ESTIMATED WATER BALANCE FOR THE PROPOSED HADITHA RESERVOIR ON THE EUPHRATES RIVER IN IRAQ

by

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TABLE OF CONTENTS

TABLE OF CONTENTS--*Continued*

LIST OF TABLES

LIST OF ILLUSTRATIONS

ABSTRACT

The Iraqi Government is seriously considering the construction of a dam on the Euphrates River near the town of Haditha to better control water for irrigation on the Mesopotamian Plain, to generate hydropower and to alleviate flooding. The objective of the present study was to estimate the magnitude of possible losses from the reservoir due to seepage and evaporation.

To estimate the water balance for the reservoir, all components must be estimated. Inflow was estimated based on the historical flow regime of the river but adjusted for the water requirements upstream in Syria and Turkey. Evaporation from the reservoir was estimated from pan evaporation data. Seepage losses were estimated by the Green and Ampt approach for infiltration. Complexity of the reservoir bed soil and limited data allowed only rough estimates of the water balance components.

Annual expected evaporation losses from the reservoir was estimated to be 1.47 km^3. The estimated seepage from the reservoir averages 0.47 km^3/year for 11.5 years. Therefore, about 14% of inflow to the reservoir will be lost through seepage and evaporation for the first decade of operation.

Further hydrological and geological studies are required before the feasibility of the project can be accurately assessed.

CHAPTER 1

INTRODUCTION

The Euphrates River, originating in Syria and Turkey, traverses Iraq from the northwestern boundary to the Arabian Gulf after joining the Tigris River, a distance of 1200 km in Iraq (see Figure 1). Water from the uncontrolled river has been used for centuries to irrigate millions of hectares of the Mesopotamian Plain. Floods and water shortages have been frequent causes of damages and cropping constraints. In addition, the recent construction of dams on the river in Syria and Turkey have influenced the river regime in Iraq. The Iraqi government is seriously considering the construction of a reservoir within Iraq to more effectively control releases for irrigation, to generate hydropower, and to alleviate periodic flooding.

Several alternative dam sites have been evaluated by engineering consulting firms. These investigations prior to April 1975, narrowed the alternatives to a site near the village of Abu-Shabur, 7 km upstream from the town of Haditha, which is 260 km northwest of Baghdad. The final site selection was based on several complicated physical, economical, and geographical factors. The major factors being:

1. Geological-engineering conditions;
2. Topography, allowing a live storage capacity of 5-7 km^3;
3. Power generating capacity;
4. Capital investment requirements; and

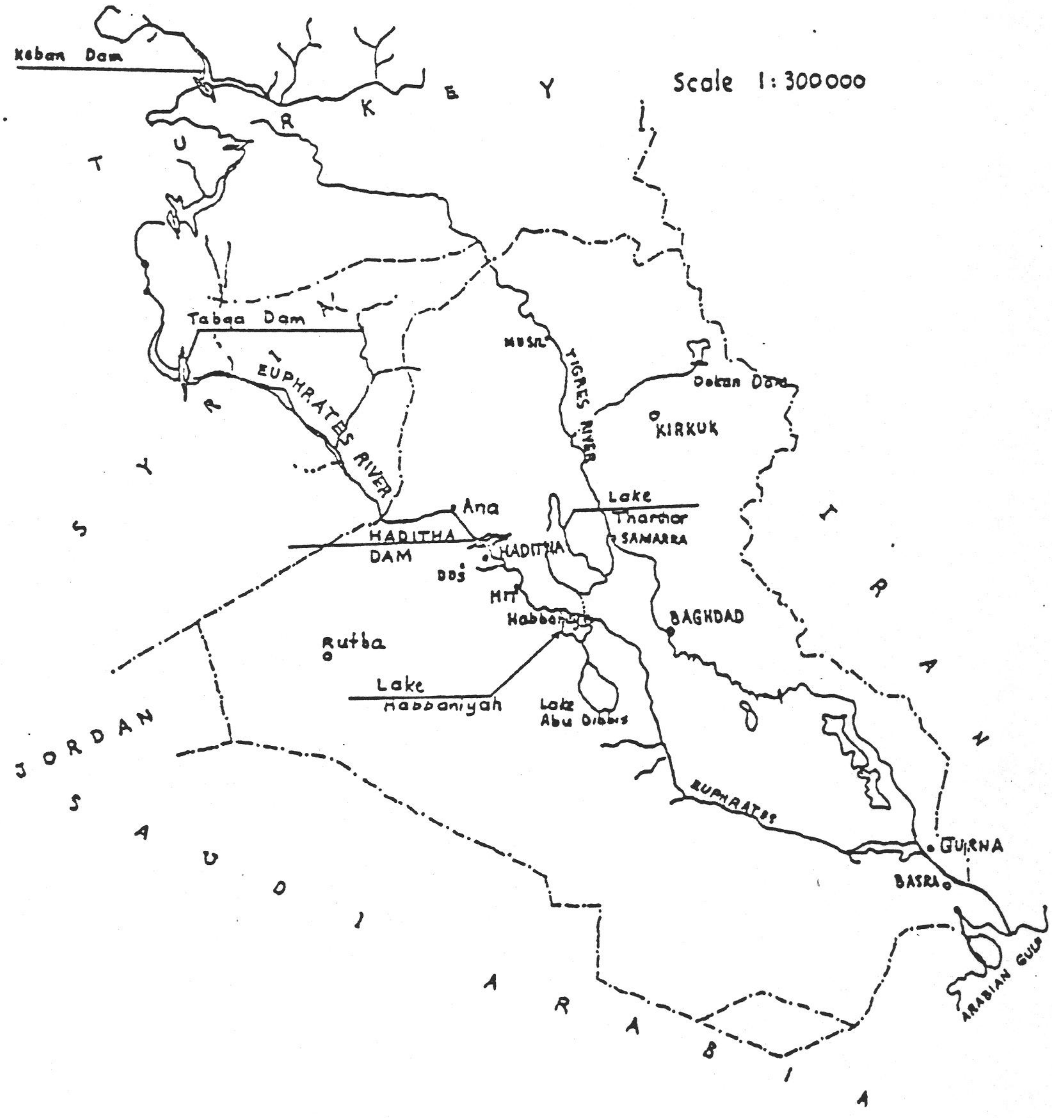

Figure 1. Map of the Euphrates River

5. Containment of the reservoir entirely within Iraq to avoid risk of damages in Syria.

The selected reservoir site is far from ideal because of the required length of the dam, the high surface to depth ratio for the reservoir, and the karst formation which bounds most of the reservoir area. However, the selected site appears to be the most feasible when all factors are considered. The project is commonly referred to as the Haditha project and has an estimated cost (1973 prices) of 270 million Iraqi Dinars (U.S. $910,000,000).

Until 1974, the main water consumption in the Euphrates basin was concentrated in the lower reaches of the river in Iraq. At the end of 1974, both the Keban hydroelectric project in Turkey and the Tabqa project in Syria were put into operation. The reservoirs of these two projects have a combined live storage of about 23 km^3. The existence of these projects will reduce the natural fluctuations of the river flow and decrease the annual flow of the river into Iraq. To manage the river flow in Iraq to meet prescribed schedules, an agreement with the governments of Turkey and Syria on the regime of water releases from the two dams must yet be developed.

At present there is only one regulating reservoir for the river in Iraq. It is the Habbaniyah Lake with a live storage of 2.76 km^3. The Haditha Reservoir may be considered the second important regulator of the river in Iraq. With the Haditha Reservoir the total regulating capacity in Iraq will be: 2.76 km^3 for Habbaniyah Reservoir, and 6.20 km^3 for the proposed Haditha Reservoir, giving a total of 8.96 km^3.

The total reservoir capacity is still less than the required holdover capacity after the expected abstractions of water in Syria and Turkey. Other means of augmenting the water supply of the Euphrates River includes transporting a portion of the flow of the Tigris River to the Euphrates via the Tharthar depression.

The Euphrates River

The Euphrates River starts at the confluence of the Murat and Karasu Rivers in Turkey, 10 km north of the town of Keban. These rivers originate in the Armenian uplands at an altitude of over 3000 m. The Euphrates flows mainly in a southeasterly direction through the territories of Turkey, Syria and Iraq. The Euphrates and the Tigris Rivers join downstream of the town of El-Qurna to form the Shatt-al-Arab River, which flows for 195 km before discharging into the Arabian Gulf. The length of the Euphrates from Keban to El-Qurna is 2210 km. The change in elevation of the river from the Syrian border to the confluence of the Tigris, a distance of 1005 km, is 163 m, or an average slope of 0.016% (Iraqi Ministry of Economics and Communications, 1955).

The mountainous part of the Euphrates basin in Turkey is characterized by a highly developed drainage network and is the principal source of runoff to the river. The catchment area above the town of Keban is 64,000 km^2. The average annual precipitation is 850 mm.

Three important tributaries join the Euphrates on the desert plateau in Syria. They are the Sadjur River (catchment area 2,350 km^2), the Balikh River (14,400 km^2), and the Khabur River (36,900 km^2). The Sadjur enters the Euphrates above the Tabqa dam and the other two enter below.

The historical average flow of the Euphrates at the Syrian-Iraqi border is 870 cumecs (m^3/sec), the maximum recorded flow is 7,400 cumecs, and the maximum discharge of 0.01% probability is 13,500 cumecs. No sizeable rivers enter the Euphrates in Iraq.

The river width at Haditha, near the proposed project site, varies from 200 to 1100 m with normal flows ranging from 300 to 7,390 cumecs. The depth ranges from 2 to 10 m or more. Velocities vary from 0.2 to 3.0 m/sec. The catchment area above Haditha is 234,600 km^2. Near the town of Hit, 80 km below Haditha, the river enters the Mesopotamian Plain, the main agricultural area. At Hit the river varies in width from 150 to 500 m, the depth from 2 to 10 m, and the velocity from 0.5 to 1.5 m/sec.

Three main periods in the annual flow of the river can be distinguished:

1. High water (flood) -- March-July -- 70% of flow;
2. Low water -- August-October -- 10% of flow; and
3. Rainfall high flows -- November-February -- 20% of flow.

The highest water levels normally occur in April and May, but for some years, rainfall and thawing of snow in the mountains result in floods in March and even in February.

The above data are given without consideration of the regulatory effects of the two recently constructed dams in Turkey and Syria. These projects have significantly altered the regime of the river, especially during the filling of the reservoirs. The long term effects are uncertain at this time.

Proposed Haditha Project

The reservoir of the Haditha project will have a length of 130 to 155 km and will submerge several towns and agricultural areas along the river. The ground levels in the reservoir area ranges from 102 to 190 m above mean sea level (MSL). Four terraces exist intermittently in the river valley. The flood plain terrace occurs in stretches 0.25 to 1.0 km wide and 2 to 3 m above the river on both sides and around islands. This terrace slopes toward the river and is usually inundated during the flood season.

The next higher terrace runs continuously on both sides of the river and on some of the islands. Its width runs from 0.2 to 1.2 km and is from 5 to 7 m above the average river level. The main villages and palm groves are located on this second terrace. The third terrace occurs in separate stretches with the largest stretch located on a river bend some 48 km above the proposed dam site, and with an area of 8 by 2.5 km. The alluvium of the terrace is highly eroded. The fourth terrace is nearly completely eroded away and can be traced only in isolated areas.

The specific features of the planned reservoir are as follows:

1. Reservoir storage capacity:

Total	6.4 km^3
Usable storage capacity	6.2 km^2
Working	4.0 km^3
Reserve	2.2 km^3

2. Reservoir surface area:

At normal head water level	418.4 km^2
At operation drawdown level	220.0 km^2
At maximum drawdown level	35.0 km^2

3. Reservoir dimensions:

Length along the river channel	130.0 km
Average width	3.0 km
Average depth	16.0 km

4. Reservoir water elevations (above MSL)

Normal head water level	143.0 m
Surcharged level	147.0 m
Level of operation drawdown at 90% probability	129.5 m
Level of maximum drawdown	112.0 m

5. Downstream water elevation (above MSL)

Maximum level at passing the flood of 0.01% probability	109.0 m
Minimum average monthly level meeting 150 m^3/sec sanitary release	100.5 m
Maximum level at full load hydroelectric station operation	103.5 m

Objectives of the Study

Although engineering studies have been made for the proposed dam and reservoir, several critical questions remain. The purpose of the present study is to make a more complete analysis of possible seepage losses when the reservoir is filled and the extent of evaporation losses in relation to the surface area and storage capacity of the reservoir. The magnitude of seepage and evaporation losses over time are critical to the feasibility of the project to meet irrigation requirements. Seepage is expected to be an important factor because of the geology of the region. Evaporation losses is expected to be great because of prevailing climatic conditions. The present study concentrates on the reservoir water balance as can be determined by the limited available data.

CHAPTER 2

GEOLOGY AND HYDROGEOLOGY

General Geology

The proposed reservoir site is located within the margin area of the northern slope of the Arabian-African platform where it borders the Alpine folded zone. Previous investigations (Technopromexport, 1974) have revealed complex geological conditions at the site. There are faulted strata of limestones and dolomites with occasional karst and containing a considerable amount of heterogeneous varieties. The folded structure is referred to as the southwestern limb of the near phrates trough -- gentle sloping syncline of the first order. This limb of the trough, with an average strike azimuth of 310-330° and angle of dip of 1.5° to the northeast, has a number of gentle folds of the second and higher order.

Tectonic dislocations with a break in continuity were not observed at the proposed dam site. However, fractures were found to the south near the town of Hit and to the northwest near the town of Rawa.

The upper part of the geological section of the reservoir area consists of the Lower Fars series and the upper bench of the Euphrates series. They are highly deformed due to "gypsum tectonics" (deformation caused by changing of rock volume when anhydride turn into gypsum) and have folds with amplitudes of 5-10 m and numerous fractures. Below these series are the deposits of the middle and lower benches of the Euphrates series and are deformed only in some places and to a lesser degree than the overlying series.

Small joints are prevalent but are well traced only in the strong rocks (limestones). There are systems of steeply dipping joints of the northwestern and northeastern strike and near horizontal layer interfaces. The joints of the upper portion of the geological section are often gypsum filled with a width of up to 5 cm. The carbonate massif is characterized with significant heterogeneity and changes in the vertical and horizontal direction.

Stratigraphic and Lithologic Description

The region is characterized with widespread distribution of Tertiary sedimentary rocks featured by considerably lithological non-uniformity in different degrees of dolomization and complicated by irregular leaching of the dolomites and gypsum as well as considerable karst development. These reasons and the presence of gradual passing from one lithological variety to the others aggravate the correlation of rocks and lamination of stratum into lithological benches (a distinctive lithological unit).

The Quaternary deposits of the region are encountered mainly in the Euphrates River valley in the form of alluvial sediments.

Quaternary Deposits: The Quaternary deposits are alluvial ones, forming the bottom of the Euphrates River valley, and alluvial-talus deposits developed on the upland divides and on gentle slopes. Eolian sediments are encountered within the first above-floodplain terrace and floodplain as lenses of small thickness, and proluvium-talus sediments occur at wadi openings into the valley. As shown in Figure 2, alluvial deposits are developed mainly within the floodplain (al Q_{IV}) and the first terrace above-floodplain (al Q_{III}). The total thickness of the sediments does not exceed 10-12 m.

The sediments are loams, sands, and clays in the upper portion of the geological section; below there are sands and gravel-pebble rocks with sandy filler. At some places loams are highly gypsiferous with thicknesses of 2-3 m. The bulk density of the loams is 1.28-1.74 t/m^3, and the water content is normally 16.6-29.8% in January and February. Sandy loams bulk density is 1.3 t/m^3 and water content is 14%. (The above data for physical properties and those to follow are for individual samples taken during exploration.)

Tertiary Deposits: Tertiary deposits which compose the slopes and bedrock bottom of the valley down to a depth of about 100 m below the river bed are divided into four series, referred to as Baba and Ana series (Oligocene epoch) and the Euphrates and Lower Fars series (Miocene epoch).

In these deposits eight benches can be distinguished from the viewpoint of their lithological stratigraphical characteristics (see Figure 2 (in pocket) and Table 1). Briefly, they are (from top downward):

1. Bench $N_1^2f_1$, Lower Fars series -- Rocks of this bench are about 20 m thick, are considerably deformed due to "gypsum tectonics" and represented mainly by dolomite-calcareous marls and clays. The rocks are highly gypsiferous; individual concretions and

Table 1. Lithological Description at Proposed Dam Site (from Top to Bottom)

Period		Series	Symbol	Thickness in (m)	Description
Tertiary	Miocene	Intermediate and Lower Fars	$N_1^2f1\text{-}2$	20-30	Gypsum-Limestone-Dolomite-Marls Clay, and Organogenous fragments; Hydraulic conductivity, 300-400 m/day*, 2.45-.65 m/day
		Upper Euphrates	$N_1^1eu_3$	10-15	Dolomite, Marls and Clay; hydraulic conductivity 0.1 m/day*
		Intermediate Euphrates	$N_1^1eu_2$	20-25	Organogenous, Dolomite, Chalk-like Limestone; hydraulic conductivity 3.7 m/day*, 335 m/day
	Oligocene	Lower Euphrates	$N_1^1eu_1$	10-25	Dolomitized, Aphanitic, Organogenous Limestone - Conglomerate-Breccia; Hydraulic conductivity 48.50 m/day*
		Ana	P_3^3an	16-18	Aphanatic - Fine - Crystalline - fragmental Limestone with layers of Clay; hydraulic conductivity 0.3 m/day*
		Baba	$P_2^3b_{2-3}$	25-35	Algal Dolomites with grain of Glauconite; hydraulic conductivity 6.3 m/day*
			$f_3^1b_1$	8	Clayey Limestone and Marls

* Measured values

gypsum intercalations, 2-3 cm thick, are encountered. Rocks of the bench may be classified mainly as dolomite calcareous marls, with bulk density of 1.84-2.02 t/m^3, and water content of 25.6-30%.

2. <u>Bench $N_1^2f_2$, Lower Fars series</u>-- This bench, more than 15 m thick, is permeable and composed mainly of gypsum or anhydride with individual intercalations of limestone, clayey adomite and marl, 1-2 m thick. Rocks of this bench are intensively deformed and enveloped with gypsum karst. At some places, layers of gypsum and anhydride are broken into individual fragments ranging from a few cm up to 2 m and cemented with weak, marly material.
3. <u>Bench $N_1^1eu_1$, Euphrates series</u>-- Rocks of this bench, 15-25 m thick, occur above the uneven surface of the Ana series. Breccia and conglomerate-breccia on calcareous-marly and dolomite-calcareous cement, frequently cavernous and karsted, are present near the bottom of the bench. These rocks are overlain with aphanite and organogenous-detritral limestone, intercalated with organogenous-detrital dolomites, some times very weak, turning nto mud while drilling. Bulk density of the dolomites is 1.57-2.29 t/m^3, water saturation 4.75-21.3%. Bulk density of conglomerate-breccia on calcareous marly cement is 1.91-2.69 t/m^3, water saturation is 0.8-10.9%.
4. <u>Bench $N_1^1eu_2$, Euphrates series</u>-- This bench, 20-25 m thick, is permeable and composed mainly of weak, mealy, organogenous-detrital dolomites turning into mud while drilling. In the

middle portion of the bench, a "oolitic" key horizon is encountered, saturated with foraminifera.

5. Bench N_1eu_3, Euphrates series-- This bench, 15-25 m thick, is represented mainly with breccia and conglomerate-breccia with marly-clayey cement. Aphanite and fine-grained limestones, sometimes dolomized and highly-jointed, lie above. Rocks of this bench are considerably crumpled because of "gypsum tectonics". Dry bulk density of the dolomite fragments is 1.54-1.9 t/m^3 and water content of 10-22.3%. The clay marl (serves as cement) has a dry bulk density of 1.72 t/m^3 and water content of 22.2%.

6. Bench f_3^3an, Ana series-- The Ana series, 15-20 m thick, is composed of hard, mainly aphanite and microcrystalline limestones with diverse fauna of gastropods, brachiopods, and corals. At some places, the limestone is highly cavernous. The cavities are frequently filled with greenish or brownish clay with limestone fragments. Tests carried out on some samples showed the following properties: water content - 24.6-28%; dry bulk density = 1.57-1.65 t/m^3; and water saturation ratio = .99.

7. Bench P_3b_1, Baba series-- Rocks of this bench occur in the bottom of the section at a depth of 70-80 m below the river bed (40-50 m below the bottom elevation of the proposed dam structure). Thikcness of this bench is 10-15 m. The rocks consist of clayey limestones and dolomites with glauconititic granules includions and individual intercalations of clay and marl. Bulk

density of tested dolomite samples in air dry state is 1.79-2.16 t/m^3 (tons/m^3) and in water saturated state is 2.08-2.36 t/m^3.

8. Bench F$_3^2$b$_{2-3}$, Baba series-- The rocks of this bench (total thickness 30-40 m) include organogenous-detrital, foraminiferal and calcareous dolomites, macroporous and cavernous of diverse degree of preservation. Some times while crushing rocks, hydrogen sulfide smell is evident. Algal limestones and dolomites with average hardness and sometimes highly porous occur at the top of the bench. Considerable difference in indices of physical and mechanical properties of individual varieties of dolomites can be explained by diverse degree of preservation. According to tests and analysis of samples, it is possible to divide the bench dolomites into two categories: relatively preserved and weak ones. Bulk density of relatively preserved dolomies ranges between 2.22 and 2.43 t/m^3. Bulk density of weak dolomite varieties ranges between 1.54-2.13 t/m^3.

Karsting

Karst development in the Haditha project area is evident in all eries, but mostly in the rocks of the Ana series and in the lowest rtion of the Euphrates series. In the Lower Fars series, karsting is aced in gypsum bearing deposits of bench f$_2$. Karst channels are und in carbonate rocks of bench eu$_1$.

Intensive leaching along pores in dolomite bench b_{2-3} of the Baba series, eu_2 bench and partially eu_1 bench of the Euphrates series is a specific sign of karsting.

Two types of karst are distinguished by age:

a. Older Miocene karst in the lower portions of the Ana series and in the Baba series mainly with clayey aggregate.

b. Younger Upper Pleistocene-Holocene karst in the rocks of the Euphrates series, as well as the Ana and Lower Fars series.

Depth of Miocene karst development, traced by boreholes drilled in the area goes down to elevations of 52-53 m (above MSL) and frequently found in the interval between elevations 60-70 m.

Young Upper Pleistocene-Holocene karst, widely extended in the is represented by three zones:

a. Right bank zone of regional karst of the northwestern strike with big slump holes in the rocks of the Euphrates series and with smaller karst forms in the Ana series limestones.

b. Traces of karst in carbonate rocks of the Ana series and lower bench of the Euphrates series near the river bed.

c. Left bank zone of karst developed in gypsum of the Lower Fars series.

There are large holes, open to the surface and up to 30 m deep, found mainly on the right bank with the nearest ones being only 2 km from the river. Some of the holes have running water at the bottom through openings of large diameter.

These karst zones are significant because of possible water seepage from the proposed reservoir. Karst channels range in diameter from 1 to 30 m at depths of 8 to 100 m below the valley floor.

Fissures of northewstern strike, sometimes inclined, are found in some holes. Often the smell of hydrogen sulphide is evident in sinkholes. All this indicates that the separate karst channels are controlled by echelon-like fissures. These holes are mainly found on the slopes of wadis. This karst zone intercepts and drains the regional right bank aquifer with partial unloading in Hajlan wadi (karst spring with discharge of 1.7 cumecs). The contour of water table, presence of springs in Fihami and Al Akdar wadis (18 and 22 L/sec) at the levels above the river stage, and the higher water temperature at the spring in Hajlan wadi, give the indication that the Euphrates River water does not enter the regional aquifer but the ground water discharges to the river. After a heavy rain occurred on January 11, 1974, 5-7 cumecs flowed in Thanaya wadi but disappeared in one of the holes located in Talweg gorge. After heavy rains, the water in springs cools down and carries suspended material, indicating open channels through the rocks.

Hydrogeology

There are two aquifers in the area of the proposed reservoir: the alluvial aquifer and the Oligocene-Miocene aquifer (Technoexport, 1971).

The alluvial aquifer is located in the sand-gravel deposits of the Euphrates valley bottom under the floodplain and the next terrace above. The aquifer thickness does not exceed 5-6 m and is recharged from the river and the Oligocene-Miocene aquifer. It is an unconfined aquifer with the level of the water table influenced by the level of water in the river. However, this aquifer is hydraulically linked to the regional Oligocene-Miocene aquifer.

The Oligocene-Miocene aquifer which is regionally developed is considered the main aquifer in the reservoir area. The thickness of the aquifer is 20-50 m. It is related to the jointed and intensively karsted dolomites and limestones of the Ana and Baba series. Its recharge is from the seepage of rain water and is drained by the Euphrates River. The waer table slope toward the river from both sides does not exceed 0.002, and within the limits of the river bed karst development, the slope increases to 0.005. Figure 3 (in pocket) shows the ground water contours in the reservoir area.

The ground water of the Oligocene-Miocene aquifer discharges to the Euphrates River through springs in the karst zones. Important springs are Haglan, Fihamy and Akdar with discharges in January, 1974, of 1.7 cumecs, 27 L/sec and 18 L/sec, respectively. The springs discharges do not influence the river flow significantly (see Figure 4, in pocket), but they do influence the chemical composition of river water, such as the chloride, carbonate, magnesium and calcium contents. Mineral composition of spring water varies from 3 g/L to 6 g/L with the minimum concentration observed within the karst region where water moves more directly from surface flows.

Water movement in the aquifer ranges from 0.1 m/day up to 48.5 m/day. Maximum values of the velocities are observed in rocks of Ana and eu_1 Euphrates benches.

CHAPTER 3

REGIONAL CLIMATIC CHARACTERISTICS

General

The climate of Iraq is mainly continental and subtropical. In the extreme north and south of the country the climate is, respectively, mediterranean and wet tropical. Throughout the year the prevalent air mass over Iraq is continental, tropical air. In winter the cyclonic activity develops and the passage of "fronts" result in precipitation. In summer thermal depression centers occur over Iraq (frontless almost not moving, region of low pressure) and transformation of air masses and the formation of tropical continental air take place.

Dry and hot summers, mild winters and low precipitation are the general climatic features of the Haditha Reservoir area. Only scant data are available to specifically characterize the climatic conditions of the area.

The nearest data sources are for the meteorological stations at Haditha (lat. 34° 04', Long. 42° 21', Elev. 140 m) and Ana (Lat. 34° 28', Long. 41° 57', Elev. 150 m). The data for Ana consist of minimum and maximum air temperature since 1967. Data of precipitation at Ana are also available for the period 1935-1956. For Haditha, air temperature, wind velocity, relative humidity, and precipitation data are for the period of 1937-1944, but with some missing data. Since 1972, complete data on precipitation, air temperature, wind velocity, and relative humidity are available.

The nearest locations to the proposed reservoir area with complete and long-period climatological data are the Rutbah meteorological station (Lat. 33° 02', Long. 40° 17', Elev. 615.5 m) and the Habbaniyah station (Lat. 33° 02', Long. 43° 34', and Elev. 43.6 m). Data of precipitation, temperature, humidity, and wind velocity are available since 1928 for the Rutba station and since 1935 for Habbaniyah station (Iraqi Ministry of Communication, 1962).

Air Temperature

The mean annual air temperature in the region of interest is 19-23°C. The mean temperature in January is 7-10°C, and in July it is 30-35°C. Table 2 shows the mean monthly and annual air temperatures recorded at the Rutbah and Habbaniyah meteorological stations and calculated for Haditha. The data for Haditha were obtained only at 6 a.m. daily. The mean shown in Table 2 for Haditha were obtained by adjusting the data from the other two stations by using 6 a.m. readings. The measured data for 1974 and 1975 only for Haditha are also shown in Table 2.

Table 3 shows the monthly maximum and minimum measured temperatures for 40 years of observations at Rutbah and Habbaniyah.

Wind

Through the year westerly winds are prevailing. In summer, north winds occur more frequently, south winds are rare. Annual frequency of wind direction and mean monthly and annual wind speeds are

Table 2. Mean Monthly and Annual Air Temperature (C°)

Month	Meteorological Stations			
	Rutbah	Habbaniyah	Haditha	
J	6.8	9.5	7.0*	6.6**
F	8.8	11.8	9.1	8.5
M	12.5	15.6	12.5	15.2
A	18.2	21.5	18.9	18.9
M	23.8	28.3	26.1	28.3
J	26.9	32.6	30.1	33.6
J	30.3	34.9	32.4	35.7
A	30.1	34.2	32.0	34.1
S	26.6	30.2	28.1	28.5
O	21.1	24.4	22.2	26.2
N	13.8	16.8	14.1	15.3
D	8.3	10.9	8.0	8.0
Annual	18.9	22.7	20.0	21.6

*Calculated from Rutbah and Habbaniyah data
**Measured for 1974 and 1975 only

Table 3. Minimum and Maximum Measured Air Temperatures (C°)

Month	Rutbah Maximum	Rutbah Minimum	Habbaniyah Maximum	Habbaniyah Minimum
J	25	-14	26	-9
F	32	-10	30	-5
M	36	-6	36	-2
A	39	-2	41	2
M	42	6	47	10
J	44	12	49	16
J	46	14	51	21
A	45	15	49	19
S	45	9	48	13
O	38	0	42	6
N	35	-6	35	-3
D	26	-9	31	-7
Annual	46	-14	51	-9

shown in Tables 4 and 5. Mean annual wind speeds are not high, i.e., about 3.0-3.4 m/sec. In summer the wind speed is higher than in winter with the highest average monthly wind speeds usually occurring in July. For summer months a considerable fluctuation of daily wind speed is typical, i.e., from 2-3 m/sec at night to 5-6 m/sec at noon.

Air Humidity

The absolute air humidity in the considered area is relatively low; the annual mean for Rutbah is 8.5 mb (from 6.5 mb in February to 10.3 mb in July) and for Habbaniyah is 11.1 mb (from 8.6 mb in February to 13.2 mb in August). The annual mean relative humidity in Rutbah is 38 percent (from 23% in August to 69% in December and January) and in Habbaniyah it is 41% (from 23% in July to 76% in January).

Relative humidity for Haditha was obtained based on 6 a.m. records as described earlier for temperature. The annual mean relative humidity is 46%. In June it is 24%, and in January it is 74%. In July and August, the mean monthly relative humidity at noon is 12-15% and in some days it falls to 3-5%. Table 6 shows values of mean monthly and annual relative humidities.

Precipitation

Precipitation in the proposed reservoir area is very small, 100-150 mm per year with the major amounts occurring in winter and spring (see Table 7). From June to September there are usually no rainfalls. Daily maximum precipitation (obtained from 20-50 years of records) is 47 mm in Rutbah, 36 mm in Habbaniyah and 67 mm in Ana. These

Table 4. Annual Frequency of Wind Direction (%)

Meteorological Stations	N	NE	E	SE	S	SW	W	NW	Still
Rutbah	12	5	7	7	10	14	25	20	21
Habbaniyah	12	5	8	7	6	4	17	41	22

Table 5. Mean Monthly and Annual Wind Speeds (m/sec)

	Meteorological Station	
Month	Rutbah	Habbaniyah
J	3.1	2.5
F	3.8	3.2
M	4.2	3.4
A	3.9	3.2
M	3.7	3.6
J	3.6	3.8
J	4.1	4.0
A	3.5	3.4
S	2.8	2.5
O	2.4	2.2
N.	2.5	2.1
D	2.6	2.0
Annual	3.4	3.0

Table 6. Mean Monthly and Annual Relative Humidity (%)

	Meteorological Station		
Month	Rutbah	Habbaniyah	Haditha
J	69	76	74
F	56	62	69
M	48	58	57
A	39	44	45
M	32	31	28
J	25	24	24
J	24	23	25
A	23	25	27
S	27	29	26
O	32	36	38
N	54	58	61
D	69	75	73
Annual	38	41	46

Table 7. Mean Monthly and Annual Precipitation (mm)

	Meteorological Station		
Month	Rutbah	Ana	Habbaniyah
J	16.9	16.9	20.8
F	15.2	19.5	17.0
M	18.6	19.3	26.0
A	18.9	20.9	16.9
M	10.2	8.7	3.7
J	0.1	0	0
J	0	0	0
A	0	0	0
S	0.6	0	0.1
O	5.5	3.5	1.7
N	11.4	10.0	18.7
D	19.1	25.4	20.0
Annual	116.5	124.2	124.9

daily maxima were all recorded in April. Records show an average of 15 rainy days per year at Haditha and 14 at Ana.

Evaporation from Water Surface

The high temperature and dryness of air for the region causes high evaporation losses from water surfaces. The only evaporation data near the reservoir site have been collected at the Desert Development Station, which is located 30 km southwest of the reservoir site. The evaporation data were gained by daily readings of a U.S. Weather Service Class A evaporation pan, starting in May 1974. The monthly evaporation data are presented in Table 8. The average total annual evaporation for years 1974-1975, 1975-1976 was 4555 mm (Desert Development Station, 1976), with maximum evaporation occurring in July and minimum occurring in December or January. Although there may have been measurement errors, the total appears reasonable. For example, annual pan evaporation for Death Valley, California, with a similar climate is given by Sellers and Hill (1974) as 4261 mm.

Table 8. Monthly Pan Evaporation for a Site Near Haditha

Month	1974	1975	1976	2 Year Average
J	--	94	112	103
F	--	140	102	121
M	--	234	211	223
A	--	374	204	289
M	517	490		504
J	704	675		699
J	842	806		824
A	795	713		754
S	468	555		512
O	280	211		246
N	140	225		183
D	94	99		97
Total				4555 mm

CHAPTER 4

HYDROLOGY AND AVAILABLE WATER RESOURCES

Before the dams were built on the Euphrates, the stage and discharge of the river were measured at Keban for 28 years, Tabqa for 11 years, and Hit for 45 years. Records of the river flow at Hit were started in 1924 by the Iraqi Ministry of Irrigation, the source of the data to follow. The data for Keban from 1936 to 1964 were taken from a report by EBASCO Services (1964) (Hydroproject Institute, 1971). The source of data for Tabqa was the Iraqi Ministry of Irrigation. Flows at Haditha were calculated by Technoexport (1971) based primarily on the flow at Hit. Fluctuations of the river flow made with the help of mass difference curves, has shown that the period of 45 years is quite sufficient for evaluating the normal flow of the river (Iraqi Ministry of Irrigation, 1975; Wilson, E.M., 1969).

Table 9 shows the mean annual flow of the river at Keban, Tabqa, Haditha and Hit before the dams were constructed. Also shown in the table are the catchment areas and intermediate flows between dam sites before dam construction. For comparison, the river flows at Tabqa and Hit during June through August before and after the dams in Turkey and Syria were operating are shown in Table 11. The mean annual for Haditha was estimated at 889 cumecs before 1974 and 301 cumecs during 1974.

Table 9. Observed Data of Annual Runoff of the Euphrates River at Dam Sites and Intermediate Inflow

Site	Length of the Euphrates km	Catch-ment area sq. km	Annual runoff cumecs
Keban	10	64,100	622
Keban-Tabqa Stretch		56,600	222
Tabqa	710	120,700	844
Tabqa-Haditha Stretch		109,300	46
Haditha	1456	230,000	889
Haditha-Hit Stretch		34,100	34
Hit	1568	264,100	923

Table 10. Mean Monthly and Mean Annual Water Discharges (cumecs) and Seasonal Runoff (km^3) of the Euphrates River at Hit, Tabqa and Keban

Month	Hit	Tabqa	Keban
J	702	642	289
F	795	770	368
M	1136	1219	709
A	2157	2540	1978
M	2446	2416	1793
J	1272	1062	792
J	567	476	362
A	331	310	246
S	282	278	217
O	333	318	249
N	452	398	302
D	596	530	303
Annual	923	913	634
N-F	6.62	6.09	3.35
Mar-July	20.20	20.40	14.89
Aug-Oct	2.54	2.45	1.88

Table 11. Mean Monthly Water Discharges (cumecs) at Hit and Tabqa for June, July, and August before and after 1974 Operation of Tabqa Reservoir

	June		July		August	
	Before 1974	After 1974	Before 1974	After 1974	Before 1974	After 1974
Hit	1272	122	567	69	331	153
Tabqa	1062	136	476	154	310	275

Quantities of water diverted in Turkey and Syria were estimated by VBB (1964) to be 4.0 km^3 in Turkey and 7.1 km^3 in Syria.

Water Level and Discharge at Natural Flow (Pre-Dams)

The Euphrates river flow is formed mainly by snow melting in the mountainous area of its basin and by rains, which usually fall during the period from November through May. The ground water supply does not contribute much if compared with the rain and snow melting sources.

The river annual flow cycle may be divided into three periods:

1. Floods, from March through July
2. Summer low water period, from August through October
3. Rain period, from November through February

About 70% of the annual flow passes in the Euphrates (above Hit) during floods, about 10% during the low water period, and about 20% during the rainly period.

The water level fluctuation in the river are of a multi-peak character (5 to 7 peaks a year). Approximately, in July, a gradual lowering of the water levels begins and goes on to November. The rise of the water levels after November due to rainfalls and snow melt in the mountains is 3-5 m above the low water period level. The utmost fluctuation during one year of the river water level (6.1 m) was recorded at Hit in 1969, the least (2.2 m) in 1930. The highest water levels and discharges are usually observed in April and May. The lowest ones in September and October.

The discharge rating curve was interpolated at the Haditha dam site in the following way (Technoexport, 1971). For a measured stage of 140.26 m in 1969, the measured discharge was 7330 cumecs. Using this one point, the entire curve was interpolated based on the combined relation curve of the respective water levels and discharges at Hit and Ana. Water discharges and stages measured at proposed dam site in November-December 1970 have proved the lower part of the curve (from El. 135.5 to El. 136.5 m). Above El. 140.26 m to the maximum discharge at 0.01 % probability (with guarantee correction) (Q = 15000 cumecs), the curve was extrapolated using the Chezy-Manning formula with the river cross section made by soundings and leveling. The water surface gradient of 0.00060 is taken as the average one for river stretch of 1.5 km taken as the basis of the longitudinal water surface profile made by the mark of the recent floods. The coefficient of the river channel roughness (n = 0.027) was determined also by the high discharge of 1969.

Maximum Water Discharges

The maximum water discharges of the Euphrates River are observed usually during the flood period (second half April, first half May). They are caused by snow melting in the mountainous part of the basin which is often concurrent with rainfall. The flood peaks continues usually for 1-2 days. The maximum water discharge on the Euphrates tributaries are caused by rainstorms falling in the basin upper reaches and may occur in any month from December through April but usually the maximum water discharge occurs in January and February.

The highest maximum discharge recorded at Hit for the long term period of 1924-1969 was 7330 cumecs water, El. 59.92 on May 13, 1969.

The maximum discharge of the inflow to the proposed reservoir is considered to correspond to the outflow from the Tabqa Reservoir taking into account its natural routing when passing in the river channel. Since there are no topographical data for hydraulic calculations of routing the outflow discharges from the Tabqa Reservoir on their way along the 524 km from Tabqa to Haditha, the maximum inflow to Haditha site of 0.01% frequency (with guarantee correction) is estimated tentatively on the basis of the rating curve of corresponding maximum discharges of the Euphrates River at Tabqa and Hit sites. The relation curve reflects the flattening-out of the maximum discharges on this stretch. So the maximum discharge is accepted as 13,500 cumecs.

Available Water Resources

The Euphrates River runoff at Hit over the 45-year period of record (1924-1969) varied from 10.5 km^3 in the lowest water year 1929/30 to 63.8 km^3 in the highest water year 1968/69, with the average equal to 28.5 km^3. The monthly distribution of the natural runoff of the Euphrates River (70% of the annual runoff volumes passes during the flood period) does not coincide with the schedule of irrigation water consumption. The diversion of water for irrigation in Iraq during 50 years with the Habbaniyah reservoir operating was approximately 13.15 km^3, and during some water years it went down to 10 to 12 km^3.

The water consumption under conditions of full development of irrigation in Syria was evaluated and was arbitrary timed to the level of the year 1990. The estimated volumes of non-return water consumption which affects durectly the runoff of the Euphrates River approaching Iraq are shown in Table 12.

The water economy studies for the Tabqa hydroelectric project as well as those for Haditha have been performed conformably to the irrigation water requirement in Turkey and in Syria equal to 11 km^3.

The average annual inflow to the Keban dam is equal to 19.63 km^3. The average intermediate inflow for many years between Keban and Tabqa is 7.01 km^3. The diversion of water for irrigation on the Turkish territory in future is estimated at 4.0 km^3, with the evaporation losses from the surface of the Keban reservoir being 0.60 km^3. Thus, the annual average inflow to the Tabqa reservoir equals 22.04 km^3. Evaporation losses from the Tabqa reservoir varies from 0.7 km^3 to 1.6 km^3 per year.

According to the water economy data contained in the "Euphrates Dam Project Report" prepared and issued by the Swedish Firm, VBB (1964), the average annual volume of water released from the Tabqa Reservoir for the 31 year period (1932-1963) makes up 15.74 km^3 and the inflow to Iraq is 13.44 km^3.

The above volumes of water correspond to the diversion of 10.8 km^3 of water for irrigation of 580 thousand hectares on the Syrian

Table 12. Nonreturnable Water Consumption in Syria and Turkey

Design levels	Nonreturnable irrigation water diversion (km^3)		
	In Turkey	In Syria	Total
1975	1.0	2.9	3.9
1980	2.0	4.5	6.5
1985	3.0	5.7	8.7
1990	4.0	6.5	10.5
1994	4.0	7.1	11.1

territory with 5.60 km^3 and 5.20 km^3 of the above volumes withdrawn from the reservoir and from the downstream pool below the Tabqa hydroelectric project, respectively. The return flow from the irrigated lands in Syria is estimated at 2.9 km^3.

Recent studies by the Technoexport (1971) specified the water requirement for irrigation in Syria as the following irrigated area was decreased to 528,000 hectares (against 580,000 hectares taken by "VBB"), and accordingly the water requirements were reduced to 5.02 km^3 upstream of Tabqa project and to 4.74 km^3 downstream of it. The return water flow was accepted to be equal to 2.63 km^3.

In accordance with the above stated changes in the design water consumption on the Syria territory, the design inflow to Iraq had been also specified to be equal to 14.21 km^3. That is by 0.77 km^3 more than that in the "VBB" report. The intermediate inflow on the Tabqa Haditha stretch is estimated at 1.42 km^3 (normal runoff).

Thus, the average annual inflow to Haditha reservoir with the above scope of irrigation in the Euphrates River basin on the Turkish and Syria is 15.63 km^3 (summary total consumption is 11.1 km^3).

Due to the flow control of the Euphrates River by Keban and Tabqa reservoirs, the river runoff regime on the territory of Iraq will differ to a great extent from that of the natural one.

Volumes of irrigation water diverted within Turkey and Syria as well as water losses due to evaporation from upstream reservoirs will cause the decrease (compared to the present conditions) of average runoff at Haditha Dam site by more than 12 km^3, i.e., by almost 45%.

The annual volume of inflow to the Haditha Reservoir according to the data of VBB calculations will be 9 km^3 and not less.

The duty of the Tabqa Reservoir as accepted in the VBB report does not fully take into account the irrigation requirements in Iraq. Besides, the intermediate inflow on the Tabqa Haditha stretch is not controlled.

The discrepancy between the inflow and water requirements can be eliminated or decreased by the control of the runoff by the Haditha Reservoir.

The design annual inflow to Haditha Reservoir (on condition of full development of irrigation in Turkey and Syria) of 90% probability this figure will be 12.3 km^3 and with 50% probability it will be equal to 15 km^3.

At the present time the work on constructing the canal between the Euphrates River and Tharthar depression which is used for storing the flood water from the Tigris River is underway on completion. Through the Tharthar canal the Euphrates River flow can be increased due to exportation of some Tigris River flow.

Water Consumption

As it was mentioned before, the growth of irrigation water requirement in Turkey and Syria will cause the gradual decrease of the available water resources of the Euphrates River in Iraq.

When irrigation of the Turkish and Syrian territories reaches its design full development, the Euphrates River will carry at an average about 15 km^3 of water per year to Iraq.

In view of the limited water resources, one may not expect growth of irrigated land in the Euphrates River basin in future. In connection with this the monthly distribution of the water requirement for irrigation in Iraq to be diverted from the Euphrates River is accepted similar to that required for the present time, i.e., (in percent of the annual flow):

January	6.0	July	9.8
February	5.9	August	9.8
March	11.8	September	5.7
April	11.9	October	3.0
May	8.2	November	9.3
June	10.3	December	8.3

CHAPTER 5

PROPOSED RESERVOIR WATER BALANCE

Both the river flow into the proposed reservoir and the water requirements for downstream uses vary seasonally. Thus, it will be more useful to consider the water balance of the reservoir on a seasonal basis. But because of the recent change in the regime of the Euphrates River flow in Iraq, as a result of operating Keban and Tabqa Reservoir, and due to unavailable stable seasonal flow data, it is difficult to assign figures of river inflow and then calculating the water balance of the reservoir on a seasonal basis. However, it is possible to estimate the annual water balance of the reservoir, because data of the average annual flow of the Euphrates River is known, and the approximate annual requirement for water in both Turkey and Syria is known. For these reasons, the estimation of the water balance of the reservoir will be on an annual basis. The same methodology could be used for any period of time, if data are available.

The calculation of the water balance elements could be done either numerically by using a computer model, or analytically by using some of the analytical mathematic equiations which are applicable to the physical, hydrological conditions of the reservoir. A third method is building of electrical analog model. Applying finite difference scheme, or finite element approach and writing a computer program for the reservoir and aquifer characteristics, will give an idea of the present and future changes in the parameters of the reservoirs and aquifers in the area. The shortage of available data on the large reservoir makes it difficult to construct a computer program. Building an electrical analog model is expensive and at the same time requires more data than the available data at the present. Thus, for the purpose of this study, it is appropriate to use an analytical mathematical method for calculating the components of the water balance equation and equating them.

Elements of the Water Balance

In general, the water balance of a given volume of soil or space consists of the inflow, outflow, and change in storage of water during a specified period of time. It is represented by the following equation:

Inflow - Outflow = change in storage

Inflow: The inflow to the Haditha reservoir consists of:

a. Euphrates River flow into the reservoir;
b. Precipitation on the reservoir surface; and
c. Discharge from bank storage.

A separate description and calculation of the above elements are presented later in the paper.

Outflow: The outflow of the Haditha reservoir consists of:

a. Releases for downstream uses;

b. Evaporation losses; and
c. Seepage losses.

Change in Storage: The change in storage is equal to the increase or decrease in the volume of water stored in the reservoir.

Water Balance Calculations

Inflow to the Reservoir

Different quantities of the Euphrates River inflow to Haditha Reservoir were estimated. As mentioned in a report by Technopromexport (1974), the average annual inflow to the reservoir is expected to be between 15 and 68 km^3. According to the Swedish Firm (VBB) in their "Euphrates Dam Project Report" in 1964, the inflow to Iraq will be 13.44 km^3 and the inflow to the river from the Syrian-Iraqi border to the Haditha project will be 0.4 km^3, resulting in a total of 13.84 km^3 as river inflow to the reservoir. In a report written by the Directorate General of Dams and Reservoirs in Iraq in late 1975 (Iraqi Ministry of Irrigation, 1975), it was calculated that the amount of river flow entering Iraq in 1985 will be 17.8 km^3 and by 1995 it will be 14.8 km^3. Also, the report gives the inflow of the Euphrates River to Iraq (in the dry years) as 6.9 km^3 at probability of 90% and 8.5 km^3 at probability 75%. On the above considerations an annual inflow of 14.0 km^3 could be reasonable and that will be used in the following considerations.

The average annual precipitation on the reservoir surface will be 112 mm. The average area of the reservoir will be 418 km^2. The product of the two gives the annual amount of water added directly to the reservoir from precipitation as 0.047 km^3, which is insignificant.

With the normal fluctuations of the reservoir level during filling, water will infiltrate into the alluvium of the banks and as the water in the reservoir is lowered water may be discharged back into the reservoir. It is considered as returned seepage losses. According to Harza Engr. Co. report (1963) bank storage was experience in Dokan Reservoir in the north of Iraq amounting to 10% of the reservoir storage. But the topography of Dokan is much different from Haditha. A reasonable estimate of bank storage may be 3% of the reservoir capacity. Assuming a specified yield of 10% and using estimates of the volume of alluvium that may desaturate, the recharge to the reservoir may be of the order of 0.1 km^3 -- again, a small percentage of the river inflow to the reservoir.

The total inflow to the reservoir may be estimated as 14 km^3.

Outflow from the Reservoir

As reported in 1965, the area of agricultural land that depends on the Euphrates River was estimated at 846,700 hectares. Each hectare requires about 17,400 m^3 of irrigation water. Therefore, the total irrigation requirement is 14.7 km^3. The requirement for power is less than this amount, so it is assumed that 14.7 km^3 of water will meet both irrigation and power requirements.

Evaporation

The rate of evaporation is a function of solar radiation, difference in vapor pressure between the water surface and the overlying air, temperature, wind, atmosphere pressure, and water quality. The estimation of evaporation from a reservoir is generally based on a water budget, energy budget, mass transfer techniques, or pan evaporation data. The choice of method used depends on available data and required accuracy. Because of data restriction only the pan evaporation method and a method previously used by Technoexport were used.

A widely used method of estimating reservoir evaporation is from evaporation pan data. The standard U.S. Weather Bureau Class A Pan is the most popular. Relationships developed between pan and actual evaporation from large bodies of water indicate multiplying the pan value by a factor of 0.70 to 0.75 (pan coefficient) gives an approximation of lake evaporation (Viessman, Harbaugh and Knapp, 1972).

The total evaporation losses from a reservoir is the depth of evaporated water times the surface area of water in the reservoir. The surface area of the reservoir is changing according to the water level in the reservoir. Table 13 shows the surface area of the Haditha Reservoir at different water levels as calculated from topographic maps with a scale of 1:2500, and Table 14 presents the depth of water for different distances from the center of the Euphrates just above the proposed dam site. At designed normal head water level for the months of January through June, the average water surface area is 418.4 km^2.

Table 13. Water Elevation Versus Surface Area at the Reservoir

Elevation (m) above MSL	Normal HWL (143)	140.0	135.0	129.5 operation level	125.0	120.0	115.0	112.0 Maximum drawdown
Surface area (km2)	418.4	352.4	273.7	220.0	161.0	115.1	75.8	35.0

Table 14. Depth of Water against Distance from the Euphrates at Dam Site (Right Side)

Distance (km) from Euphrates	G.S. (above MSL) (m)	Depth of water (m) at N.H.W.L.
0 - 1.00	105 - 115	38 - 28
1.00 - 2.00	115 - 135	28 - 8
2.00 - 3.00	135 - 140	8 - 3
3.00 - 4.00	140 - 150	3 - 0

As estimated by Technoexport (1971), the evaporation losses for these months is 1100 mm, which is equivalent to 0.46 km^3. At operational drawdown level, for the months of July through December, the surface area is 220.0 km^2. The evaporation during these months was estimated at 1400 mm. The total evaporation during this period is estimated at 0.31 km^3. Some additional evaporation will occur from the land surface previously flooded by the reservoir. These additional evaporation losses, as reported by Hydroproject Institute (1971), result in an evaporated volume of 0.5 km^3. Then the total water losses by evaporation amounts to 1.27 km^3.

The annual evaporation from the reservoir surface calculated using pan evaporation data presented in Chapter 3 from the Desert Development Station (1976) yields a depth of evaporation of 3278 mm and total annual losses of 1.67 km^3.

An average of the two above values would be the best estimate possible at this time, or 1.47 km^3 per year.

Seepage Losses

The elevation and gradient of the regional ground water table and aquifer characteristics, adjacent to the proposed reservoir, provide the most reliable means of predicting reservoir leakage. If the ground water levels are higher than the proposed reservoir level then one can predict no seepage of consequence, except perhaps near the reservoir banks as the reservoir level fluctuates.

If the regional ground water level is appreciably lower than the proposed reservoir and there is adequate permeability, as the case we have under Haditha reservoir, a careful study should be made before proceeding with the more expensive portions of the investigations.

There are many uncertainties in Haditha reservoir study. The unstable regime of the Euphrates River flow, insufficient ground water hydrological data, and inhomogeneity of the reservoir geological condition cause some difficulty in estimating seepage losses, and may give misleading results.

In dealing with a fractured rock (or karst) aquifer, hydrologists cannot always neglect the vertical hydraulic conductivity. In such aquifers, the vertical hydraulic conductivity may be appreciable. Knowledge of the vertical hydraulic conductivity of a fractured rock aquifer may be useful information in itself, especially with respect to estimating ground water recharge and pollution movement (Davis and DeWiest, 1966).

The geological characteristics of the reservoir as described previously, and the topography of the area, help us to assume the following in order to simplify analytical solution (see Figure 5). The upper layers of the reservoir (Euphrates series, $N_1^1eu_1$, $N_1^1eu_2$, and $N_1^1eu_3$) have similar physical properties. They are the layers above the water table in which seepage will take place, in general, they are weak, cavernous, and karsted.

The bulk density of these layers ranges from 1.57 - 2.69 t/m^3. The porosity is 44% and the hydraulic conductivity ranges from

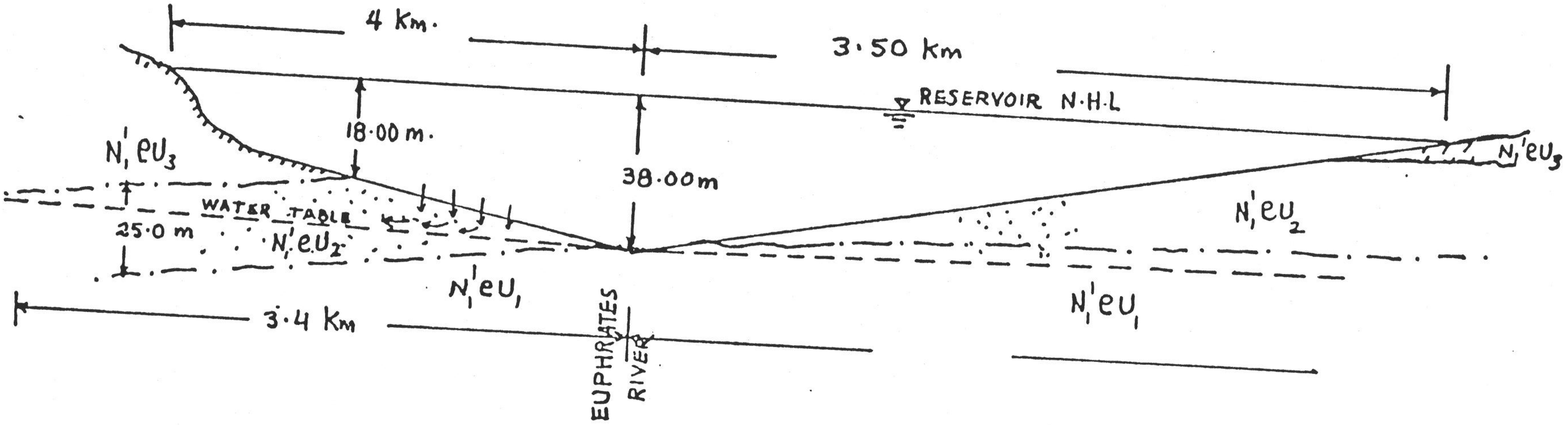

Figure 5. Cross Section at Dam Site Showing Head and Seepage Layer

3.7 - 48.5 m/day, so an average value of 28 m/day will be used. The hydraulic conductivity values were obtained by pumping tests for boreholes in the reservoir area.

The formulas applied by the Hydroproject Institute (1971) for calculating hydraulic conductivity K was:

$$K = \frac{0.73\ Q}{(2H-S)S} \log \frac{R}{r}$$

in which

H = thickness of aquifer (layer)

S = drawdown

R = radius of influence

r = well radius

Q = steady discharge

Another way of estimating hydraulic conductivity is by injection (pouring) water into the borehole. The following formula was used:

$$K = 0.525\ q \log \frac{0.661}{r}$$

q = specific discharge

It was noted that values of hydraulic conductivity gained by injection method were less than those gained from pumping tests which was probably due to sealing.

In this study, concern is given to estimating the quantity of seepage from the reservoir in its first period of operation, and the time it takes to saturate the bed and banks of the reservoir.

The water from the reservoir is assumed to flow in two directions, vertically in the first stage until it encounters the water table and then it flows horizontally until it saturates the medium above the water table and below the level of the reservoir water.

Green and Ampt's approach for infiltration is convenient. The principal assumptions of the Green and Ampt approach are that there exists a distinct and precisely definable wetting front, and the matrix suction at this wetting front remains effectively constant, regardless of time and position (Hillel, 1973). Furthermore, this approach assumes that behind the wetting front, the soil is uniformly wet and of constant conductivity. This supposes the K vs Θ (water content) relation to be discontinuous, i.e., to change abruptly at the suction value prevailing at the wetting front.

These assumptions simplify the flow equation, making it amenable to analytical solution. For horizontal infiltration (i), a Darcy type equation can be applied directly:

$$i = \frac{dI}{dt} = K \frac{H_o - H_f}{L_f}$$

where

i is the flux into the soil and through the transmission zone,

I is cumulative infiltration,

K is the hydraulic conductivity of the transmission zone

H_o is hydraulic head at the entry surface,

H_f is hydraulic head at the wetting front, and

L_f is the distance from the surface to the wetting front (the length of the wetting zone).

In case Θ_o (initial water content) is sufficiently small, the gravitational field will not cause it to vary appreciably with z (DeWiest, 1969). Thus, the same analytical solution will be applied for vertical and horizontal flow.

Since the distance travelled by vertical flow is very short (maximum 20 m), the time of saturation of this volume beneath the reservoir is negligible in comparison to the time taken for horizontal flow in the adjacent zone (distance 2600 m). Thus, the calculations were made for horizontal flow only. Horizontal flow mostly will take place in the upper part of the unsaturated flow which has hydraulic conductivity in some places up to 48 m/day, however, an average hydraulic conductivity of 28 m/day is reasonable and was used in the calculation.

Maximum amount of water absorbed by the soil is given by:

$$Q = SA\frac{dx}{dt} \tag{1}$$

where

S = storage coefficient

A = cross-sectional area

$\frac{dx}{dt}$ = rate of change of wetting front in the horizontal direction

and from Darcy's Law:

$$Q = KAI = KA\frac{\Delta H}{L_f} \tag{2}$$

where

K = hydraulic conductivity

A = cross-sectional area

I = hydraulic gradient

L_f = distance of wetting front from reservoir.

Since the flow is horizontal only, there is no effect of the elevation head z on the pressure.

Thus,

$$Q = KA \frac{H_o - H_f}{L_f}$$

Substiting L_f for x in equation (1), and equating with equation (2)

$$SA \frac{dL_f}{dt} = KA \frac{H_o - H_f}{L_f} \ ; \ H_o - H_f = \text{const.}$$

$$\frac{L_f dL_f}{H_o - H_f} = \frac{K}{S} dt$$

By integrating both sides of the equation:

$$\int_o^{L_f} \frac{L_f dL_f}{H_o - H_f} = \int_o^{t_1} \frac{K}{S} dt$$

$$\frac{L_f^2}{2(H_o - H_f)} = \frac{K}{S} t_1$$

$$t_1 = \frac{L_f^2 \cdot S}{2(H_o - H_f)K} \tag{3}$$

where t_1 is the time required to fill the unsaturated zone to a distance L_f from the reservoir. Theoretically, water will continue to move horizontally due to pressure gradient until the regional water table reaches a certain shape.

Estimation of quantity of water that will seep from the reservoir to saturate the unsaturated zone above the water table, and the time required to fill the volume in the vicinity of 4 km at the sides of the reservoir are of interest.

The zone to be saturated is assumed to be 130 km in length, 8 km wide and 12.5 m deep and has a porosity of 0.40. Hence, the total volume of water required to saturate this volume is 5.2 km^3. Using equation (3) and an assumed value for H_o-H_f of 3 m, the time required to completely fill this volume is calculated using the above equation to be 4023 days (11.5 years). The average seepage rate for the 11.5 years is 0.47 km^3/year, or 8% of the storage capacity of the reservoir.

Complete Water Balance

The calculated inflows and outflows on an annual basis are given in Table 15. The estimated amount for dam releases is 14.64 km^3, while the calculated amount by the water balance method is 12.70 km^3. Of this, 1.94 km^3 must be allocated to maintain minimum flows to the Gulf. Therefore, only 10.76 km^3 are available for irrigation. This is less than the estimated required amount by 1985 (17.8 km^3) by 7.04 km^3, and less than the requirement of year 1995 (14.7 km^3) by 3.94 km^3.

To meet the requirements of irrigation other water resources to the Euphrates River must be found. The most convenient solution is the diversion of the Tigris River flow to the Euphrates River via the Tharthar depression. The anticipated annual volume of flow supplied from the Tharthar depression to the Euphrates River ranges between 0.75 to 11.75 km^3 (Iraqi Agricultural Council, 1974), depending on the flow

Table 15. Summary of Annual Water Balance

Balance Component	Value (km^3)
River flow to reservoir	14.40
Precipitation on reservoir surface	.047
Bank storage discharge	0.19
Annual Total Inflow	14.64 km^3
Evaporation losses	1.47
Seepage losses	.47
Dam releases	12.70
Annual Total Outflow	14.64 km^3

of the Tigris. The regulating capacity of the Tharthar depression may be sufficient to meet irrigation requirements, at least during some years.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

The Euphrates River is undergoing a critical period of its history with the new dams in operation in Turkey and Syria. To adjust to the new regime of the river as it enters Iraq, the Iraqi Government is giving serious consideration as to the most feasible approach to maximize the use of the reduced flows of the river. An additional regulating reservoir on the river seems imperative. However, the topography and geology of the Euphrates valley do not offer good dam and reservoir sites. The feasibility of a reservoir depends greatly upon its capacity and evaporation and deep seepage losses from the reservoir. This study has provided a rough approximation of these losses in relation to the other components of the water balance for the proposed reservoir above Haditha.

Precise calculation of the water balance components have not been possible, first because of scarcity of data and second because of the complex and heterogeneous geological conditions. Climatological data near the proposed site are for a short number of years and some are of questionable accuracy. Data were not adequate to use some of the more sophisticated methods of predicting evaporation, so an estimate was made based on two years pan evaporation data.

Seepage may pose a critical threat to the feasibility of the reservoir for two geological reasons: (1) the geological structure, which no doubt has caused openings along fault or joint planes in the carbonate rocks resulting in advanced karstic conditions in some sections, and (2) the geochemistry, because of continued solution and decomposition after the reservoir is filled of the gypsum and carbonate rocks, especially where circulation of meteoric waters occurs.

Although consulting firms have drilled several exploratory boreholes in the vicinity of the proposed reservoir, the data and observations are not sufficient to adequately describe the lithological structure along the 130 km reservoir length. Available data have been used in a simplified approach to approximate deep seepage losses into strata which are now unsaturated and above the present river level but will be submerged when the reservoir is filled. These are highly porous strata with a sizeable hydraulic conductivity and water holding capacity. Several approximations and assumptions were made, but the results are considered of the right order-of-magnitude. Thus, for better evaluation of this problem additional geological field work and test drilling are recommended.

Table 15 in the preceding chapter gives a summary of the approximated water balance for the reservoir. The annual evaporation losses from the reservoir has been estimated as 2888 mm, which is equivalent to 1.47 km^3/year. This is 23% of the storage capacity of the reservoir, 10% of the total inflow.

The expected lateral seepage from the reservoir has been shown to average 0.47 km^3 per year for 11.5 years after the reservoir is filled. The total volume of seepage during the 11.5 years is nearly equal to the storage capacity of the reservoir. After this time, the regional ground water profile would have adjusted resulting in recharge to the reservoir. A critical question remains as to the seepage around the dam through these porous strata. This question was not considered in this study.

Sediment coming into the reservoir, which has been estimated to be 60 million tons per year, may reduce the life time of the reservoir and reduce the rate of seepage losses extending the period of seepage beyond the 11.5 years but the total amount of seepage should remain the same.

The water balance definitely shows that the quantity of water available for releases will not be sufficient to meet expected irrigation requirements on the Mesopotamian Plain. Supplemental water can be diverted from the Tigris to account for the deficiency. If the reservoir comes into existence, it is important that operating rules be developed which will minimize spills through the spillway to more effectively use this water resource.

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BINED RELATION CURVES OF WATER DISCHARGES AND S [illegible] ENT
CONCENTRATION VARIATIONS IN THE EUPHRATES RIVER [illegible]
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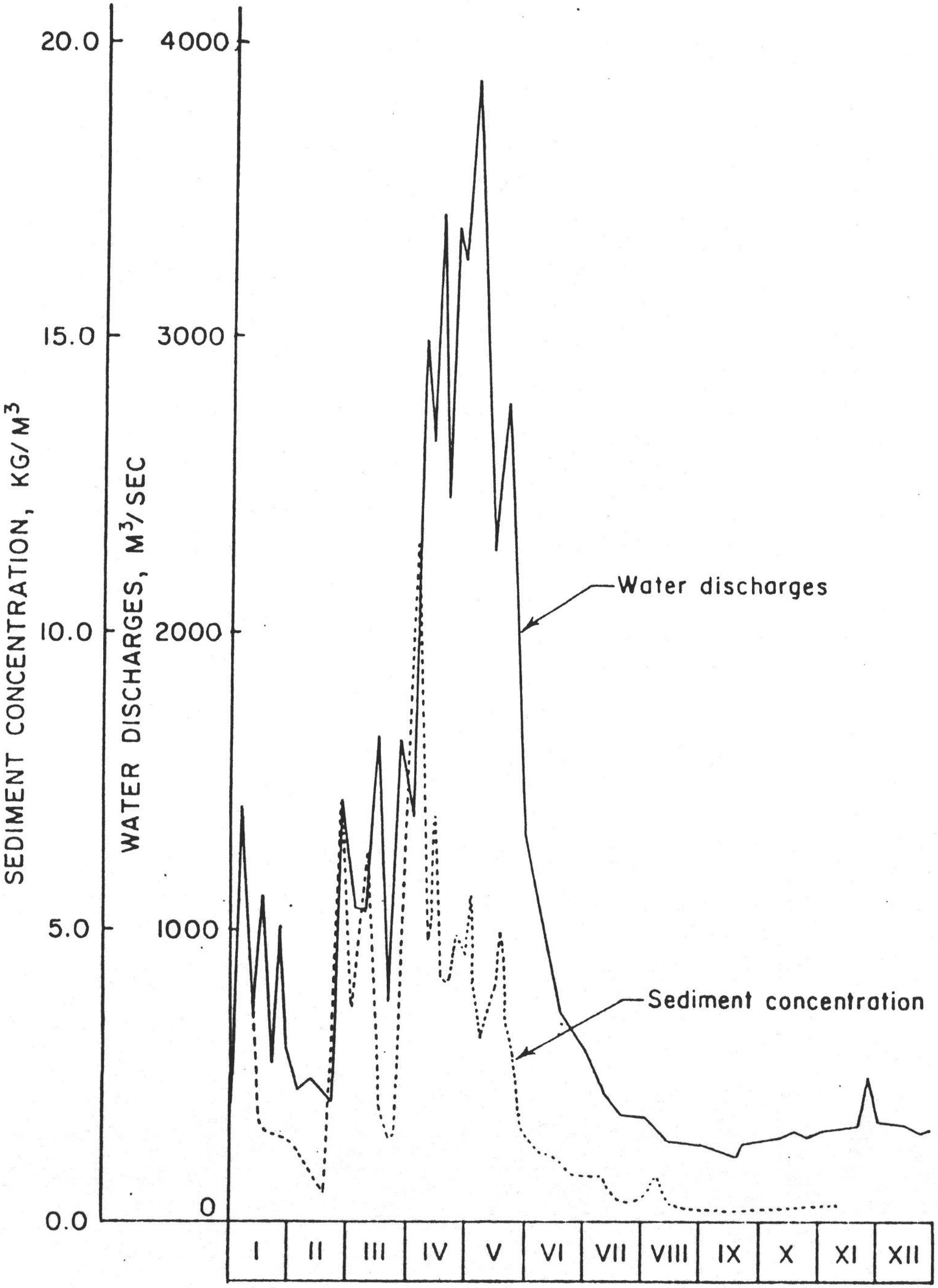

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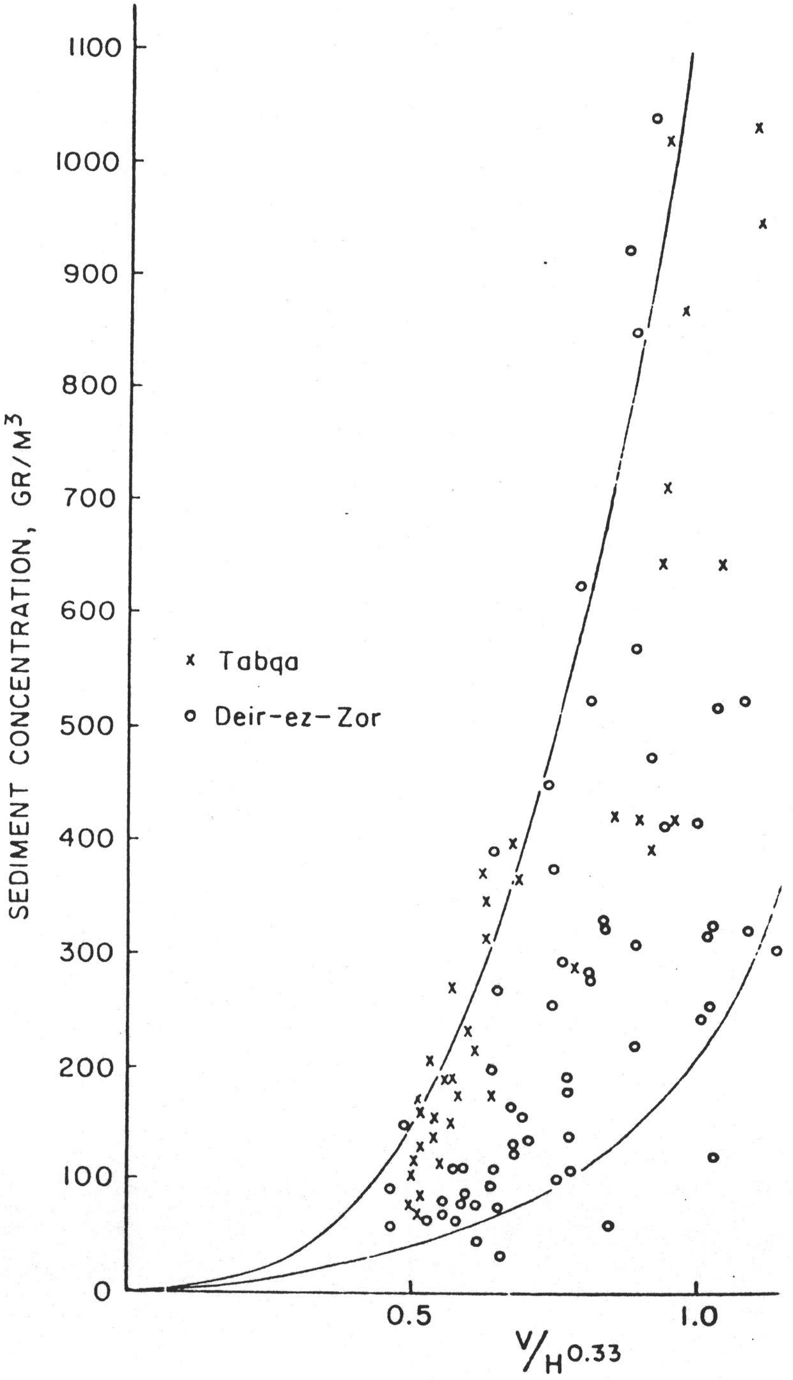

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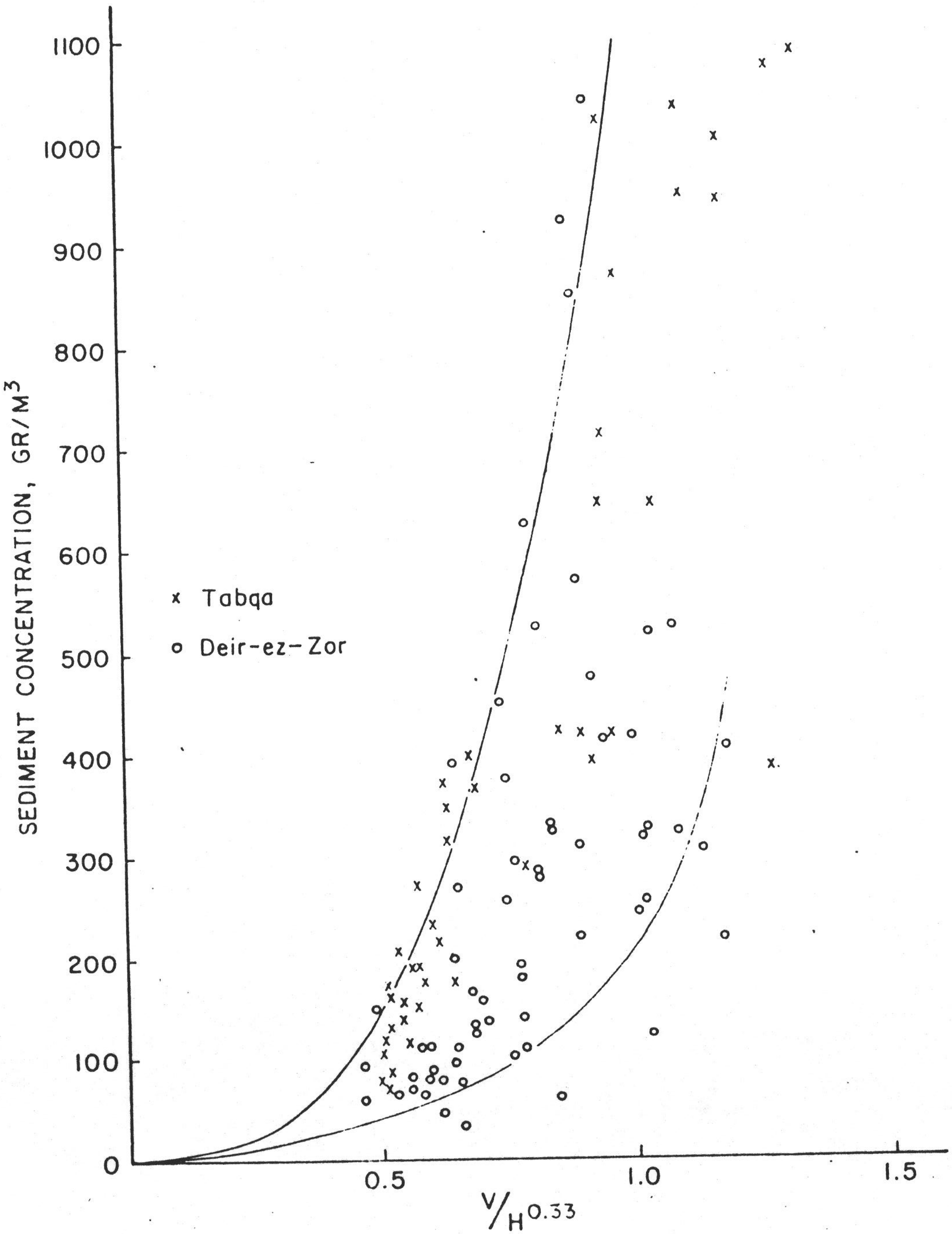

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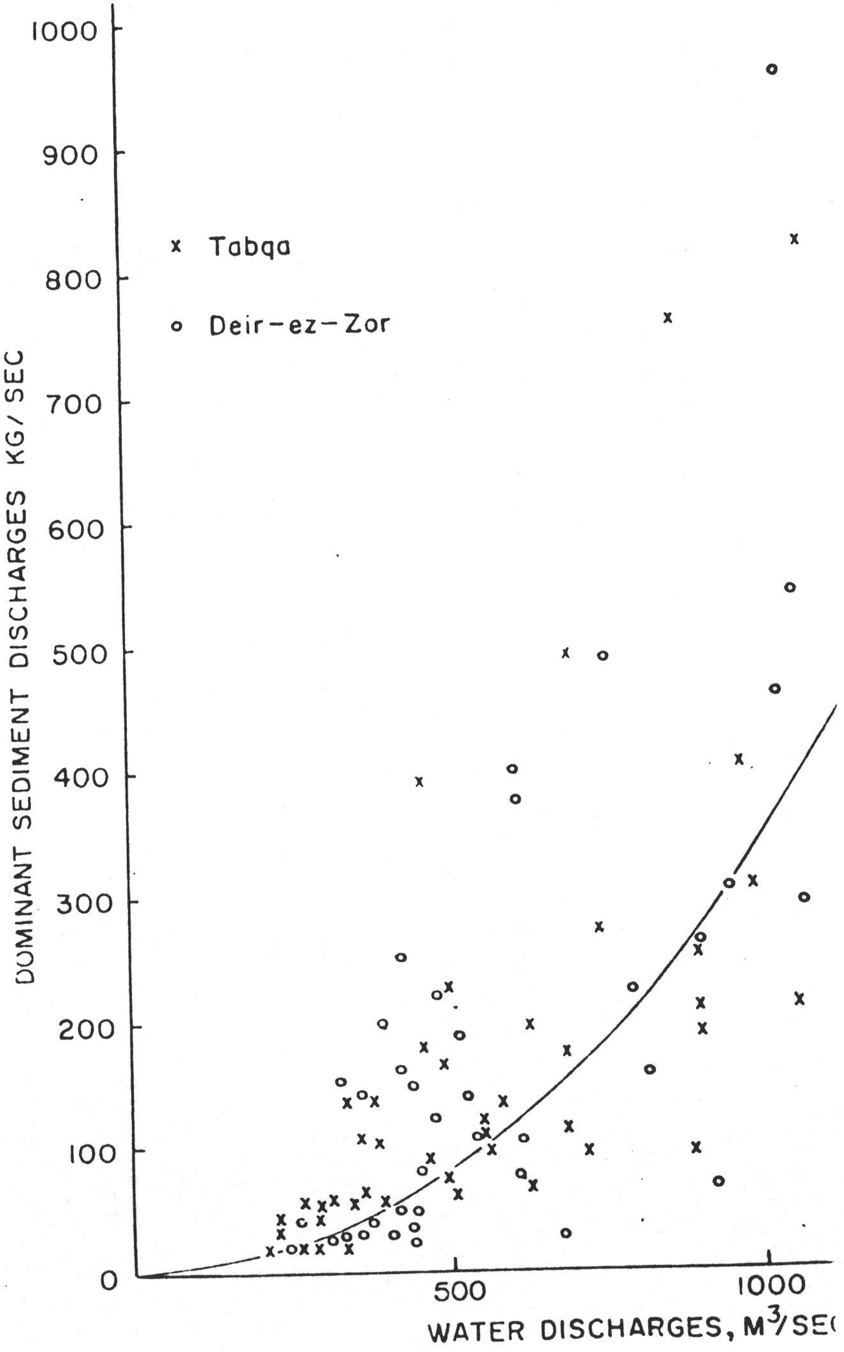

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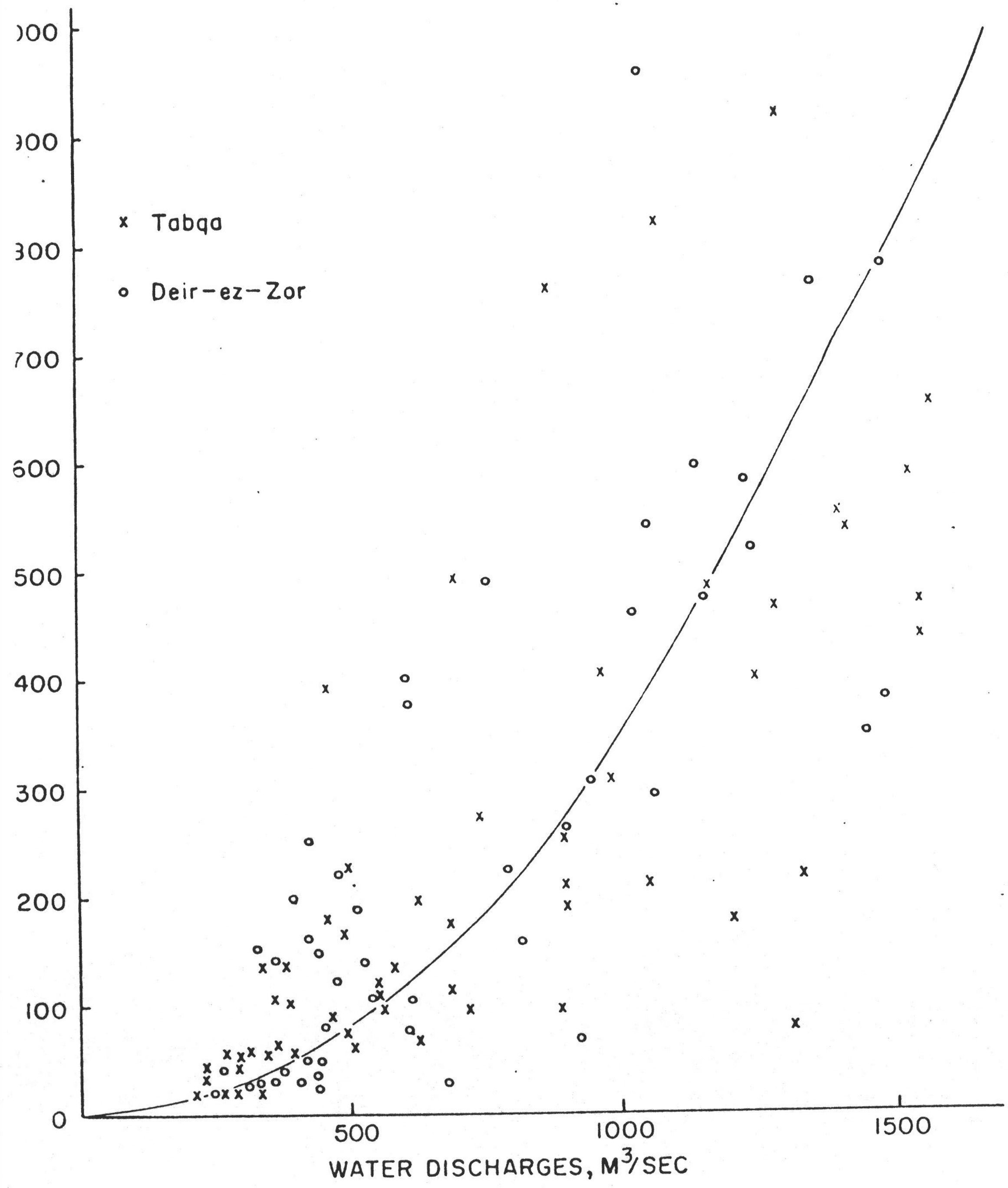

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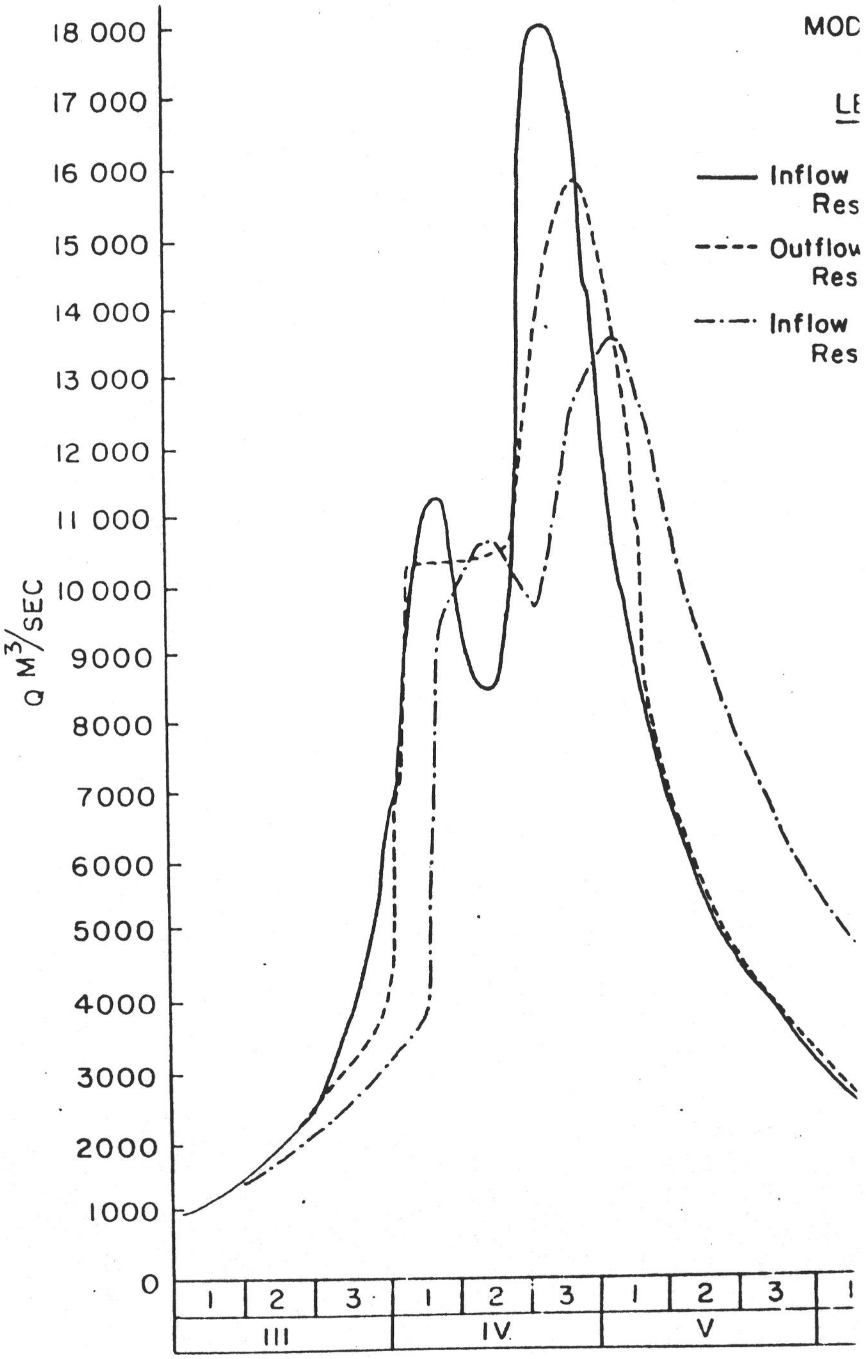
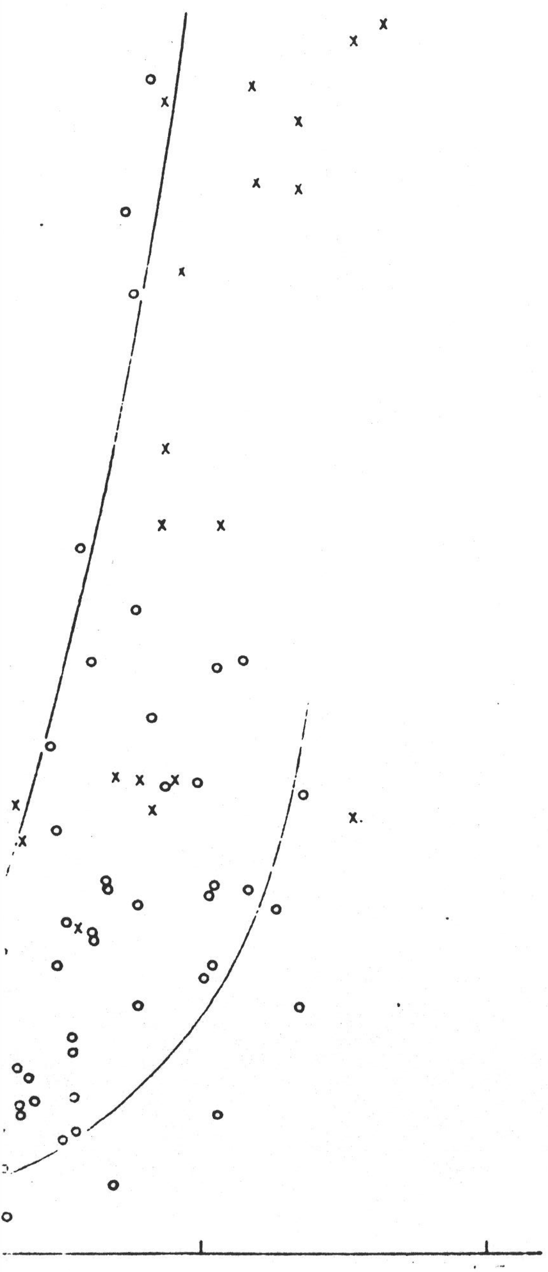


FIGUR_ 6. HYDROGRAPHS OF THE EUPHR . ES RIVER AND SEDIMENT CONCE ATION

SEDIMENT FRACTIONS CONCENTRA-
AGE WATER VELOCITY AND
RATES RIVER



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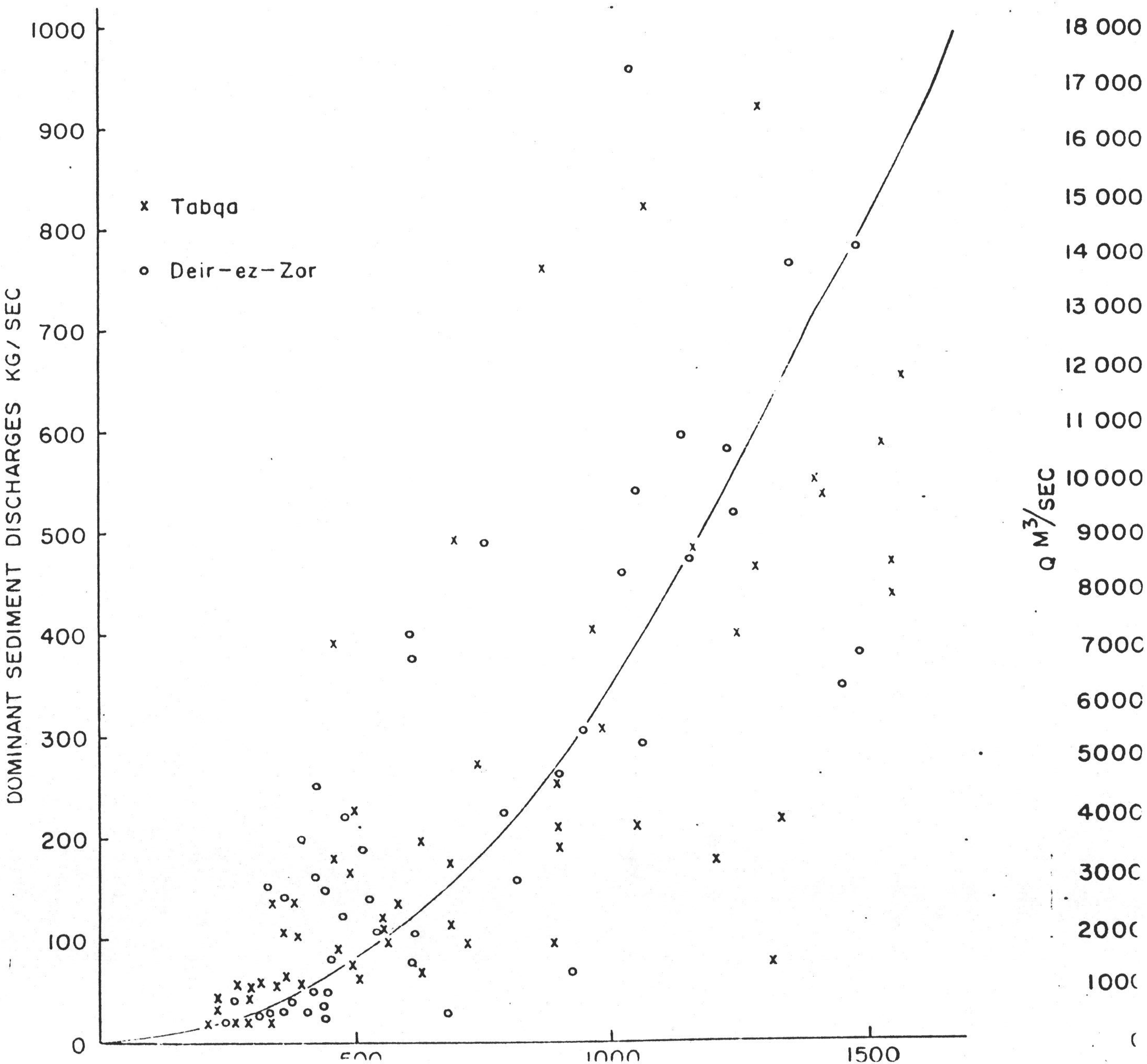

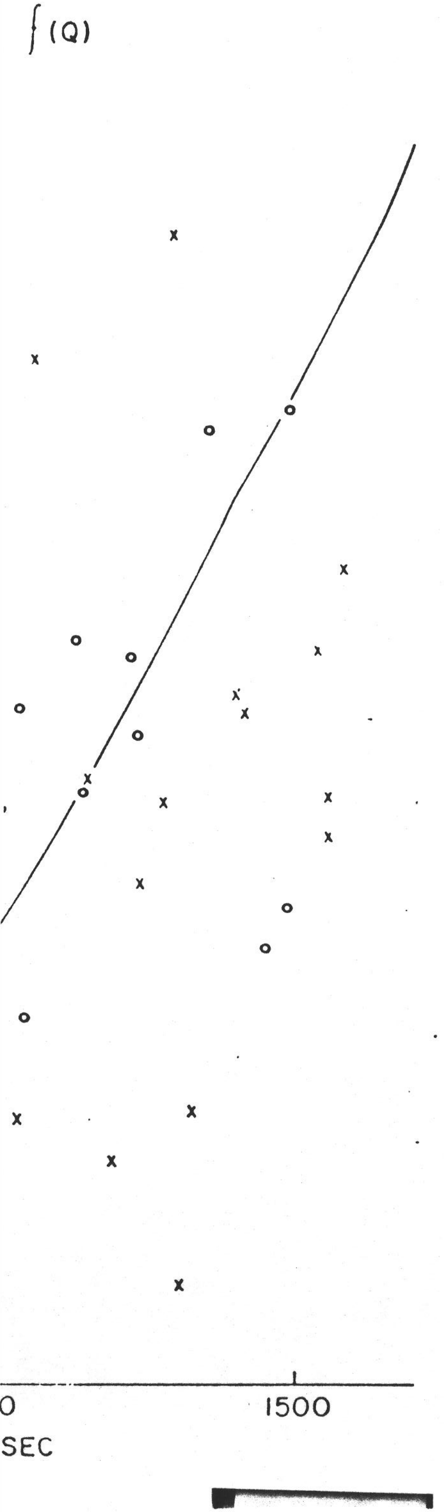

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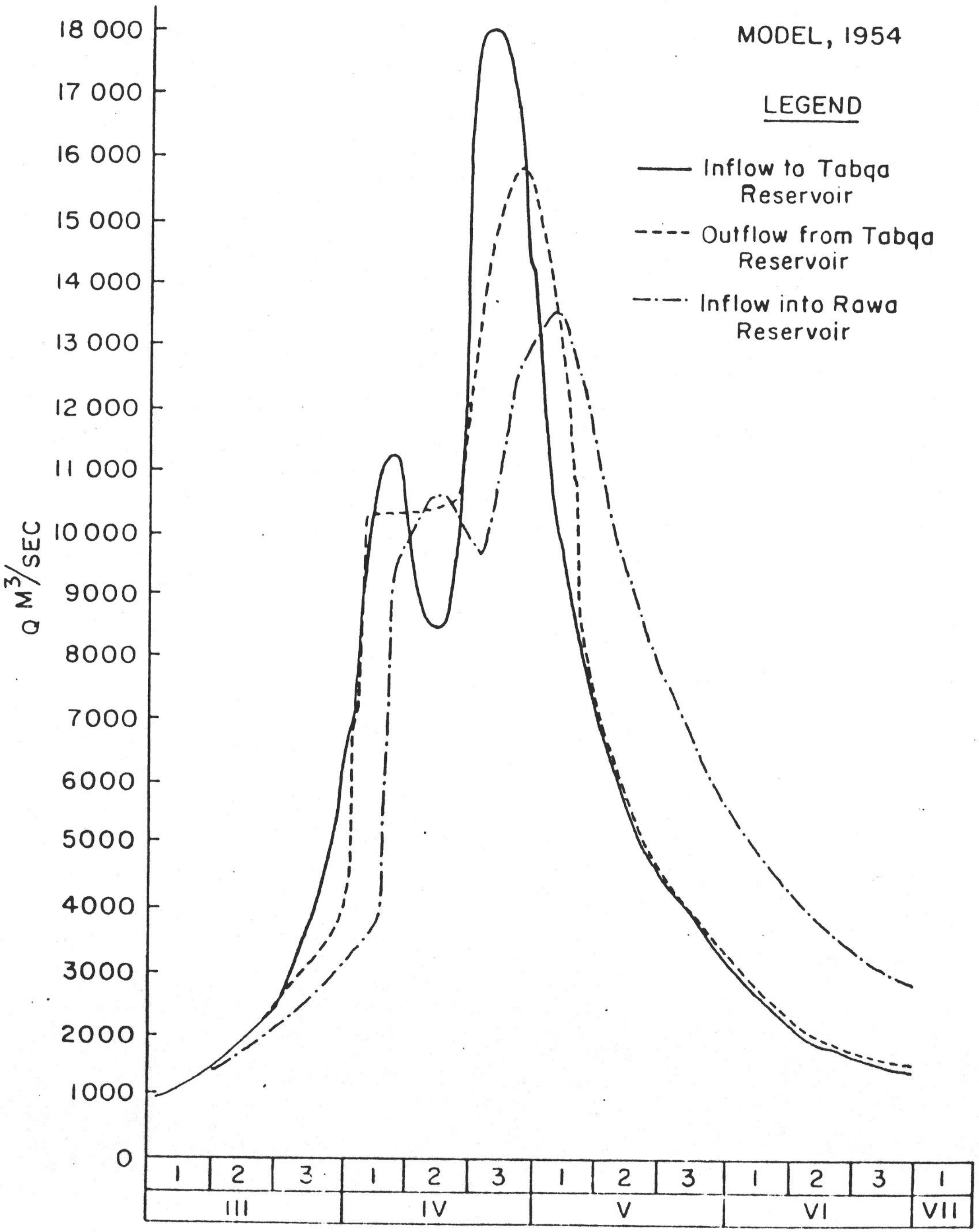
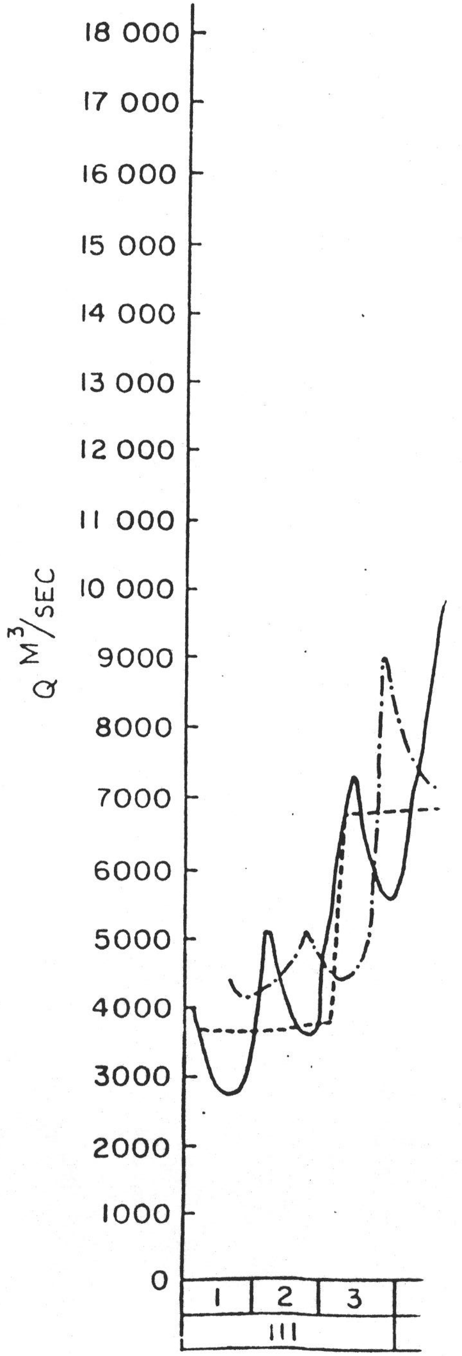
INFLOW TO RAWA RESERVOIR, OF 0.01 PER CENT FREQUENCY WITH GUARANT





S OF INFLOW TO TABQA RESERVOIR, OUTFLOW FROM TABQA RESERVOIR, AND
VA RESERVOIR, OF 0.01 PER CENT FREQUENCY WITH GUARANTEE CORRECTION