Contributions to Water Management in Iraq

Thesis

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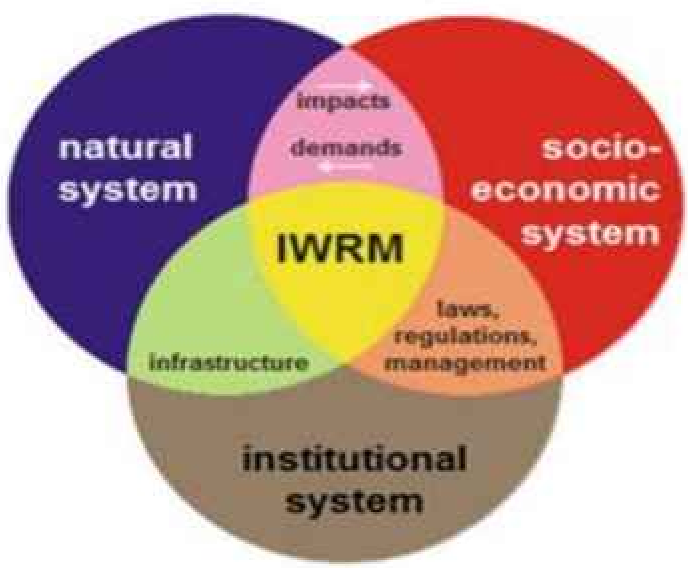
Chapter one

INTRUDUCTION

Integrated Water Resources Management

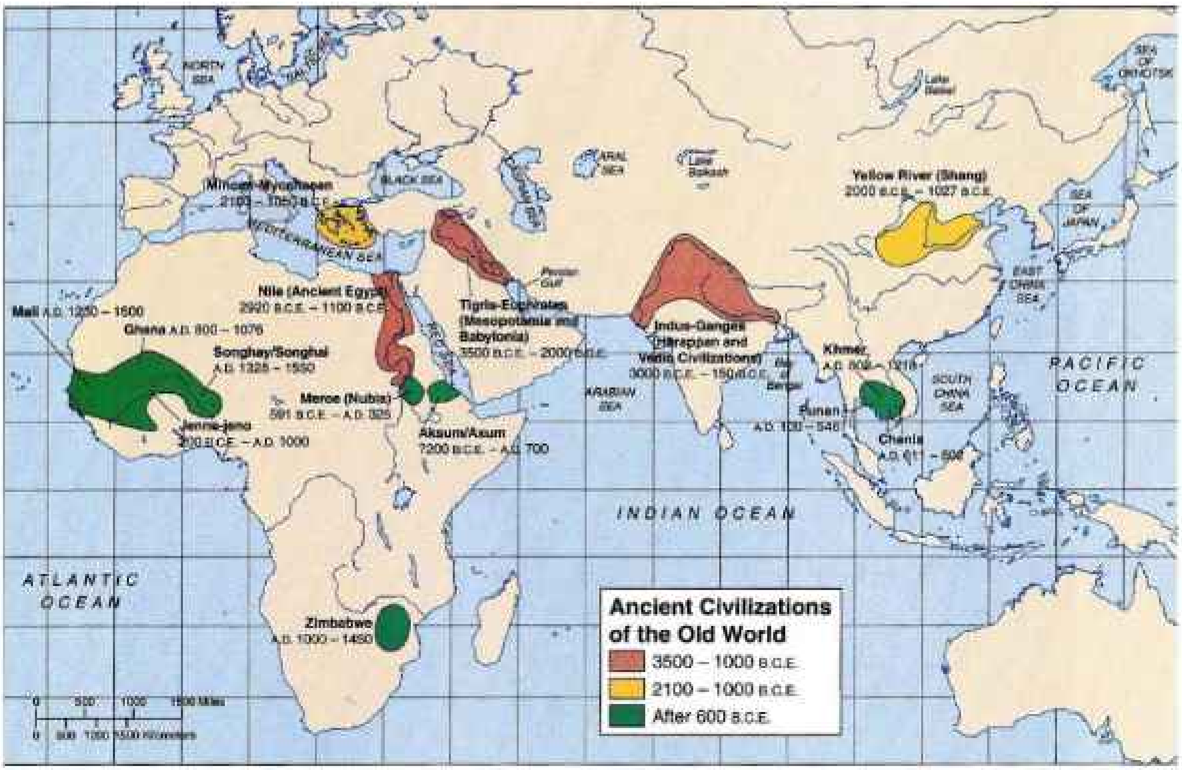
IWRM is an acronym for Integrated Water Resources Management, which refers to a procedure that aims to develop and assist all of the improvements and optimal management of water, arrive, and associated sources. In order to achieve the desired level of economic and social growth in an equitable manner and without jeopardizing the long-term viability of the crucial roles played by ecosystems, this agreement was made. Over the course of the last several decades, the idea of integrated water resources administration, often known as IWRM, has been developing. IWRM is the response to the increasing weight on our water resources systems that is produced by obviously expanding population ratios and socioeconomic advancements. This weight is developing as a result of the fact that our population ratios are growing. Many countries throughout the globe have been forced to reevaluate their plans for technological growth in relation to the management of their water sources as a result of water shortages and a decline in the quality of their available water supplies. As a result, water resources management (WRM) is going through a transition all over the world. This transition involves shifting away from an approach that is primarily supply-oriented and engineering-biased and toward an approach that is demand-oriented and multispectral. This type of approach is typically referred to as integrated water resources management. The idea of integrated water resource management shifts away from top-down "water master planning," which typically focuses on water availability and development, and toward "comprehensive water policy planning," which addresses the interaction between various subsectors, seeks to establish priorities, considers institutional requirements, and deals with the building of management capacity. In other words, IWRM shifts away from top-down "water master planning" and toward "comprehensive water policy planning.". *(Daniel P. Loucks, 2016)*



Interactions among the natural, administrative, and socioeconomic water resource subsectors and between them and their environment

Historical overview of ancient water systems in Mesopotamia

Mesopotamia was the term given to the territory of Iraq that was located in Europe during the time of the ancient Greeks. It is a historical area in western Asia that is situated in the northern section of the Fertile Crescent inside the Tigris and Euphrates River system. It now holds territory in what is now Iraq and Kuwait, in addition to portions of Iran, Syria, and Turkey. Beginning about 10,000 B.C., Mesopotamia was the location of some of the first innovations of the Neolithic Revolution. It has been credited with serving as "the inspiration for some of the most significant advances in human history, including the creation of the wheel, the cultivation of the first grain crops, the development of continuous line, mathematics, astronomy, and agriculture." It was considered to be one of the world's oldest civilizations at the time.(*Web Reference 1, 2021*)



Ancient Civilizations of the Old World 3500 to after 600 BCE

Mesopotamia's plains are very flat (Varoujan K. Sissakian, 2020), have poor drainage, and are subject to a severe climate; as a result, the region has always struggled with problems such as poor soil, drought, frequent flood waves, silt accumulation, water logging, and salt accumulation. These issues have persisted since the region was first inhabited. The floods were unexpected and destructive, causing the destruction of several settlements and the loss of many lives (Frenken, 2009). Rivers have been known to branch out or take different paths as a result of floods. Rivers that have altered their courses have caused a great deal of damage to the crops grown by farmers. (*Mukhalad Abdullah, 2020*).

The irrigation systems used in Mesopotamia

Objectives

The main objectives of this thesis are:

- To determine the spatial and temporal changes in water quantity in Iraq.
- To identify the reasons for these changes.
- Analysis of the hydrological data of the water resources system in the Tigris and Euphrates basins inside Iraq.
- Operation of water resources in the Euphrates and Tigris basins through the dams and reservoirs.
- The high deficit in the supply of water resources due to the increasing demand.
- Obstacles and goals achieved from operating the Tigris and Euphrates basins system.
- Conclusion and Recommendations.

Chapter two

WATER RESOURCES IN IRAQ

The Tigris River and the Euphrates River combined account for 98 percent of the total water resources in Iraq. This means that the water resources in Iraq are mostly concentrated in these two rivers. The Euphrates and the Tigris are two of the three biggest rivers that flow through the region that is colloquially known as the Middle East. The availability of water in this region is significantly impacted by the contributions made by these two rivers. These two rivers, together with the Nile, are the only ones in this region that meet the criteria for being considered big by global standards. The Euphrates and the Tigris, in addition to some of the rivers' tributaries, have their beginnings in the mountainous regions of Turkey and run through an area that is located between 45 and 25 degrees North latitude. The Euphrates River flows through Syria before entering Iraq and joining forces with the Tigris River, which also flows through Syria. Together, these two rivers create Shat Al Arab in the southern part of Iraq and flow a combined 190 kilometers before emptying their waters into the Gulf.

Before water shortage, Iraq thrived with efficient irrigation systems and flood control structures. The first flood control (date unknown) structures were built on the Habbaniya and Abu Dibbs lakes (now it is called Al Razaza), followed in 1911 with the construction of the Al Hindiah Barrage on the Euphrates (*Frenken, 2009*).

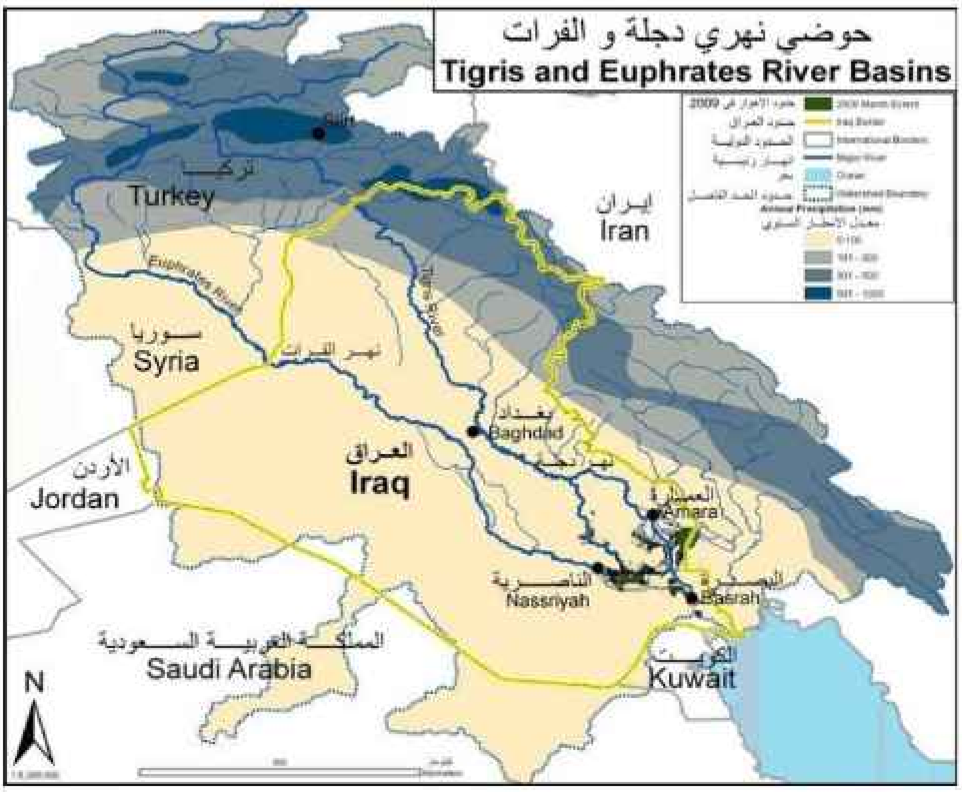
About 80 to 84.2 billion cubic metres of water pass through the Euphrates and Tigris Rivers each year. Of this total, approximately 65.7 billion cubic metres come from Turkey, 11.2 billion cubic metres come from Iran, 6.8 billion cubic metres come from Iraq, and 0.5 billion cubic metres come from Syria (different authors has given somewhat different numbers). Countries that are bordered by the two rivers often get the majority of their water supply from them. Iraq's water resource management system has been compromised as a result of the water policies of upstream nations, as well as more than three decades of war in Iraq, sanctions, and degradation of infrastructure, mixed with low environmental awareness. In Iraq, the deterioration of water quality, the decline in water flow rates, and the loss of important rivers, all of which are shown in figure 2.3, are having an influence not only on people's day-to-day life but also on the aquatic system and other creatures in the country. (*Mohamed Abd-El-Mooty, 2016*)

The drought in Iraq

In the most recent few decades, Turkey has had a tendency to create its water usage plans unilaterally, without due regard for the environment and the real water potentiality of the river basin. As a result, Iraq and occasionally Syria have experienced a serious lack of available water. Utilizing the country's rivers to generate hydroelectric power and provide agricultural water are two of Turkey's primary goals. In the 1960s, they initiated a brand-new enterprise that they dubbed GAP there. This initiative was first conceived with the intention of supplying Turkey's most impoverished municipalities with irrigation water and electrical power. It entails the building of around 19 hydroelectric power facilities and 22 new dams on the Euphrates River alone. (*ALTINBILEK, 2004)*.

Main rivers system

The Tigris and Euphrates rivers are the most important water sources in Iraq. The Tigris River has a river basin size of 126,900 km2, while the Euphrates River basin area is 177,600 km2 and neither river has any tributaries (Frenken, 2009). Both of these rivers have their headwaters in the mountainous regions of Turkey, and they are similar to one another in terms of their geography, climate, hydrology, and geology (figure 2.4). However, there are a few distinct schools of thought on how to approach the management of these two river basins, and a few experts consider these rivers to be identical twins. Therefore, it is advantageous to regard them as belonging to a single basin for the purposes of integrated water resources management (Kliot, 2005). It is important to keep in mind that the flow patterns and flow rates of the Tigris and the Euphrates are distinct from one another.



Tigris and Euphrates river's basin

Chapter 3

WATER INFRASTRUCTURES

Since the beginning of recorded history, Iraq has been known across the world for the irrigated farmland that led to the development of civilisation. Since ancient times, efforts have been made to control and manage the flow of water in the Tigris and Euphrates rivers via the construction of dams, reservoirs, and distribution networks. The wheel was set in motion once again to construct irrigation projects that would cover the whole of Iraq from north to south and east to west shortly after its integration into the new Iraq in 1921. First on the agenda for the development board was the issue of the massive Dukan dam. The development board was responsible for the initial construction of the Darbandikhan dam. Later, in the second part of the 1970s, attention moved to the forefront again when the second group of dams were being constructed. These dams included the Hemrin, Haditha, and Mosul dams. The Adhaim Dam was constructed in the decade of the 1990s (M. Abdullah, 2021).

Dam name	Dam type	River name	Purpose of dam	Normal storage (MCM)	Maximum storage (MCM)
Mosul dam	Earth-fill	Tigris	Flood control, Irrigation, Hydropower generation	11,100	13,200
Haditha dam	Earth-fill	Euphrates	Irrigation, Electric energy generation, Partial storage extreme inflow	8,000	10,000
Dokan dam	Arch	Lesser Zab	Multi-purpose as flood control and hydropower	6,800	7,890
Darbadikhan dam	Embankment dam with clay core and rock fill shoulders	Diyala	Flood control irrigation& water supply, hydro-power generation	3,000	3,850
Hemrin dam	Earth-fill	Diyala	Irrigation, Flood control and power generation	2,450	3,950
Adhaim dam	Earth-fill	Adhaim	Flood control-water regulating-power supply	1,600	3,750

Dams in Iraq

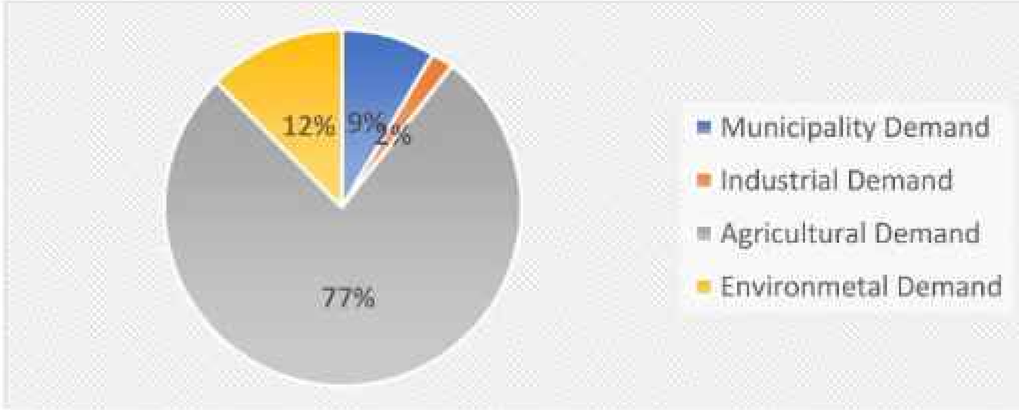
Chapter 4

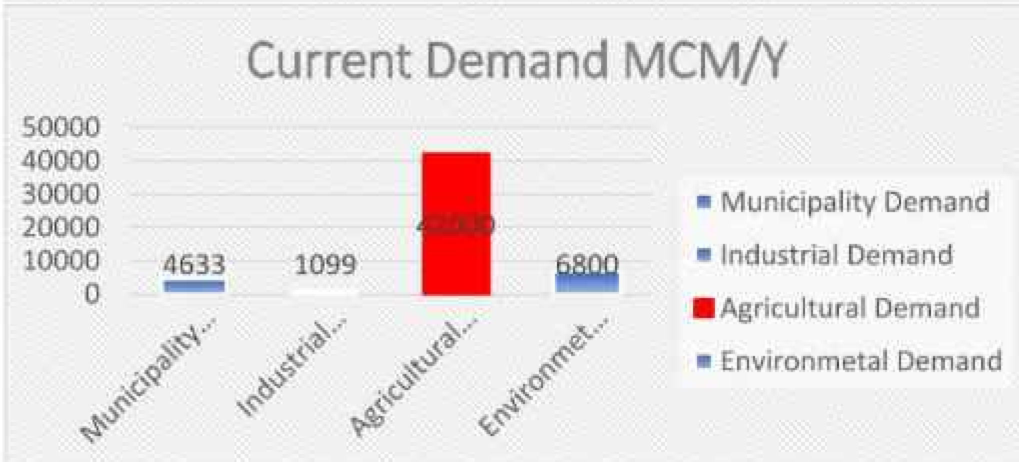
WATER DEMAND IN IRAQ AND CHALLENGES

In Iraq, the issue of supplying drinkable water to rural populations as well as agricultural productivity is of the utmost significance. Due to the fact that it is quite urgent, the government of the republic of Iraq places a significant amount of emphasis on effective measures aimed at completely supplying the rural population with potable water of a high standard. This is done in an effort to improve the welfare of the Iraqi people. The material and technological foundation of agricultural production is now undergoing consolidation and enhancement. The implementation of a large-scale farm construction programme is now taking place. This programme not only allows for the creation of big agricultural projects, but also of villages that are fully equipped with all of the essential amenities. All of these settlements and farm production projects that are in the planning stages (animal farms, businesses dealing with the primary processing of agricultural goods; repair shops, garages, and storage rooms, etc.) need to have a reliable source of water supply. As a result, we are in the process of tackling the problems of water supply and developing the sewage system in irrigation areas and dryland cultivation, as well as watering large areas of natural pasture for livestock. This is all in addition to the process of irrigating large areas of natural pasture.

Water self-sufficiency is one of the most crucial pillars for a developed and sustainable economy wherever in the globe. This is because it is needed to maintain food security and is thus one of the most critical pillars. This is particularly true in arid and semi-arid countries that are highly reliant on water supplies that are controlled from outside of their international boundaries, as is the situation with Iraq. Since ancient times, the rivers Tigris and Euphrates have been providing Iraq with the majority of its fresh water supply. The combination of these two rivers is what gave Iraq its name in Greek: Mesopotamia (the land between two rivers). The mountains of Turkey are home to the headwaters of both the Tigris River and the Euphrates River. These two rivers eventually converge in the Shatt-al-Arab River, which is located at the southernmost part of Iraq, before emptying into the Arabian (Persian) Gulf. Approximately 98 percent of Iraq's total water usage comes from these two rivers and the tributaries that branch off of them. *(Al-Furaiji, 2016)*.

- Municipal water demand
- Industerial water demand
- Agricultural water demand
- Environmental water demand





Water challenges in Iraq

There are many challenges (internal and external):

- Low water flow due to the construction of Turkish and Iranian dams.
- Climate change, drought and reduction of renewable water resources.
- Lack of a coordinated spatial plan for the development of industries, urban and rural settlements and agriculture.
- Lack of an economical view on water and barriers to private investment in the water sector.
- Imbalance of water supply and consumption and increasing water competition among users causing internal conflicts among provinces, tribes and beneficiaries on water quotas.
- Lack of effective project execution to develop water resources and agriculture.
- Deterioration of water quality and pollution of water resources.
- Lack of implementation of an integrated water resources management system.
- The limits of comprehensive planning for water use within the geopolitical boundaries, which take into account the economic plans.

Chapter 5

Operation Rules

It is necessary to first compile the data that reflects the particular facts in order to achieve the goal of becoming familiar with the regulations that govern the operation of dams and reservoirs in Iraq. The physical system and operating rules associated with water management structures along the Tigris and Euphrates rivers and their tributaries within Iraq, where data on incoming flows have been collected over the past 30 years, as well as chronologically inflows and transfers corresponding to the selected flow state. These structures are located within Iraq. Operating rules are the instruments that influence release determinations in order to strike a balance between satisfying downstream regulations and attempting to manage reservoir storage in relation to the rule curve. This is accomplished by satisfying downstream regulations while also trying to manage reservoir storage.

Methodological Approach

Extracting water for a new water user has consequences for allocating water to all water users at the upstream and downstream of the intake section. In order to assess impact, two systematic approaches can be used:

- The successive alteration of the discharge hydrograph along the river;
- The cumulative balance method.

Both methods lead to the same results.

The Successive Alteration of the Discharge Hydrograph along the River

This method is based on the computation of the flow's evolution in each section along the watercourse. The balance equation in the current section i has the expression:

$$Q_i^d = Q_i^n + \sum_{j=1}^{i} \Delta Q_j^{w.m} + \sum_{j=1}^{i-1} \Delta Q_j^n - Q_i^a \,. \tag{1}$$

In this method, only the downstream hydrometer is calculated for the intake sections; In all other sections (restitution sections downstream, downstream of confluence or upstream of intake sections) the water balance is more favorable.

The Cumulative Balance Method

The cumulative balance method is to compare the natural flow of each arithmetic section, unaffected by human activities, with the required discharge for all water users in the upper part of the current section. Thus, the impact of water users and water management works is hypothetically examined for the entire basin up to the studied section.

The cumulative balance equation is:

$$B_i = Q_i^n - Q_i^{cd} \tag{2}$$

$$Q_i^{cd} = \sum_{j=1}^{i-1} Q_j^c + \sum_{j=1}^{i-1} Q_j^u + Q_i^u + Q_i^c , \tag{3}$$

By combining the relation (2) and (3) the cumulative balance equation results:

$$B_i = Q_i^n - \sum_{j=1}^{i-1} Q_j^c - \sum_{j=1}^{i-1} Q_j^u - Q_i^u - Q_i^c . \tag{4}$$

Computation of the Necessary Resource in the Reservoir

In the current operation of the system, when the water balance is negative, the natural flow of the reservoir must be increased in order to cover the water requirements by using the volumes stored in the periods of excess water. In order to assess the necessary volumes in the reservoir, the following algorithm is used:

a) The first step is the determination of the coordinated balance between all sections:

$$B_j = \min_i \left(B_{i,j}\right) \tag{5}$$

b) Based on the coordinated balance values the necessary resource at the beginning of each month is computed. The computation starts at the end of the period with available data, when the reservoir is supposed empty.

If the coordinated balance B_j in the month *j* is negative the necessary resource, expressed as the discharge Q_j^{nec} at the beginning of the same month is:

$$Q_j^{nec} = Q_j^{ant} - B_j \tag{6}$$

Where Q_j^{ant} is the antecedent value of the necessary resource.

$Q_j^{nec} < 0$ corresponds to a surplus period, meaning that even if the reservoir is empty at the beginning of the month *j* the water demand can be covered due to the excess water during the current month. As a consequence, if $Q_j^{nec} < 0$ the necessary resource at the beginning of the month is replaced by 0:

$$Q_j^{nec} < 0 \quad \rightarrow \quad Q_j^{nec} = 0 \tag{7}$$

c) For each month *j*, a statistical processing will lead to the necessary resource which will cover the water demands corresponding to a probability of non-exceedance of P%; here P% is the security degree of water supply corresponding to the most important water user (usually the population, for which usually P%= 97%)

Because of the relatively small number of years for which the simulation was performed, the resource value corresponding to P%=97% for the month *j* is usually the maximum value of all values from the column *j*.

$$Q_j^{P\%} = \max_j \left(Q_j^{nec}\right) \tag{8}$$

The obtained values are then transformed into volumes using the relation:

$$V_j^{P\%} = 2.63\ Q_j^{P\%} \tag{9}$$

The volume of the reservoir satisfying the water demands with a probability P% is the maximum value of the necessary monthly volumes:

$$V_{reservoir} = \max_j \left(V_j^{P\%}\right)$$

Tigris River Basin

Mosul Reservoir

The water flow of the Tigris River is rather complicated and is controlled from the Mosul reservoir, the Greater Zab River, part of the Lesser Zab, the Adhaim River, and the Diyala River. As a result, the operation of the Mosul Dam, which is operated in common by the water management authorities in Iraq, is also somewhat complicated. The Mosul Dam is located in Iraq. The reservoir serves as a source of water for the Iraqi people, as well as for industry, animal farming, irrigation, fisheries, and the generation of hydropower. It is situated on Iraqi land, near the mouth of the Tigris River.

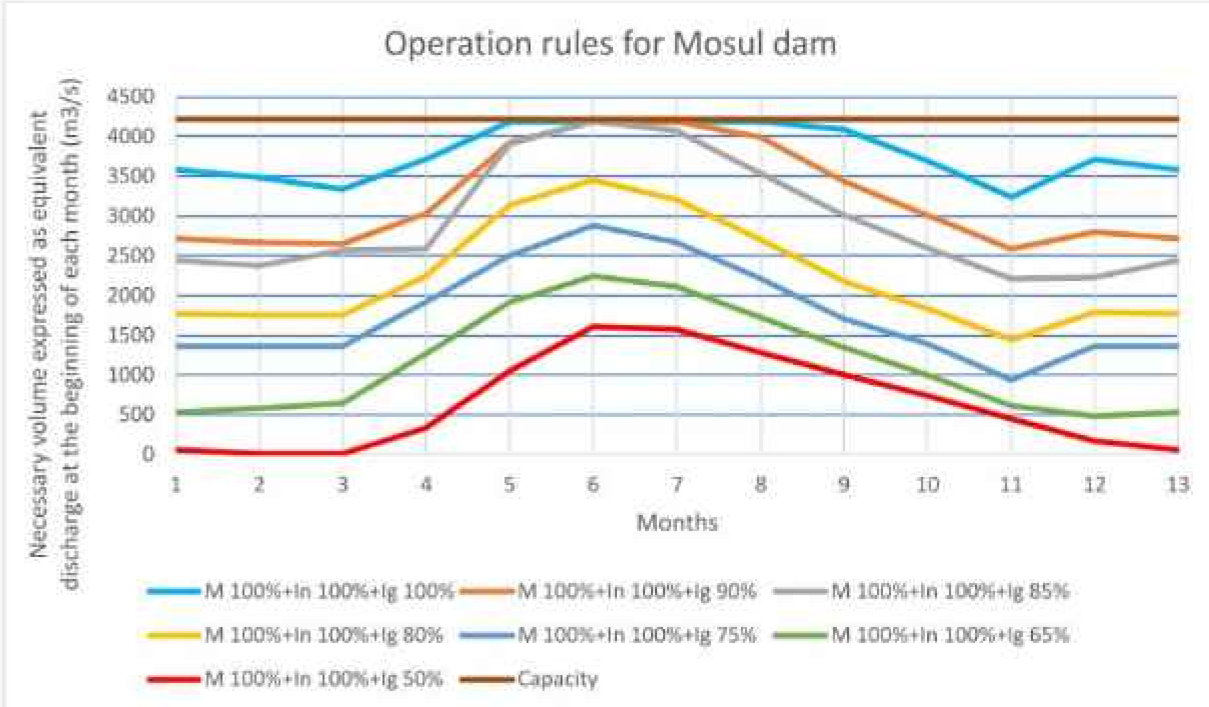
Main Water Users on Tigris River

The water resources of the Tigris River are divided as follows:

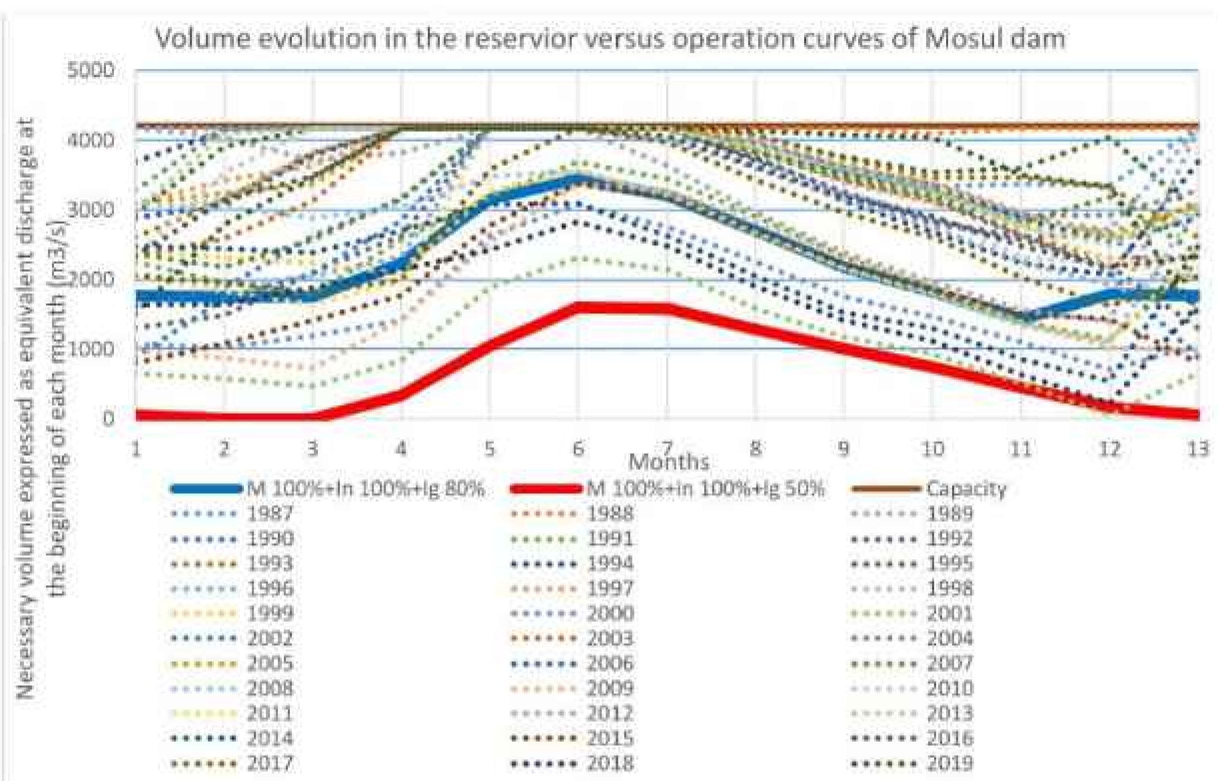
- **Irrigation** – Total: 18,500 mil.m^3 (8,849,197 du) more than 2.2 million ha.
- **Municipality** – Total: 3,150 mil.m^3
- **Industry** – Total: 600 mil.m^3.
- **Environmental** – Total: 3300 mil.m^3

Because the total necessary demand (population + industry + 100 percent irrigation demand) cannot be met in every year, I presumed that the operating rules should be based on the dam's operational capacity to cover the agricultural requirements as percentages (100 percent, 90 percent, 85 percent, 80 percent, 75 percent, 80 percent, 75 percent, 65 percent, 60 percent, 55 percent, and 50 percent), in addition to the 100 percent of requirements for municipal, industrial, and agricultural uses.

In Chart 2 the operation rules of Mosul reservoir are presented. The operation of the reservoir based on the main operation rules (municipal demands 100%, industry 100%, irrigation 80% - solid blue line and municipal demands 100%, industry 100%, irrigation 50% - solid red line) is presented in Chart 3. One can notice that in all the years the trajectories representing the evolution of the water volumes in the reservoir are above the solid red line, meaning that in all years the irrigation demands are satisfied at least 50% of the demand, while population and industry receive the whole water demand.



Operation rule for Mosul dam (Discharges)



Volume evolution in the reservior versus operarion curves of Mosul dam

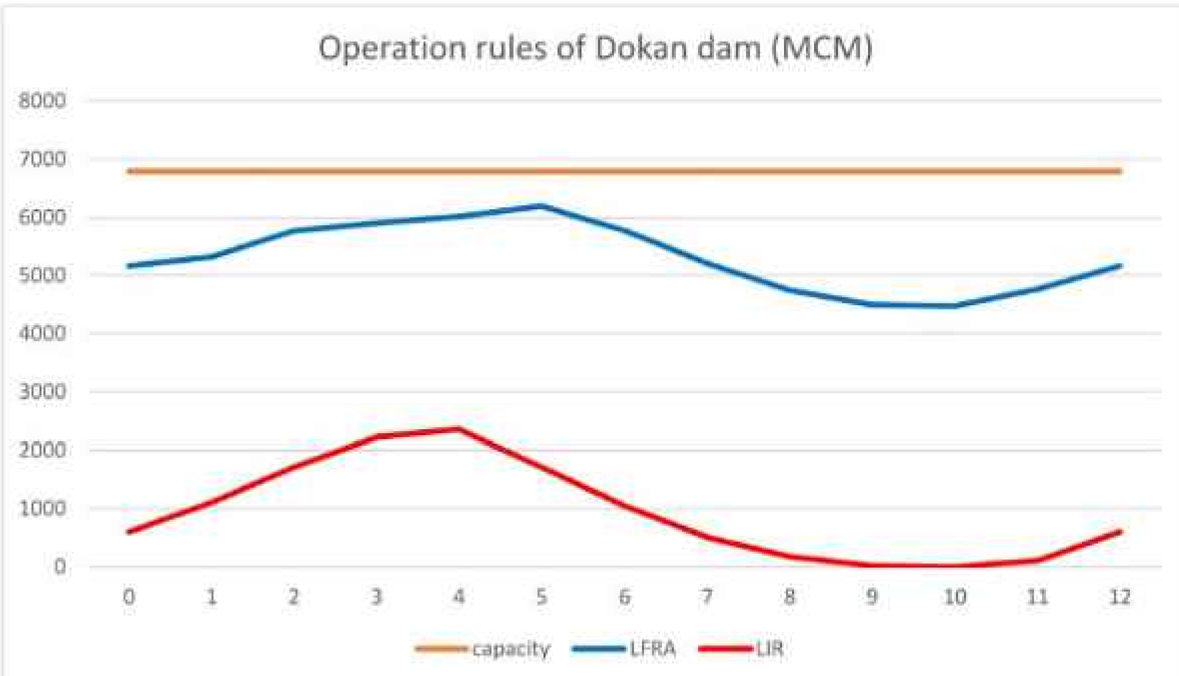
Lesser Zab Basin

Dokan Reservoir

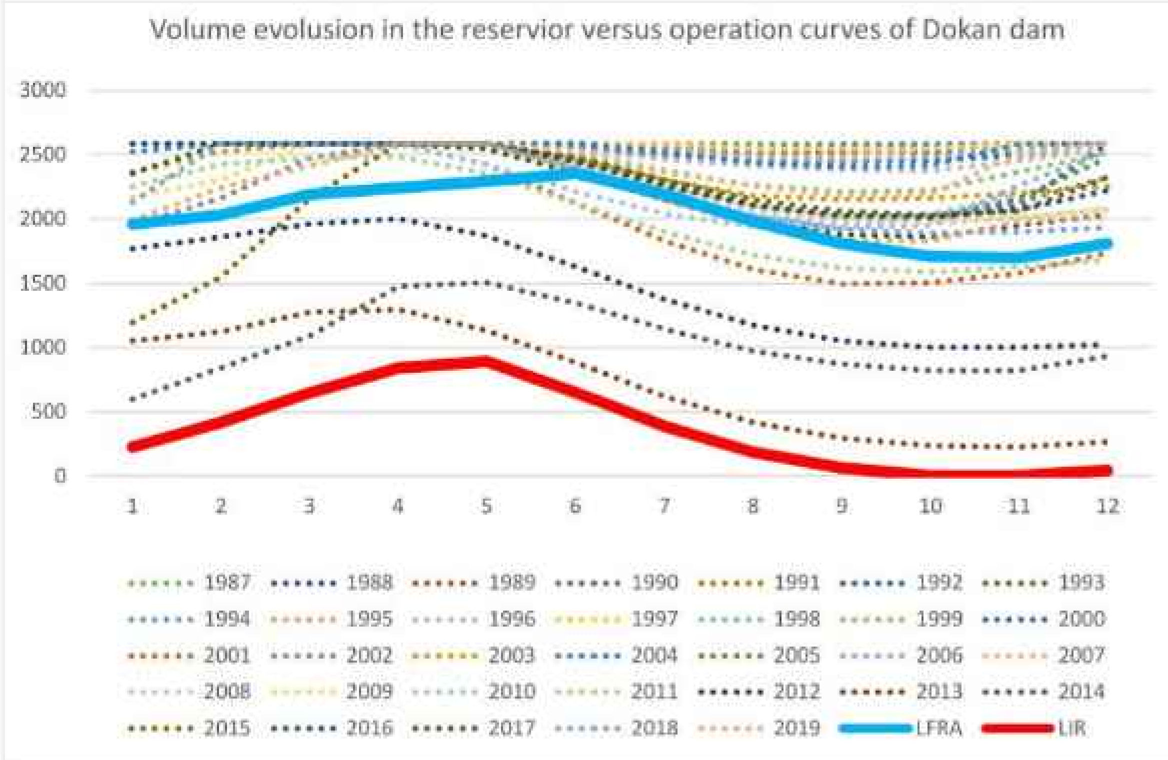
Main Water Users on Lesser Zab River

The water resources of the Lesser Zab River are divided as follows:

- **Irrigation** – Total: 2,500 mil.m^3 (1,244,310 du) more than 300 ha.
- **Municipality** – Total: 580 mil.m^3.
- **Industry** – Total: 35 mil.m^3.
- **Fishery** – Total: 80 mil.m^3



Operation rules for Dokan dam



Volume evolution in the reservior versus operarion curves of Dokan dam

One can notice that in all the years the trajectories representing the evolution of the water volumes in the reservoir are above the solid red line (LIR), meaning that in all years the irrigation demands are satisfied at least 50% of the demand, while population and industry receive the whole water demand.

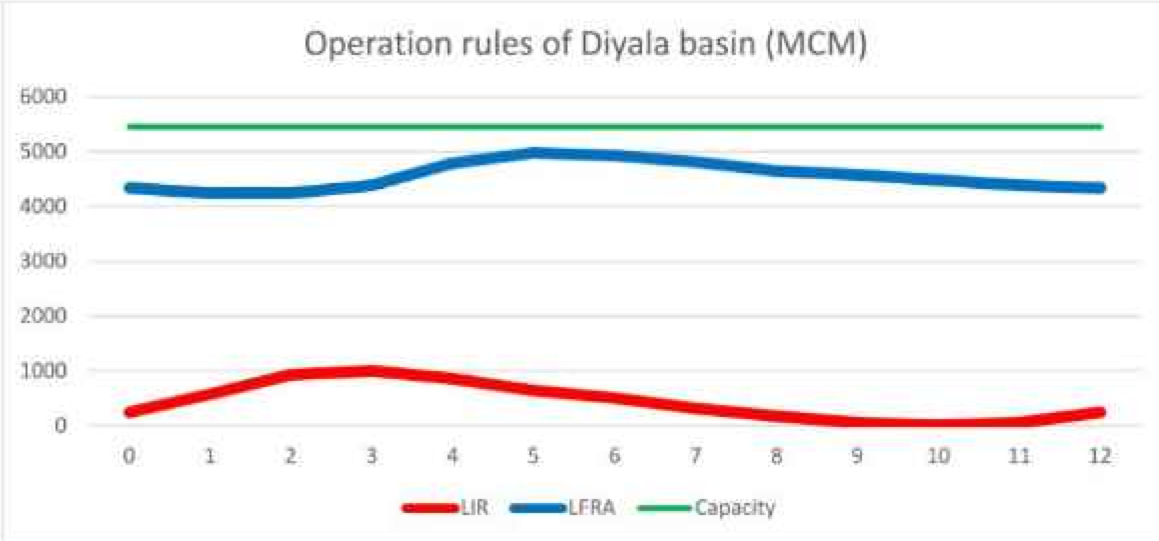
Diyala River Basin

Darbandikhan and Hemrin reservoirs

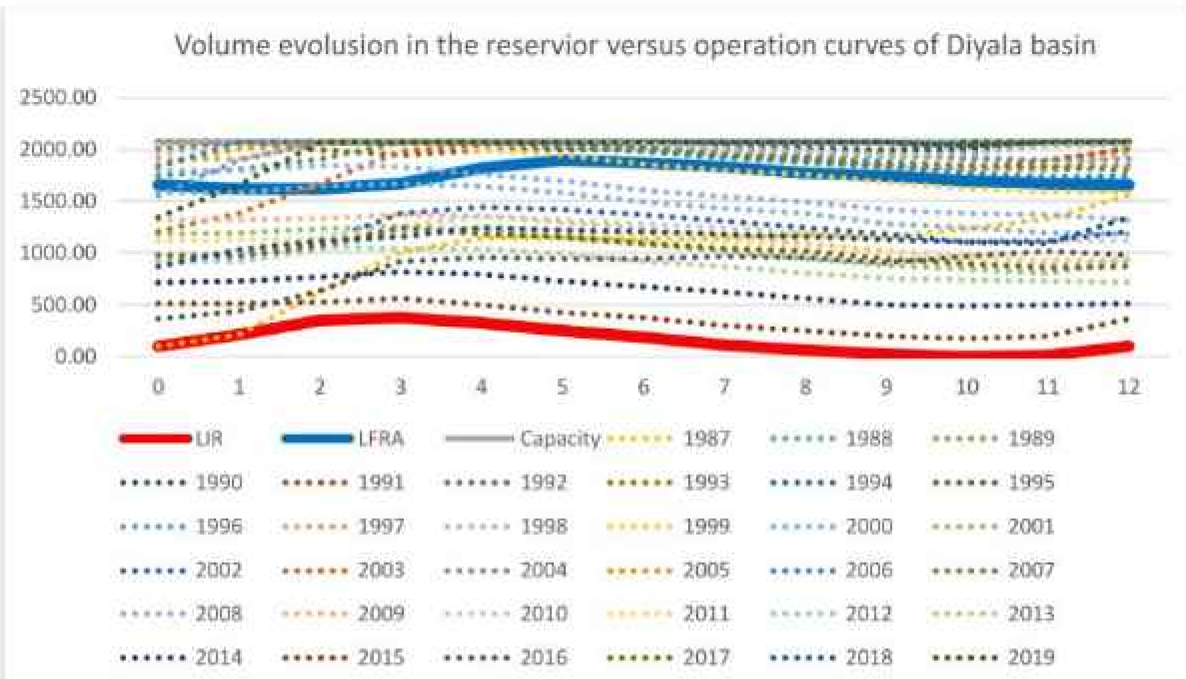
Main Water Users on Diyala River

The water resources of the Diyala River are divided as follows:

- **Irrigation** – Total: 3,600 mil.m^3 (1,423,200 du) more than 355 ha.
- **Municipality** – Total: 210 mil.m^3.
- **Industry** – Total: 20 mil.m^3.
- **Fishery** – Total: 50 mil.m^3



Operation rules for Diyala basin



Volume evolution in the reservior versus operarion curves of Diyala basin

One can notice that in the case of Diyala reservoir in all the years the trajectories representing the evolution of the water volumes in the reservoir are above the solid red line (LIR), meaning that in all years the irrigation demands are satisfied at least 50% of the demand, while population and industry receive the whole water demand.

Euphrates River Basin

Haditha reservoir

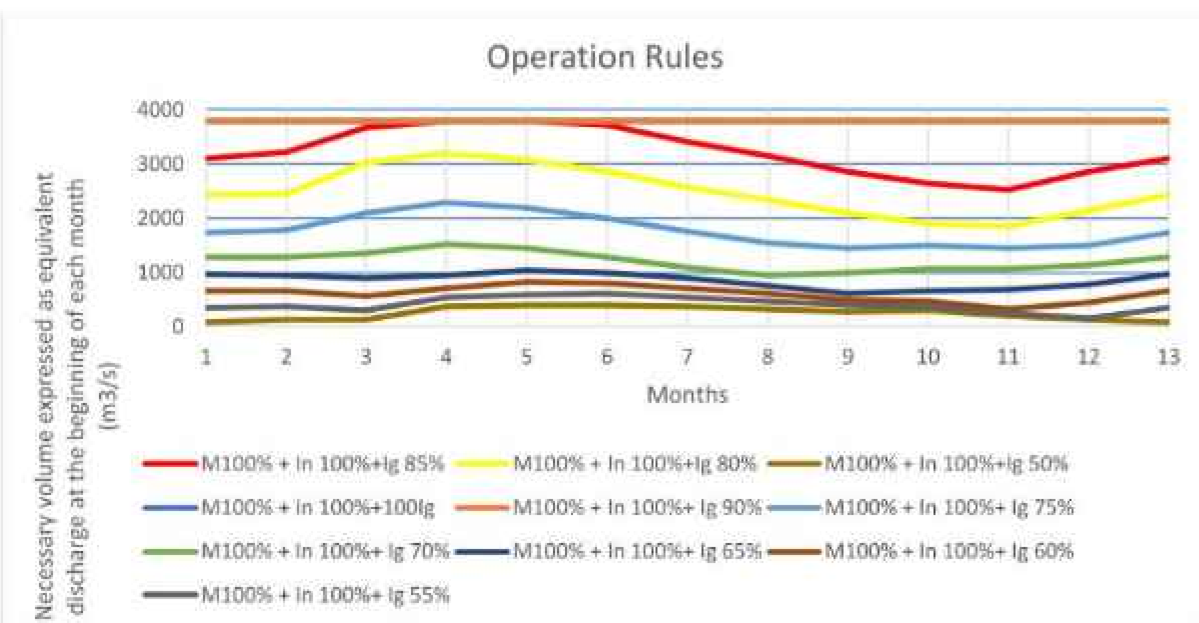
The water management authorities in Iraq use the Haditha reservoir as their primary means of regulating the flow of water in the Euphrates River. The reservoir is managed in the public interest. On Iraqi land, near the headwaters of the Euphrates River, there is a reservoir that serves as a source of water for the country's people, as well as for industry, cattle husbandry, irrigation, fisheries, and the generation of hydropower. The reservoir has a massive active storage area that is equal to 8000 Mm3 in total volume.

Main Water Users on Euphrates River

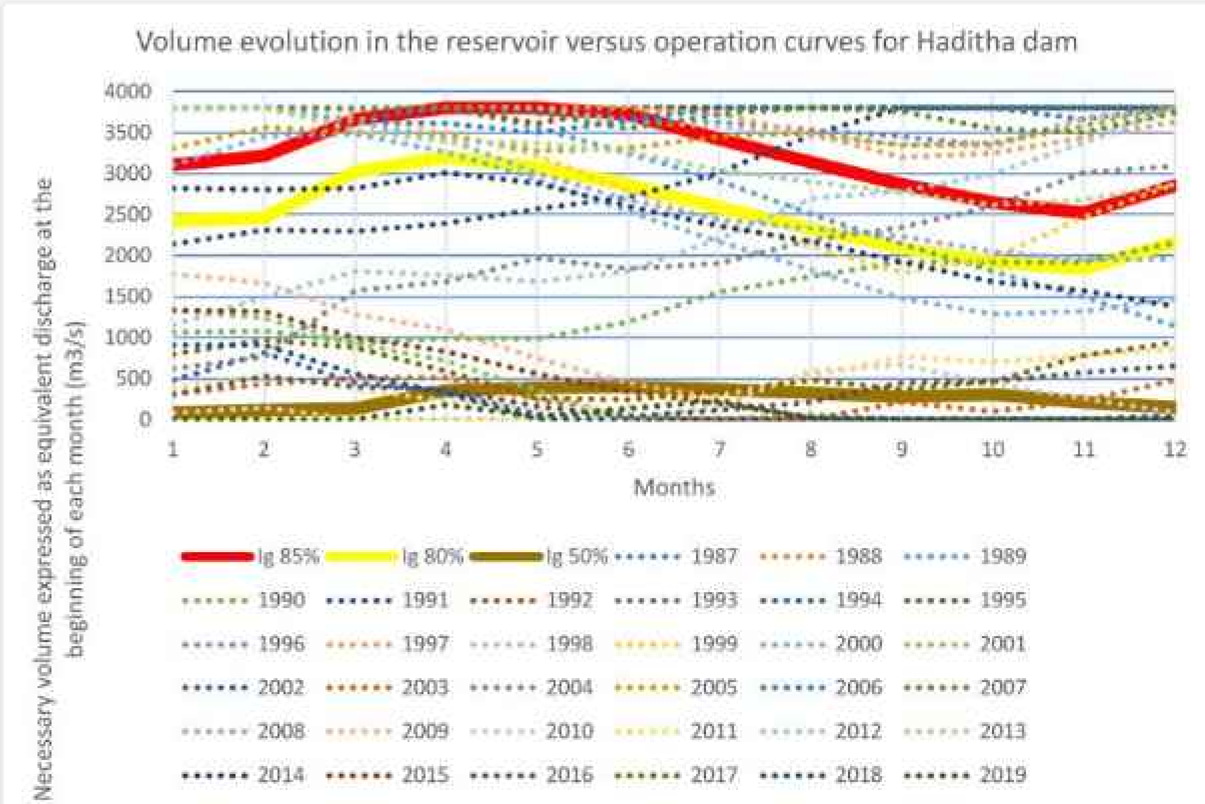
The water resources of the Euphrates River are divided as follows:

- **Irrigation** – Total: 16,000 mil.m^3 (5,550,000 du) more than 1.3 million ha.
- **Municipality** – Total: 1,741 mil.m^3.
- **Industry** – Total: 499 mil.m^3.
- **Environmental** – Total: 2000 mil.m^3

The total necessary demand (population + industry + 100% irrigation demand) cannot be provided in all years, so, I supposed that the operating rules should be according to the dam's operational capacity to cover the agricultural requirements as percentages (100%, 90%, 85%, 80%, 75%, 70%, 65%, 60%, 55% and 50%) in addition to the 100% of requirements of municipal, industrial and environmental and then projecting the agricultural requirements in the graph represented by the proportions the above-mentioned agricultural requirements to know what the real agricultural requirements are covered, and in the case of the Euphrates Basin and what the Haditha Dam provides, it covers in the best cases between 50% and 70% of the agricultural requirements in addition to the complete municipal and industrial requirements.



Operation rules for Haditha dam



Volume evolution in the reservior versus operarion curves of Haditha dam

In the case of Haditha reservoir in some years the trajectories representing the evolution of the water volumes are below the solid red line, meaning that the irrigation demands cannot receive in these years at least 50% of the demand, while population and industry receive the whole water demand. This result put into evidence a serious problem of shortage of water for agriculture, putting in danger the food security of the region and the country.

Chapter 6

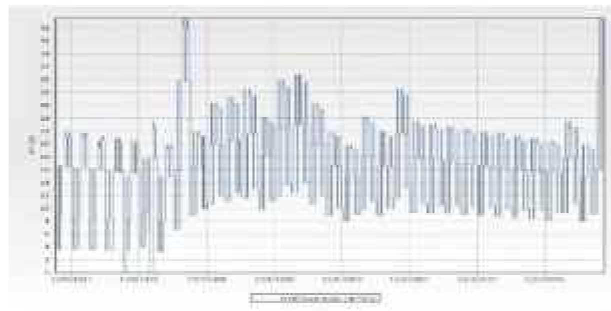
MODEL OF TEMPORAL AND SPATIAL ALLOCATION

Using the MIKE HYDRO Basin software, a simulation network was developed for "the spatial distribution of all water resource needs in Iraq within the water resources operating system for specific time periods to indicate the distribution of these resources according to" the request, which included an indication of the order of priority in processing to (municipal demands, Industrial demands, agricultural demands, and then environmental requirements), and the water demand was calculated as a result.

A simulation network has been created for "the spatial distribution of all water resource needs in Iraq using the MIKE HYDRO Basin software (Here, I must give thanks and gratitude for the kind assistance of DHI Romania, who provided free software for my research) and, accordingly, the water demand was calculated for each component (city, industrial project and agricultural project) for the period 1987-2019.

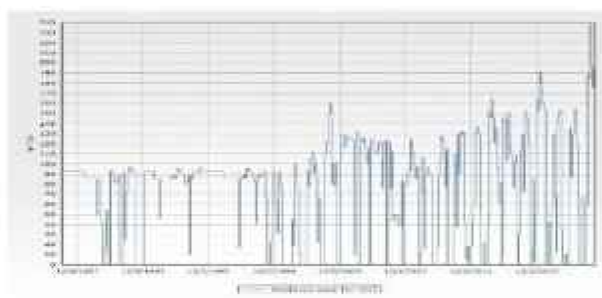
- Creating Rivers Network
- Define reservoirs
- Define water users

Al Dour Agricultural Project Location



Al Dour Agricultural Project Delivered water

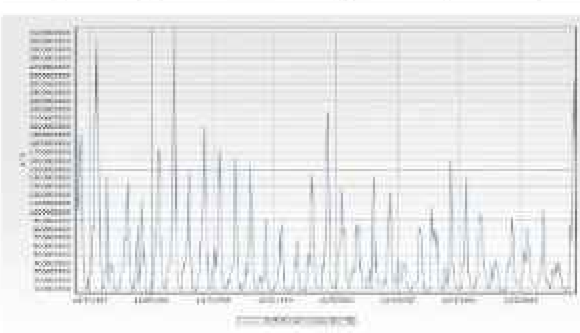
Al Gharraf Agricultural Project Location



Gharraf Agricultural Project Delivered Water

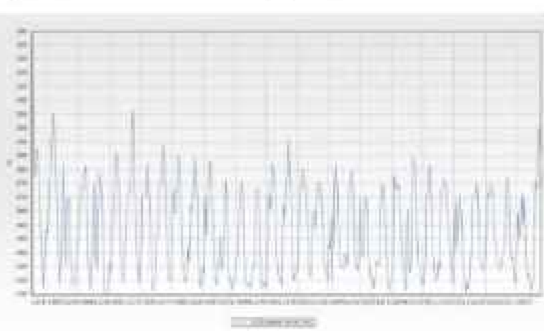
It can be seen that the upstream irrigation systems receive a large part of the demand, while the downstream systems receive the least part.

The model allows calculating the evolution of the volume of water stored and water level in each dam versus time, taking into account specific operating rules, as shown in the diagrams below:



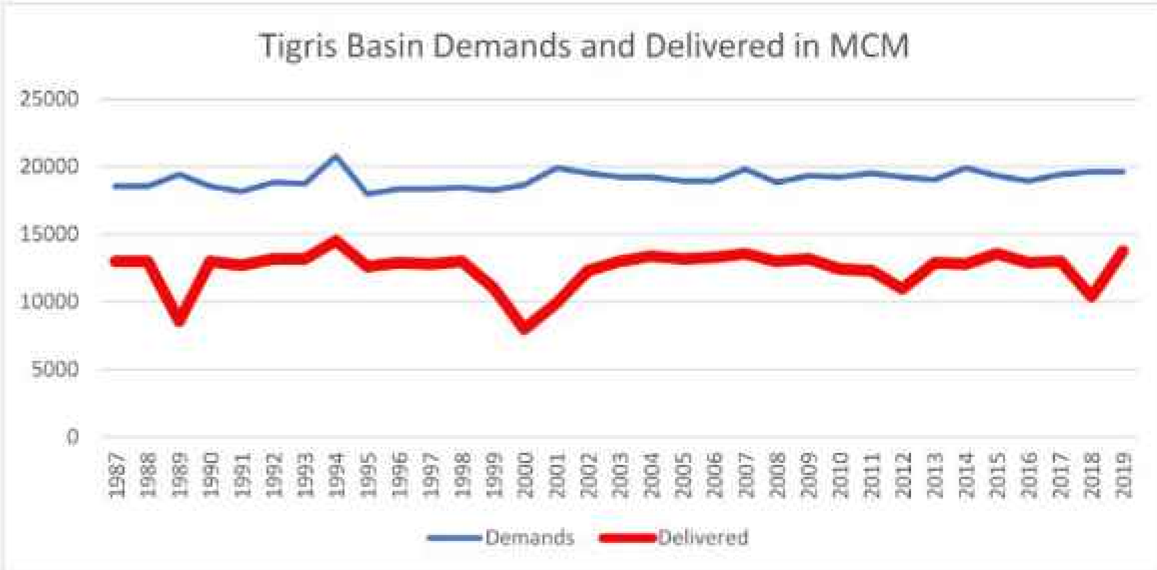
Stored Volume in Mosul Dam versus Time

(ordinates values between 100 and 3100 MCM)



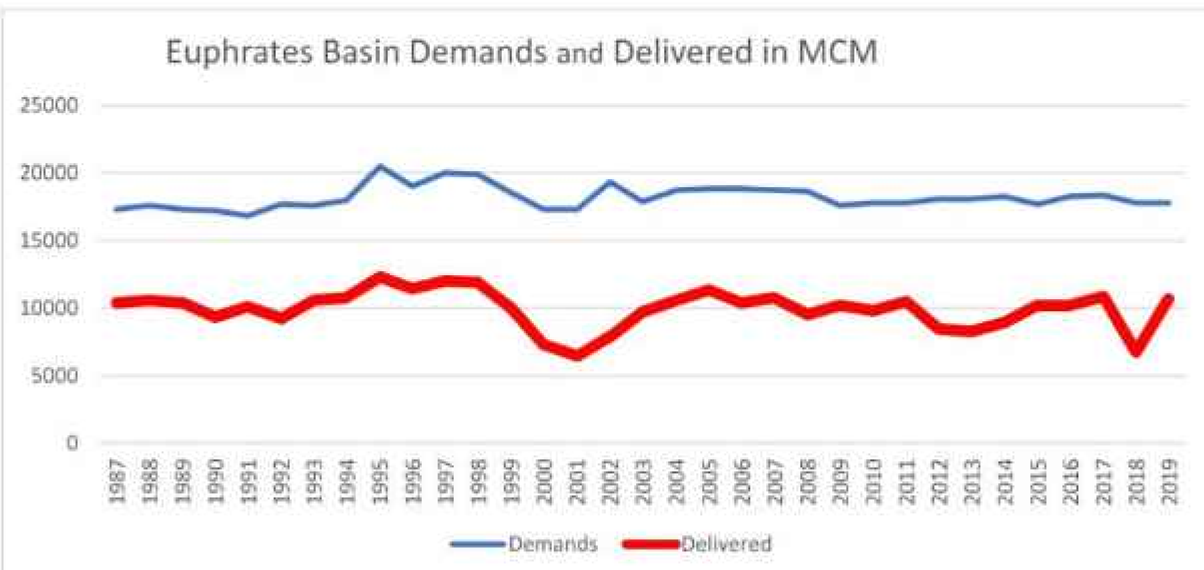
Water level in Mosul Dam versus Time

The water security degree of whole Tigris basin between 43% and 70% as shown in the diagram below, between the demand for water and the water delivered to the consumer.



Tigris Basin Demand and Delivered in MCM

For Euphrates basin, the water security degree between 37% and 60% as shown in the diagram below, between the demand for water and the water delivered to the consumer.



Euphrates Basin Demand and Delivered in MCM

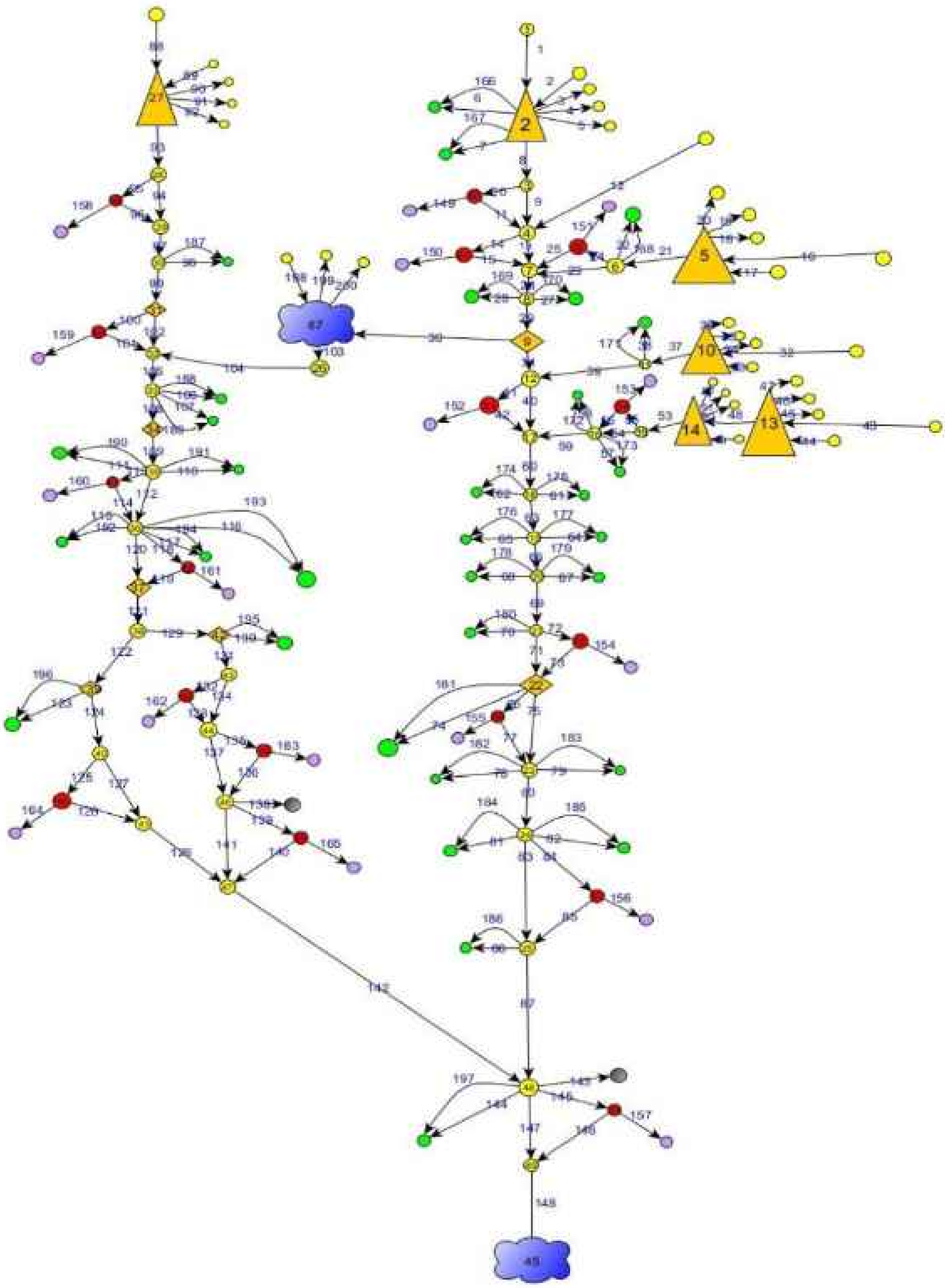
Chapter 7

ALLOC Model

A water management systems (WMS) operation optimization problem such as the flow problem in networks is formulated to find the flow that reduces cost in the entire network while satisfying continuity constraints in nodes and constraints not exceeding upper and lower flow limits on the arcs.

Short-term improvement is achieved during each month and consists in an adequate distribution of water between tanks and water users, which reduces costs associated with not meeting water requirements and not observing optimal operating rules for tanks. There is a need to balance the goal of water retention in tanks with the goal of water discharge to meet the water requirements in order to solve the short-term operation problem and this is achieved by installing an appropriate system for the costs associated with the corresponding arcs.

The ALLOC model was used to analyze the WMS in the correlative hydrographic space of the Tigris and its tributaries and the Euphrates. This model is intended to be used by the dispatcher unit for spatial water allocation between water users and reservoirs.



Euphrates – Tigris network

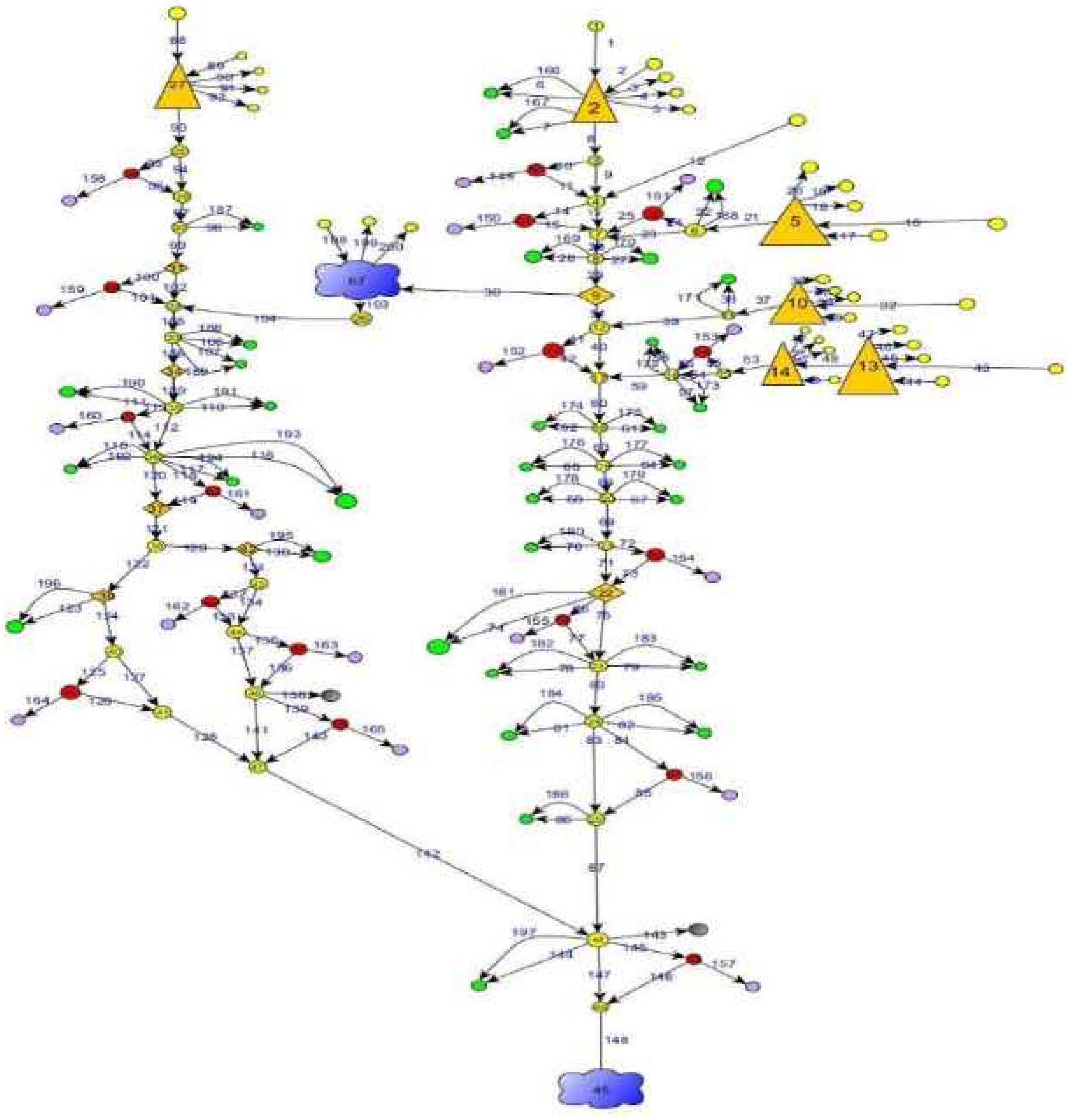
Modeling of WMS Tigris- Euphrates Basin

The arcs-nodes network reproduced has 200 arcs and 67 nodes.

The WMS elements are: rivers, water works (water reservoirs and water diversions), water users (municipal and industry water supplies, irrigation, fisheries).

Rivers: Tigris (arcs 8,9,18,26,29,31,40,60,63,66,69,71,75,80,83,87,147,148), Greater Zab (12), Lesser Zab (21,23), Adhaim (37, 39), Diyala (48,53,54,59) and Euphrates (93,94,97,99,102,105,108,109,112,120,121,122,124,127,128,129,130,131,134,137,141,142).

Inflows: upstream inflow or difference between two consecutive points (arcs 1,12,16,32,43 and 88).

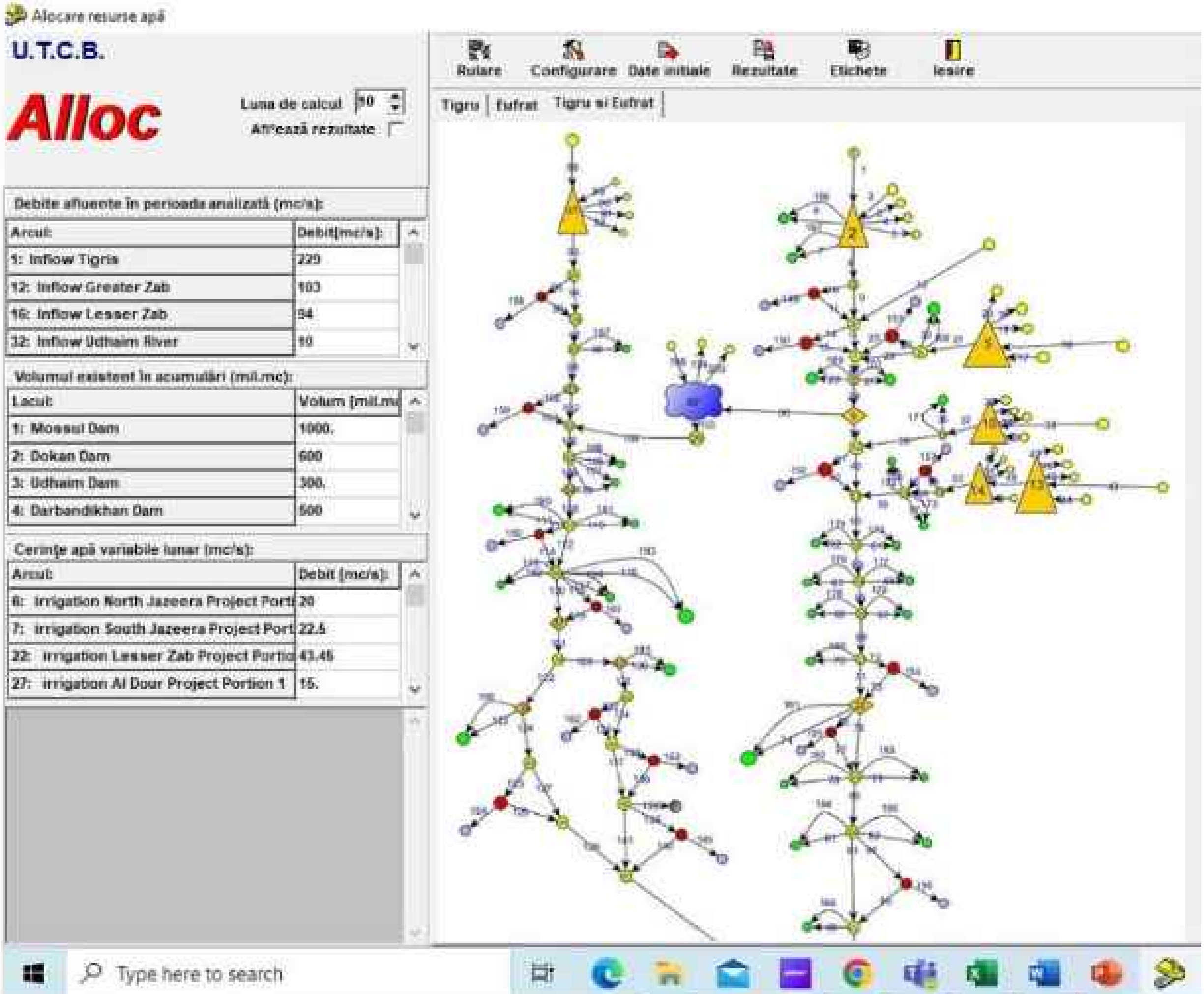


Tigris - Euphrates basin WMS

Arc nr.	Discribtions	Demand m3/s in October 1989
6	Irrigation North Jazeera Project Portion 1	20
166	Irrigation North Jazeera Project Portion 2	20
7	Irrigation South Jazeera Project Portion 1	22.5
167	Irrigation South Jazeera Project Portion 2	22.5
22	Irrigation Lesser Zab Project Portion 1	43.45
168	Irrigation Lesser Zab Project Portion 2	43.45
28	Irrigation Ishaqi Proj.Portion 1	24.5
169	Irrigation Ishaqi Proj. Portion 2	24.5
29	Irrigation Al Dour Project Portion 1	15
170	Irrigation Al Dour Project Portion 2	15
38	Irrigation Udhaim Proj.Portion 1	11.375
171	Irrigation Udhaim Proj. Portion 2	11.375
57	Irrigation Cobined head Proj.Portion 1	32
173	Irrigation Cobined head Proj. Portion 2	32
58	Irrigation Al Khalis Proj.Portion 1	18.2
172	Irrigation Al Khalis Proj.Portion 2	18.2
62	Irrigation Baghdad Proj.Portion 1	67.5
174	Irrigation Baghdad Proj.Portion 2	67.5
61	Irrigation Suwaira Proj.Portion 1	11.32
175	Irrigation Suwaira Proj.Portion 2	11.32
65	Irrigation Kusaiba Proj.Portion 1	4.05
176	Irrigation Kusaiba Proj.Portion 2	4.05
64	Irrigation Diboni Proj.Portion 1	6.37
177	Irrigation Diboni Proj.Portion 2	6.37
68	Irrigation Dalmaj Projrct	38.2
47	Irrigation Badra-Jassan Projrct.	12.74
70	Irrigation Dujaila Project.	37.16
74	Irrigation Al Gharraf Project.	162
78	Irrigation Butaira Project.	49.75
79	Irrigation Nahar saad Project.	7.3
81	Irrigation Areeth Project.	12.78
82	Irrigation Kahlaa Project.	68.51
86	Irrigation Qala'at salih Project.	50
98	Irrigation Rmadi Project.	22
106	Irrigation Saqlawiya Project.	37
107	Irrigation Al Muwahada Project	94.5
110	Irrigation Musaiab Project.	46.2
111	Irrigation Husainiya Project.	22.6
115	Irrigation Bani Hassan Project.	32
117	Irrigation Kifil Projrct.	14.4
116	Irrigation Shatt Al Hilla Project.	245
123	Irrigation D/S Kufa Barrage Project.	90.8
130	Irrigation D/S Abbasiya Barrage Project.	78.4
144	Irrigation Basra Projrct.	53.2

Main water users on Tigris- Euphrates basin

Results



Tigris - Euphrates basin and water users on ALLOC window

Arc nr.	Discribtions	Demand m3/s	Delivered m3/s
6	Irrigation North Jazeera Project Portion 1	20	20
166	Irrigation North Jazeera Project Portion 2	20	0
7	Irrigation South Jazeera Project Portion 1	22.5	22.5
167	Irrigation South Jazeera Project Portion 2	22.5	0
22	Irrigation Lesser Zab Project Portion 1	43.45	43.45
168	Irrigation Lesser Zab Project Portion 2	43.45	0
28	Irrigation Ishaqi Proj.Portion 1	24.5	24.5
169	Irrigation Ishaqi Proj. Portion 2	24.5	0
29	Irrigation Al Dour Project Portion 1	15	15
170	Irrigation Al Dour Project Portion 2	15	0
38	Irrigation Udhaim Proj.Portion 1	11.375	11.375
171	Irrigation Udhaim Proj. Portion 2	11.375	0
57	Irrigation Cobined head Proj.Portion 1	32	32
173	Irrigation Cobined head Proj. Portion 2	32	0

58	Irrigation Al Khalis Proj.Portion 1	18.2	18.2
172	Irrigation Al Khalis Proj.Portion 2	18.2	0
62	Irrigation Baghdad Proj.Portion 1	67.5	67.5
174	Irrigation Baghdad Proj.Portion 2	67.5	0
61	Irrigation Suwaira Proj.Portion 1	11.32	11.32
175	Irrigation Suwaira Proj.Portion 2	11.32	0
65	Irrigation Kusaiba Proj.Portion 1	4.05	4.05
176	Irrigation Kusaiba Proj.Portion 2	4.05	0
64	Irrigation Diboni Proj.Portion 1	6.37	6.37
177	Irrigation Diboni Proj.Portion 2	6.37	0
68	Irrigation Dalmaj Projrct	38.2	25.6
47	Irrigation Badra-Jassan Projrct.	12.74	8.71
70	Irrigation Dujaila Project.	37.16	22.37
74	Irrigation Al Gharraf Project.	162	122.3
78	Irrigation Butaira Project.	49.75	29.31
79	Irrigation Nahar saad Project.	7.3	4.55
81	Irrigation Areeth Project.	12.78	8.62
82	Irrigation Kahlaa Project.	68.51	53
86	Irrigation Qala'at salih Project.	50	34.83
98	Irrigation Rmadi Project.	22	17.2
106	Irrigation Saqlawiya Project.	37	20.9
107	Irrigation Al Muwahada Project	94.5	72.55
110	Irrigation Musaiab Project.	46.2	31.63
111	Irrigation Husainiya Project.	22.6	16.43
115	Irrigation Bani Hassan Project.	32	23.61
117	Irrigation Kifil Projrct.	14.4	8.31
116	Irrigation Shatt Al Hilla Project.	245	171.14
123	Irrigation D/S Kufa Barrage Project.	90.8	62.5
130	Irrigation D/S Abbasiya Barrage Project.	78.4	44.22
144	Irrigation Basra Projrct.	53.2	33.26

Demand and delivered water for irrigation projects on Tigris - Euphrates basin

The population and industry receive the full demand for water, while agriculture receives their demand only partially. It can be seen that the upstream irrigation systems receive a large part of the demand, while the downstream systems receive the least part.

Chapter 8

Conclusion according to obtaining results

Operation Rules

- For Tigris River basin, the population and industry are not at risk of water shortage, while the irrigation demands cannot be satisfied entirely (security degree for irrigation between 50% - 80%).
- For Lesser Zab and Diyala basins, the irrigation demand is satisfied between 50-80% in most of the cases. Only in some years the irrigation demand is fully covered.
- In case of Euphrates River basin, the irrigation demand is satisfied between 50-80% in most of the cases. In some years even 50% of the irrigation demand cannot be covered, a very difficult situation especially in the downstream part of this river basin.

Model of temporal and spatial allocation

- The results in Mike hydro basin showed that the degree of water security in the Tigris basin (43% to 70%) and in Euphrates basin (37% to 60%) between the demand for water and the water delivered to the consumer.
- The population and industry receive full demand of water, but the upstream irrigation systems receive a large part of the demand, while the downstream systems receive the least part.
- Mike hydro program gives us the ability to know the water that is provided to each of the users in the basin.
- Mike Hydro Basin provides option to know the volume of water and the level of the water versus time in the reservoir based on the operating rules of each reservoir.
- The software calculates the water balance for first month then takes the result and considers it as being the initial condition for the simulation of the second month and so on.
- The Mike-hydro takes into account the water volume at the end of each time step.
- We can know the inability (deficit) to provide water demand for each user.

ALLOC Model

- The results refer to population and industry receive the whole water demand, while the agriculture receive only partially their demand in many situations.
- All irrigation systems receive the first portion (50% of the demand).
- It can be noticed that the upstream irrigation systems receive also the whole second portion of demand, while the downstream systems receive nothing from the second portion.
- A solution to avoid such a situation is to introduce a 3rd arc for each irrigation demand and to choose adequately the penalty coefficients in order to satisfy in an equitable manner all the irrigation systems.

Water experts say that the wars of the twenty-first century will be wars for water, just as the twentieth century was the scene of global and regional wars for control of energy sources, foremost of which is oil. The serious threat to which the country is exposed has begun since Turkey and Iran began implementing their plans for the construction of dams (22 and 45 respectively) on the common river basins. The conditions surrounding Iraq as a result of wrong policies and continuous wars that harmed Iraq by not implementing a modern infrastructure for the agricultural reality, all this led to a continuous and dangerous decrease of inflow and big glitch of water resources in Iraq.

- A major imbalance in the control of water distribution in Iraq as a result of the increasing need and demand for water due to the population increase that requires securing their needs of water.
- Huge expansion of agricultural projects by increasing areas suitable for agriculture, where this sector represents food security for Iraq, as well as the expansion of the industrial sector, and this is due to the nature of growth in countries as a result of population increases, where Iraq has a high rate of growth (about 3 %).
- Because there is no dam on the Great Zab, Iraq has to construct additional dams in order to expand its storage capacity. This is particularly important in the downstream region of the Greater Zab.

Chapter 9

Personal contributions

1. Understanding the water management system in Iraq.

2. A synthesis of water demands.

3. Simulations of water management systems in different scenarios using 3 different approaches based on mathematical modelling, deriving:

   - Operation rules of each reservoir taking into account their interdependence,
   - An evaluation of the water security degree at the level of each reservoir and at the nationwide level.
   - Best allocation of water resources.

4. Interpretation and synthesis of the results.

5. Recommendations for future developments of mathematical modelling including a detailed analysis of penalties coefficients used in water allocation.

6. Recommendations for decision makers considering both internal and foreign policy:

   - Internally, the attention should be focused on the water-saving irrigation and encouraging drip irrigation; a special attention was suggested for environments issues like salinization and ecological flow.
   - Externally, to negotiate with upstream countries (Turkey and Iran) for a fair repartition of water resources based on best practices and international norms.