10000 years ago, it reached its maximum of 1 km/year [32]. The maximum transgression of the sea occurred ~6000 years ago: gulf coast shifted landward by 400 km relative the modern shore of the Shatt al-Arab delta [17]. The Lower Mesopotamia was covered by a 90-m water mass [32].

After the cessation of the Holocene transgression, the coastline started to rapidly move southward toward its present-day position. The shift of land in this direction was due to the input of large amount of denudation material from the basins of the rivers of Karun and Kerhe, as well as from the Euphrates and Tigris. The filling of the gulf by sediments was uneven, and some its parts became freshwater lakes, which later have turned into marshes.

According to [19], 3000 years B.C., three large deltas of the Euphrates, Tigris, and Karun formed simultaneously in the upper part of the sea gulf. By the beginning of the new era, the former two deltas moved far southeastward, while the especially large delta of the Karun River dammed the gulf, separating a lagoon from its major part, resulting in the formation of marshes of southern Mesopotamia. Lake Al Hammar formed ~600 years ago [19]. The Shatt al-Arab River formed only in the early new era [19].

Some researchers [32] believe that the theme of the Flood in the first book of the Bible (Genesis) and in the well-known Sumerian epos about Gilgamesh (whose cuneiform record was found during archeological excavations near the city of Mosul) is a literary description of the events that occurred during the rapid Holocene transgression. The researchers suggest that people in the past could live east of the generally accepted place of the origin of civilization, i.e., the countries of the "fertile crescent," in particular, in Mesopotamia. In that time, people could inhabit the bed of the present-day Persian Gulf, cut by the Tigris and Euphrates or, maybe, a river–prototype of the Shatt al-Arab. The retreat of the shore on a vast plain, such as the bed of the gulf, can be very fast, especially in the periods of its acceleration to 1 km/year (10000–12000 years ago). Another argument in favor of this version is the increase in moistening in the Southwestern Asia in the Early Holocene due to a change in the direction of monsoons [32]. The increase in the runoff of the ancient Tigris and Euphrates rivers, a considerable protrusion of the sea, and long rains, which could cause floods on rivers, served as the basis for biblical legends. Archeological data confirm the migration of people from the zone of the present-day mouth of the Shatt al-Arab in the northern (the Zagros Mountains), southern (Arabian Peninsula), and western (Mesopotamia) directions [3, 32].

Confirmations to the fact that the Shatt al-Arab formed in the modern historical epoch can be also found in the literature sources [7]. This was testified by the ancient Greek historian Herodotus (the V century B.C.) and geographer Strabo (the I century B.C.). Strabo wrote in his "Geography": "Both rivers terminate in the Persian Gulf," "The Tigris rises in the southern part of the same mountain, flows into Seleucia, comes near the Euphrates, forming Mesopotamia together with it; finally it empties into the same gulf as the Euphrates" [7]. The Roman scientist Pliny the Elder (the I century A.D.) in his work "Natural History in 37 Books" noted that there is no other place in the world where rivers so rapidly create land by their sediments [7]. The thickness of alluvial deposits on the place of the former gulf averages 20 m [7]. Thus, people became eyewitnesses of the formation of a new river, the Shatt al-Arab, receiving the waters of the Tigris, Euphrates, and Karun.

In the past, the Karun had several channels, none of which connected with the Shatt al-Arab, because the Karun emptied directly into the Persian Gulf. Three its old channels are known now as the rivers of Shatt al-Qadimi ("Ancient River"), Shatt al-Ameh (Blind River), and Bahmanshir. The former two channels are in essence parts of the gulf and are filled with seawater. Since 1765, the main channel of the Karun River has been the Al Haffar Branch, excavated in 986 A.D. with the aim to provide transportation between the cities of Al Basrah on the Shatt al-Arab and Ahvaz on the Karun [24].

Despite the fact that the mouth area of the Shatt al-Arab is extremely young in terms of geology and geomorphology, islands, as specific relief forms, have already appeared in the river's channel. Nevertheless, the river still has enough energy to avoid disappearing in its own alluvium, as is commonly the case with rivers in arid regions.

Now, the accumulation of sediments takes place mostly due to the sediment runoff of the Karun River, which drains the Zagros Ridge, while the Tigris and Euphrates leave the major portion of their sediments upstream of their confluence. Because of the start of the construction of reservoirs on the Karun, the discharge of sediments from this river into the Shatt al-Arab was found to decrease in the recent decades. On the other hand, this effect should have been compensated for by degradation of marshes in the southern Mesopotamia, resulting in an increase in sediment discharge by the Tigris and Euphrates into the Shatt al-Arab.

It is worth mentioning that river sediments play an important geomorphological role. The deposition of sediments delivered by the Karun, emptying into the Shatt al-Arab from the northeast, was the cause of the active displacement of the channel of the latter river in the westward direction, i.e., toward the place where the flow has enough energy to transport sediments downstream [14].

Finally, of great importance for the formation of the mouth area are modern tectonic processes. A large sea island (now Al Faw Peninsula), which had entered the river mouth because of a tectonic subsidence of the land became the southern bank of the present-day channel of the Shatt al-Arab [14].

THE PRESENT-DAY ISSUES RELATING THE USE AND PROTECTION OF NATURAL RESOURCES AT THE SHATT AL-ARAB MOUTH

The major portion of the Shatt al-Arab mouth area is occupied by vast marshes and lowlands, where the conditions for farming existed some time ago. However, various natural processes, the most significant among which is the new transgression of the sea, caused the accumulation of salts and the formation of marshes. The area near the Shatt al-Arab mouth drains, in both natural and artificial way, high-mineralization groundwater from Mesopotamian Lowland. Some parts of the Shatt al-Arab delta (e.g., Az Zubayr Lagoon) experience the effect of tides. Only halophytes, which are tolerant to salinization, can survive in these conditions [10].

A strip of land 4–6 km in width adjacent to the channel of the Shatt al-Arab is still suitable for irrigation farming. The choice of the cultivated crops is very specific: the date-palm forests on the banks of the Shatt al-Arab are largest in the world. The number of date-palms in the region was 17–18 million in the 1970s, however their number has dropped by 80% by 2002 [23]. The main cause of the degradation of this ecosystem is believed to be the secondary salinization of soils. The salinization process and its results became distinctly seen in the late 1960s [23]. A tendency toward the deterioration of the situation became even more distinct in the 1970s, when the active construction of reservoirs began in the Tigris and Euphrates basins. The regulation of the runoff of these rivers resulted in a decrease in water runoff and affected the regime of the Shatt al-Arab: the period of relatively high water abundance, when the accumulated soil could be washed out of the soil, disappeared. The degradation of the delta continued in the 1980s during the Iran–Iraq war: the banks of the Shatt al-Arab were subject to crossfire and air bombardments.

The normal vegetation of palms is possible only with artificial irrigation of the territory. Because of flood tides in the Persian Gulf, seawater dams freshwater in the Shatt al-Arab channel, water level in the river rises, and fresh river water flows into irrigation canals. During ebb tides, level in the river drops, and water from the plantations flows back into the river [10, 19].

The major watercourses in the Shatt al-Arab mouth area are in active use as transport mains. Pipelines run along the river channel toward large ports. The main oil-loading terminals are located in the cities of Al Basrah and Abadan. Large cargo ports of Az Zubayr and Umm Qasr lie out of the Shatt al-Arab River on the shores of a narrow sea bay, whose water level is strongly dependent on tides. Moreover, water from the adjacent lands is drained into this bay via the Shatt al-Basrah canal.

The well-known Kuwait oil fields are situated at the boundary of the river mouth area about 25 km southwest from the Umm Qasr port.

There are problems relating the pollution of the water of the Euphrates, Tigris, and Shatt al-Arab. Measures are being developed to prevent the pollution of water and soil [31].

Measures for land irrigation and melioration are planned in the mouth area, in particular, it is proposed to recover marshes in southern Mesopotamia, which have been among the largest and most important water–marsh areas in the world and featured wide biodiversity and high bioproduction [19, 31]. On the initiative of Saddam Hussein, the former President of Iraq, considerable areas of marshes were drained and degraded as unique ecosystems [19].

CONCLUSIONS

Notwithstanding the important strategic and transport significance, the morphological structure and hydrological regime of the Shatt al-Arab, unlike that of the Euphrates and Tigris is still poorly known. Nevertheless, the analysis of historic and recent data allows some important features of the mouth area under consideration to be established.

The delta of the Shatt al-Arab is very young from the geomorphological viewpoint. In the recent 10–12 thousand years, huge changes took place in southern Mesopotamia because of first the Holocene transgression of the sea and next the rapid protrusion of the delta in the southward direction.

The regime of the Euphrates, Tigris, Karun, and Shatt al-Arab rivers radically changed in the second half of the XX century. Because of regulation of the rivers and large withdrawal of water for irrigation, the runoff of water and sediment entering the delta abruptly dropped. The processes of degradation of soil and vegetation began. The effect of tides on the regime of the mouth became stronger.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research, project no. 07-05-00406.

REFERENCES

1. Avakyan, A.B., Saltankin, V.P., and Sharapov, V.A., *Vodokhranilishcha* (Reservoirs), Moscow: Mysl', 1987.
2. *Atlas mirovogo vodnogo balansa. M.*; (Atlas of World Water Balance), Leningrad: Gidrometeoizdat, 1974.
3. Belyakov, V.M. and Golubev, S.M., Irrigation on the Ancient Land of Iraq, *Gidrotekh. Melior.*, 1984, no. 5, pp. 75–79.
4. Bykov, V.D. and Al-Sakhaf, M., Water Resources of Iraq, *Vestn. Mosk. Univ., Ser. 5, Geography*, 1974, no. 5, pp. 34–41.
5. *Geograficheskii entsiklopedicheskii slovar'* (Geographic Encyclopedia), Moscow: BRE, 2003.
6. *Mirovoi vodnyi balans i vodnye resursy Zemli* (World Water Balance and Water Resources of the Earth), Leningrad: Gidrometeoizdat, 1974.
7. Muranov, A.P., *Reki Evfrat i Tigr* (Euphrates and Tigris Rivers), Leningrad: Gidrometeoizdat, 1959.
8. *Okeanograficheskaya entsiklopediya* (Oceanographic Encyclopedia), Leningrad: Gidrometeoizdat, 1974.
9. Samoilov, I.V., *Ust'ya rek* (River Mouths), Moscow: Geografgiz, 1952.
10. Al-Sakhaf, M., Iraq Hydrology and Hydrometry, *Extended Abstract of Cand. Sci. (Geogr.) Dissertation*, Moscow: Mosk. Gos. Univ., 1965.
11. Al-Sakhaf, M., The Use of Iraq Water Resources, *Rol' irrigatsii, drenazha i bor'by s pavodkami v sotsial'no-ekonomicheskom razvitii stran Azii i Afriki. Tr. I region. konf. MKID dlya stran Azii i Afriki* (The Role of Irrigation, Drainage, and Flood Control in the Social-Economic Development of Asian and African Countries. Proc. I Region. Conf. MKID for Asian and African Countries). M: TsBNTI Minvodkhoza SSSR, 1976, pp. 124-129.
12. Al-Ansari, N.A., Asaad, N.M., Walling, D.E., and Hussan, S.A., The Suspended Sediment Discharge of the River Euphrates at Haditha, IRAQ: An Assessment of the Potential for Establishing Sediment Rating Curves, *Geografiska Annaler. Ser. A*, 1988, vol. 70, no. 3, pp. 203–213.
13. Al-Saadi, H.A., Arndt, E.A., and Hussain, N.A., A Preliminary Report on the Basic Hydrographical Data in the Shatt Al-Arab Estuary and the Arabian Gulf, Wiss. Z. *Univ. Rostock. Math.-naturwiss. R*, 1975, vol. 4, no. 6, pp. 797–802.
14. Albadran B. N. Delta of River Shatt Al-Arab, South Iraq sedimentological study, http://www.geologyofmesopotamia.com/paper.htm
15. Coleman, J.M. and Huh, O.K., *Major World Deltas. A perspective from Space*, http://www.geol.lsu.edu/WDD/PUBLICATIONS/C&Hnasa04 /C&Hfinal04.htm
16. Consultancy Services for Dokan and Derbendikhan Dam Inspections. Inspection Report (Final) // http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2007/01/24/000020953_20070124135558/Original/E15370Dokan0an1am0Inspection0Report.doc
17. Cooke, G.A., *Reconstruction of the Mesopotamian Coastline in the Holocene,* http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6614268
18. Dai, A. and Trenberth, K.E., Estimates of Freshwater Discharge from Continents: Latitudinal and Seasonal Variations, *J. Hydrometeorology*, 2002, vol. 3, pp. 661–687.
19. Draft Report. Physical characteristics of Mesopotamian Marshlands of Southern Iraq, http://www.edenagain/org/publications/pdf/physicalcharreport/pdf
20. http://americal.edu/TED/ice/tigris.htm#r2
21. http://daac.ornl.gov
22. http://en.wikipedia.org/wiki
23. http://na.unep.net/digital_atlas2/webatlas.php?id=169
24. http://britannica.com
25. http://www.emecs.or.jp/guidebook/eng/pdf/07persian.pdf
26. Kavvas, L.M., Chen, R.Z.Q., M.L. Anderson, Ohara N., and Yoon J. A Study of Water Balances over Tigris-

Euphrates Watershed, http://balwois.com/balwois/administration/full_paper/ffp-462.pdf

27. MacQuarrie P. Water Security in the Middle East: Growing Conflict over Development in the Euphrates–Tigris Basin, http://www.transboundarywaters/orst.edu/publications/related_research/MacQuarrie2004.pdf
28. Milliman, J.D. and Meade, R.H., World-Wide Delivery of River Sediment to the Oceans, *J. Geol.,* 1983, vol. 91, no. 1, pp. 1–21.
29. Milliman, J.D., Rutkowski, Ch., and Meybeck, M., *River Discharge to the Sea. A Global River Index (GLORI). LOICZ Reports and Studies*, 1995.
30. Murakami, M., *Managing Water for Peace in the Middle East: Alternative Strategies*, Tokyo; N.Y:; Paris: United Nations Univer. Press, 1995.
31. New Eden Master Plan for Integrated Water Resources Management in the Marshlands Area http://www.newedengroup.org/VOLUME_I_BOOK_1_Water_Resources_20060915.pdf
32. Teller, J.T., Glennie, K.W., Lancaster, N., and Singhvi, A.K., Calcareous Dunes of the United Arab Emirates and Noah's Flood: the Postglacial Reflooding of the Persian (Arabian) Gulf, *Quatern. Int.,* 2000, nos. 68–71, pp. 297–308.
33. The Mesopotamian Marshlands: Demise of an Ecosystem, http://www.grid.unep.ch/activities/sustainable/tigris/mesopotamia.pdf