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Evaluation of Water Resources and Hydraulic Influences in the Restoration of the Western Part of the Mesopotamian Marshlands

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Evaluation of Water Resources and Hydraulic Influences in the Restoration of the Western Part of the Mesopotamian Marshlands

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering

by

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ABSTRACT

The purpose of this study is to assess the water resources and water conveyance system of the western part of the Mesopotamian marshes (Al-Hammar marsh) as well as develop a water conveyance system to distribute water throughout the western Al-Hammar marsh. These processes are significant to identify the current restoration problems and help to create restoration strategies for the marsh. Also, proper management strategy to the Al-Hammar marsh is necessary to preserve the marsh ecosystem, irrigate lands, and provide domestic necessities in the villages.

The overall project is divided into three main chapters which address the current ecological and hydrological issues in the western Al-Hammar marsh. Chapter 1 assesses the water used in the restoration of the western Al-Hammar after 2003. Chapter 1 also provides updated calculations concerning the water balance and the water needed for the planned restoration which promotes more efficient water management for the marsh. Chapter 2 looks at the current condition of the water conveyance system in the western Al-Hammar in order to identify its problems, such as water loss, hydraulic problems, and inefficiency. Creating a high efficiency distribution system for the water supply will increase the rate of inundation and promote better management of surface water resources as well as obtain benefits for agricultural irrigation. Chapter 3 discusses how the restoration could be improved with current available surface water resources using multiple feeding points instead several feeder canals, which improves the health of the marsh and rehabilitate the area.

The results of the water balance have showed a deficit in water supplied to the marsh, even using the drainage water from the Main Outfall Drain (MOD), due to the high evapotranspiration (ET) and limited surface water resources, which do not have a constant flow

to the marsh. The feeder canals are not efficient enough to supply water for both irrigation and restoration purposes in their current condition. Furthermore, they have many issues, including operation problems, insufficient maintenance, and water losses. Improving the feeder canals by creating a lined network of irrigation canals serve both the farmland and increase the restoration of the marsh.

DEDICATION

This thesis, and the work invested herein, is dedicated to the Iraqi Water Resources Ministry (MoWR).

ACKNOWLEDGEMENTS

I would like to thank all the people who contributed in some way to the work described in this thesis.

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1. Introduction

The Mesopotamian Marshlands exist in southern Iraq. They are the lands in between the Tigris and Euphrates rivers, and known today as the Iraqi marshes. They have been the home to civilizations such as the Sumerians and Akkadians who thrived in this area for more than five millennia. The Iraqi marshes are the largest wetlands in southwest Asia [1] with an area twice the size of the Everglades in Florida [2]. Therefore, in 2016, the Mesopotamian Marshlands (the Iraqi marshes) were listed as a World Heritage Site (UNESCO), making them most unique wetlands in the world [1].

The marshes are, moreover, critical in the ecological life-support system because they provide ecological services, such as clean water, clean air, and fertile soils. They safeguard hundreds of thousands of Arab marshes as well as wildlife, biodiversity, and habitats on a global scale [3]. In the past three decades, the Mesopotamian Marshlands have been severely damaged by anthropogenic impacts and climate factors. Therefore, there has been a huge change in the hydrology and ecology systems. The Tigris and Euphrates Rivers are the main sources of water to the Iraqi marshes [3]. The water quality and quantity of the Tigris and Euphrates rivers have degraded over the past 40- 70 years, respectively [4], [5]. The degradation in water quality caused by intensive irrigated agriculture with irrigation return flow in the upstream countries, such as Turkey, Iran, and Syria, which have most of the headwaters of these rivers [5], [6]. In contrast, the large water development projects (i.e. the building of hydroelectric dams) in basins of the Tigris and Euphrates rivers have caused a significant negative trend and serious water crisis in Iraq, which is a downstream riparian. In addition, the coordination between Iraq and the other riparian countries has not received much attention, which negatively impacted many aspects of Iraq, such as agricultural expansion and economic growth, as well as the restoration of the marshes and the water quality. Climate is another factor which has contributed to the water crisis in Iraq. The main climate drivers are temperature, precipitation, solar radiation, daytime hours, and humidity, which are interrelated and affect the availability of the surface water [7]. Iraq has a low rate of rainfall caused by a common Mediterranean climate type which consists of wet winters and dry summers. For example, the annual rainfall in Iraq is about 58.5- 6.7 mm in November and April, and 0.001-2.6 mm in May and October, respectively [8]. At the same time, the evapotransporation rate is very high due to high temperatures most months of the year (Figures 1,2).

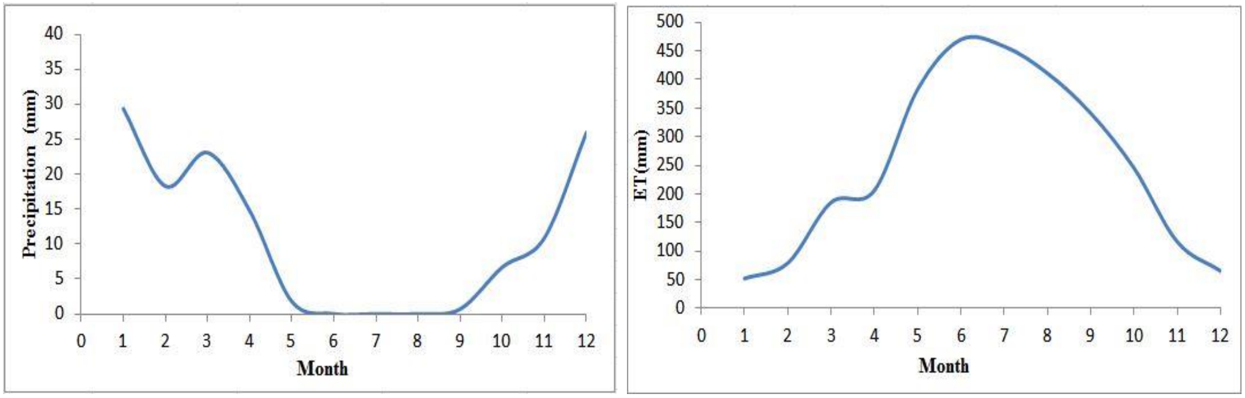

Figure 1. General pattern of the precipitation and the evapotranspiration in the Al-Hammar marsh region [8].

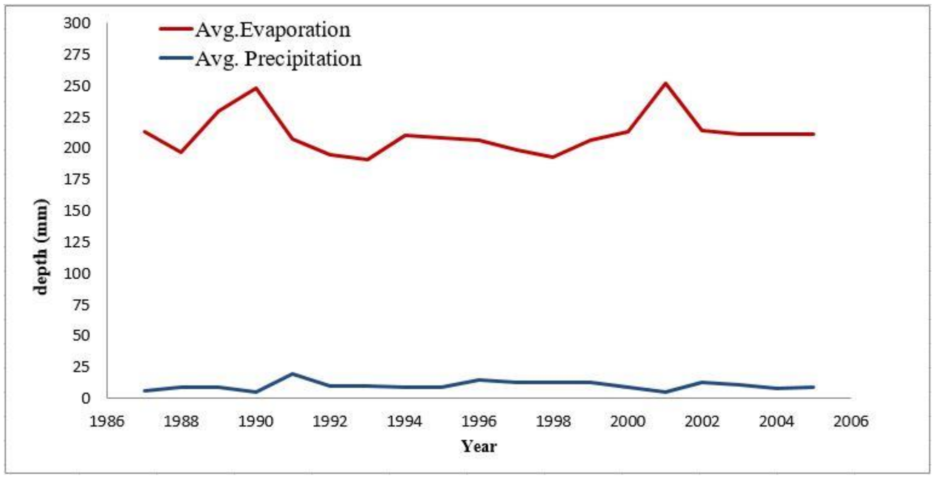

Figure 2. Precipitation and the evaporation rate in the Al-Hammer marsh region [9].

1.2 Problem Statement and Objectives

The reduction of surface water is the biggest challenge when preserving water resources in Iraq because it has a negative impact on the ecology system of the Tigris and Euphrates rivers. This reduction has caused deterioration of the aquatic environment and poor water quality in these rivers [6]. Furthermore, the reduction in the mean annual flow brought drought for a large part of the Iraqi marshes and large-scale disturbances in the environment.

Development projects in Turkey, Syria, and Iran, such as the construction of dams, are the main cause of the reduction of water entering Iraq [3]. For example, the development projects include 32 major dams on the Tigris, Euphrates, Karkheh, and Karun rivers which have caused water shortages. Eight dams are currently under construction, and thirteen more are planned [3]. Iraq’s severe climate factors, which make the water crisis more complicated (Figure 2). Based on the challenges described above and shown in Figure 3, this study aims to evaluate the water resources used in the restoration of the western Mesopotamian marshes. The main objectives of this study are:

1- Evaluate the water quantity that used in the restoration process of the western part of the Al-Hammer marsh between 2009- 2016.

2- Identify the major problems that affect the hydraulic efficiency of the main feeder canals. Many problems are obvious in these canals, such as floating aquatic plants, old and broken regulators, the use of wasteful irrigation systems along the canals, infrequent maintenance, and unlined canals.

3- Evaluate the major types of water losses, such as evaporation and seepage in the water conveyance system. Evaluating the water losses in the feeder canals would be necessary to enhance the marsh restoration.

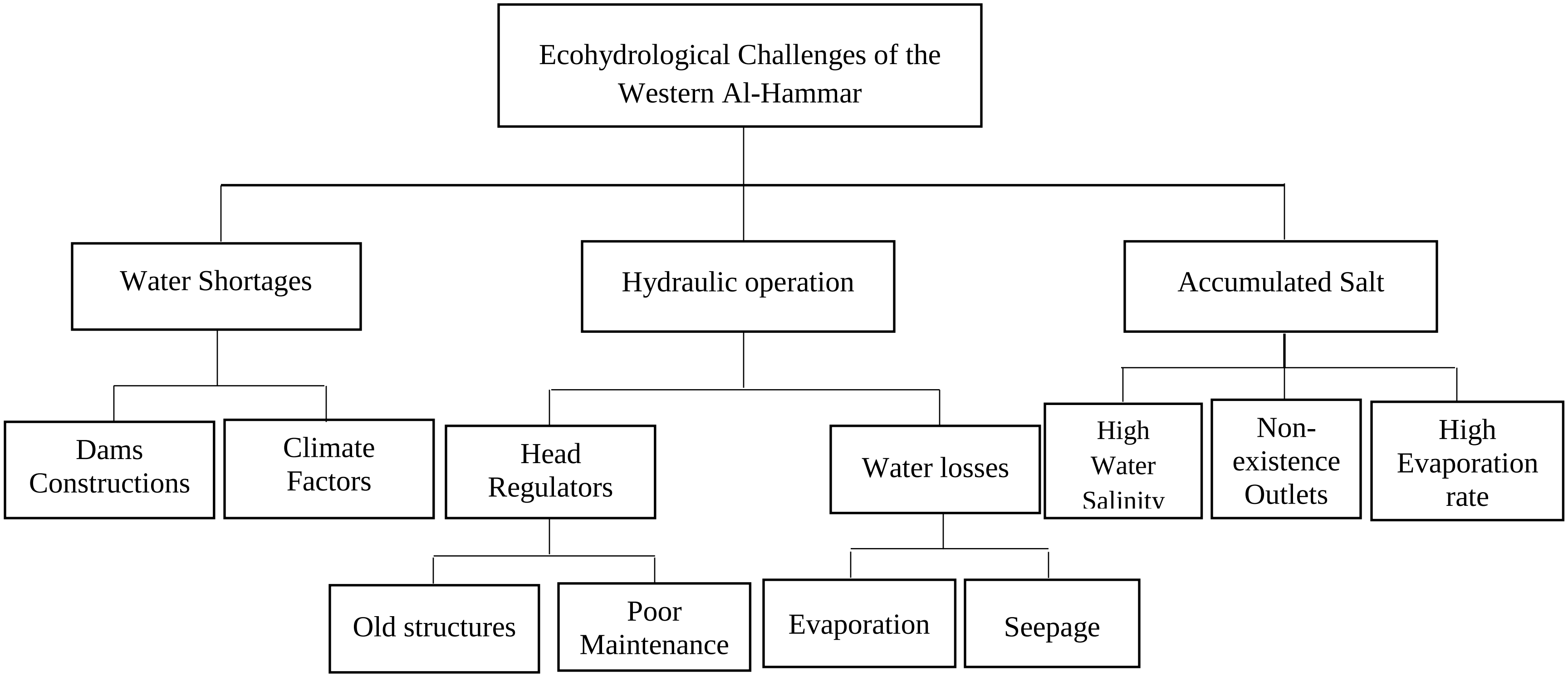

Figure 3.The main issues in restoration of the western part of the Al-Hammar marsh.

1.3 Methods Overview

The following are the proposed methods to achieve my main research objectives.

1- Using water balance equation to calculate the water budget of the western part of the Al-Hammar marsh through the study period.

2- Obtaining the updated data about the water structure and the current situation of the canals, such as the condition of regulating gates, discharge, and photographs of the feeder canals, will help to identify the main hydraulic issues in these canals.

3- Creating a lined main canals and sub canals network, lining the canals with an impermeable layer, can reduce water losses which is expected issue because the feeder canals are earthen canals. Therefore, the water conveyance system would be more efficient not only for the restoration of the marsh, but also for the irrigation of the farmlands. We also design the feeder canals to create a smaller surface area of the water can reduce evaporation.

1.4 The Significance of the Study

1. Updates the calculation of the water balance and figure out the water needed to restore the western Al-Hammer marsh in the future.
2. Identify the main challenges in the marsh restoration, including water shortage, water resources mismanagement, and hydraulic efficiency of the main feeder canals.
3. Improve the restoration management through evaluation of the current circumstances and improve the hydraulic management through replacement of the water regulators and lining the feeder canals for more efficiency and less water losses.
4. Support the environmental awareness regarding the significance of the wetland ecology and protection of the water sources as well as using modern irrigation methods to reduce water loss.

1.5 The Area of Study

The Al-Hammar marsh is one of the three major marshes in Iraq which experienced great changes in the period 1990-2003. The total area is approximately 2,800 km^2 which includes permanent and seasonal marshes and lakes [8]. The marsh is divided into two parts: the eastern part which feeds from the Tigris River, and the western part which feeds from the Euphrates River. According to the U.S. Department of Energy, the Al Hammar marsh has the two largest oil reserves in Iraq. Therefore, in 1985 the Iraqi government drained the eastern part of the Al Hammar marsh for oil exploration [2]. Figure 3 shows the eastern and western parts of the Al-Hammar marsh based on the shapefile provided by CRIMW.

This research will focus on the western part of the Al-Hammar marsh which is located in Thi Qar province, extending from near Al-Nasiriyah to the northwest of Al-Basrah province in southern Iraq. The region was selected for three main reasons: (1) the Al-Hammar marsh was entirely drained and its environment completely destroyed; (2) the western part of the Al-Hammar marsh is in the worst condition of all the Iraqi marshes because it feeds from the Euphrates River, which has serious problems in water quality (such as rising of salinity concentrations) and quantity (such as the obvious reduction in water flow); and (3) having a background about the Al- Hammar marsh through MSc. Degree in 2006. The study involved the aquatic environment of the Al-Hammar marsh after its restoration in 2003. Many of the water quality parameters were measured, such as Total Dissolved Solid (TDS), Total Suspended Solid (TSS), Dissolved Oxygen (DO), Temperature, Nutrients, and Trace elements. It is important to find an appropriate approach to solve the environmental issues of the Al-Hammar marsh. In addition, there is an availability of studies concerning the marsh conducted by CRIMW and Iraqi universities and research centers.

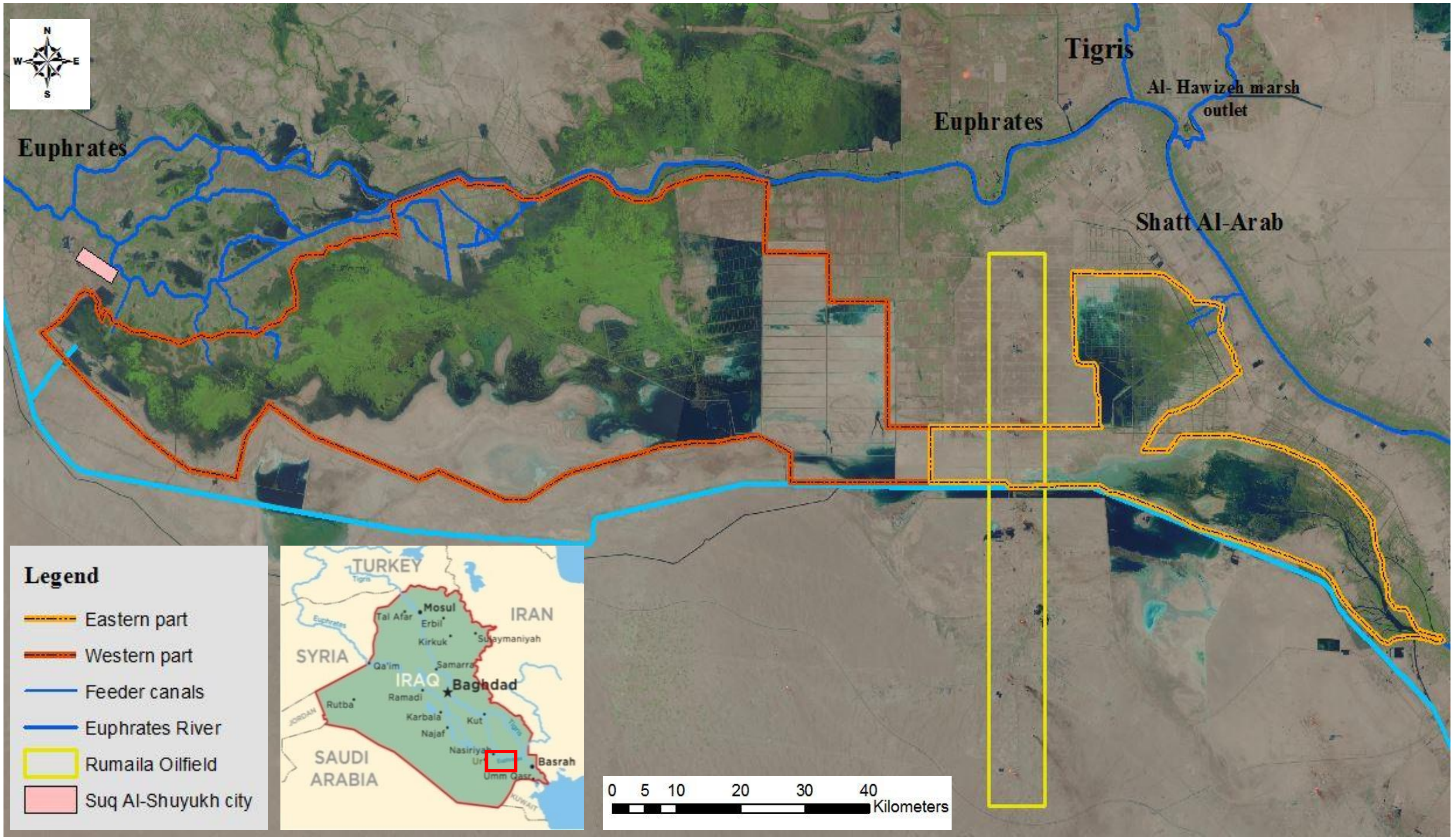

Figure 4. Map of the Al-Hammar marsh (scale1:400,000) produced by Landsat image [10], Iraqi map [11].

1.6 Data Sources and Data Required

The main source of data is the Ministry of Water Resources (MoWR) in Iraq. The Center for the Restoration Iraqi Marshes and Wetlands (CRIMW) is a one of the MoWR departments. It was established in 2003, and it is responsible for the management of the Iraqi marshes. Therefore, it collects all the data about the Iraqi marshes, such as hydrological management, water quality, biodiversity studies, social ecology studies, and other many sudies about different aspects of the marshes. The measurements of water discharges in all the marshes are traditionally reported monthly by gauging stations. CRIMW also worked with the local and international institues and agencies to develop the plan for the marsh's management and to eliminate possible environmental threats. The hydrologic data such as flow measurements requested from MoWR by an official letter supporting this project. Other sources of data are UNESCO publications and studies in Iraqi universities. These studies present different data, approches, and conclusions. Therefore, they are informative and supportive for future studies about the Iraqi marshes in different disciplines. In addition, many countries and NGOs worked together with the Iraqi government to create a long-term development strategy in order to restore the Iraqi marshes and develop their sectors. For example, in 2003, Italian Ministry for the environment, land and sea and Nature Iraq conducted The New Eden Project which supports the Iraqi government in restoring the Mesopotemian marshes. This cooperative work included other Iraqi Ministries, such as the Ministry of Water Resources (IMoWR), the Ministry of Municipalities and Public Works (MoMPW) and the Ministry of Environment (MoE). Subsequently, this initiative had two significant accomplishments, the “Abu Zirig Marsh Monitoring Program” and the “Water and Energy Optimization Feasibility Study”. In New York, in April 2004, the results were presented at the 12th United Nations Sustainable Development Conference (CSD-12) [12].

1.7 Water Resources in Iraq

The Euphrates River is the main source of fresh water to the western part of the Al-Hammar marsh [4]. The marsh area is a flood plain to the river during high-flow periods in winter and spring caused by a mixture of rain- and snow melt in these seasons. The Euphrates originates in the Armenian highlands of eastern Turkey, about 3000 m asl, and has a total length of 2,786 km. It crosses three riparian countries from the headwaters until it joins the Tigris River in Iraq to form Shatt Al-Arab, which discharges in the Arabian Gulf. Historically, the period 1938-1973 is considered to represent the near natural flow of the river because there was limited water regulation in the river's basin. In contrast, the period between 1974 and 1998 was the first phase of water infrastructure development in the Euphrates basin, which has had a significant negative impact on the flow regime. For instance, the Euphrates' annual inflow rate at Hussaybah station in Iraq (at the Iraqi- Syrian border) between the years 1990-2010 was constantly decreasing. The lowest inflow of water 250 m^3/sec was recorded in 2009. Therefore, a negative discharge trend in the Euphrates occurred due to the construction of dams, such as the Keban dam in Turkey in 1974 and the Tabqa dam in Syria in 1975 [4]. Figure 4 shows comparisons in the monthly flow regime of the Euphrates River during different time periods. According to the Russian Master Plan forecasts, the volume of water that will flow into Iraq by 2050 may fall to 6 billion m^3/ year. International agreements guarantee that the volume of water entering Iraq at Iraq-Syrian border may not be less than 9.15 billion m^3/ year, which is the threshold that may be reached 2030 [12]. Figure 5 shows the projected amount of water available in the Euphrates River based on the Russian Master Plan [12].

As a result of the drop in the water level of the Euphrates River, the Center for the Restoration of the Iraqi Marshes and Wetlands (CRIMW), which is responsible for the Iraqi marsh restoration and management, diverted the Main Outfall Drain (MOD) water to feed the western part of Al-Hammar and reduce the water deficit [12].

The MOD is a main drainage channel, which collects the drainage water from the irrigation projects that extend from southern Iraq to Baghdad. The design and implementation of the MOD started 1950, and work was completed in 1960,(except for one final sector which was completed in 1992). The MOD has a total length of 528 km, collects from 22 drainage channels, and dischages 140 m^3/sec at its southern terminus. MOD water is brackish and TDS is variate based on the section (North, Middle, South). The TDS is about 5000-10,000 ppm, where the western part of the Al-Hammar is located [13].

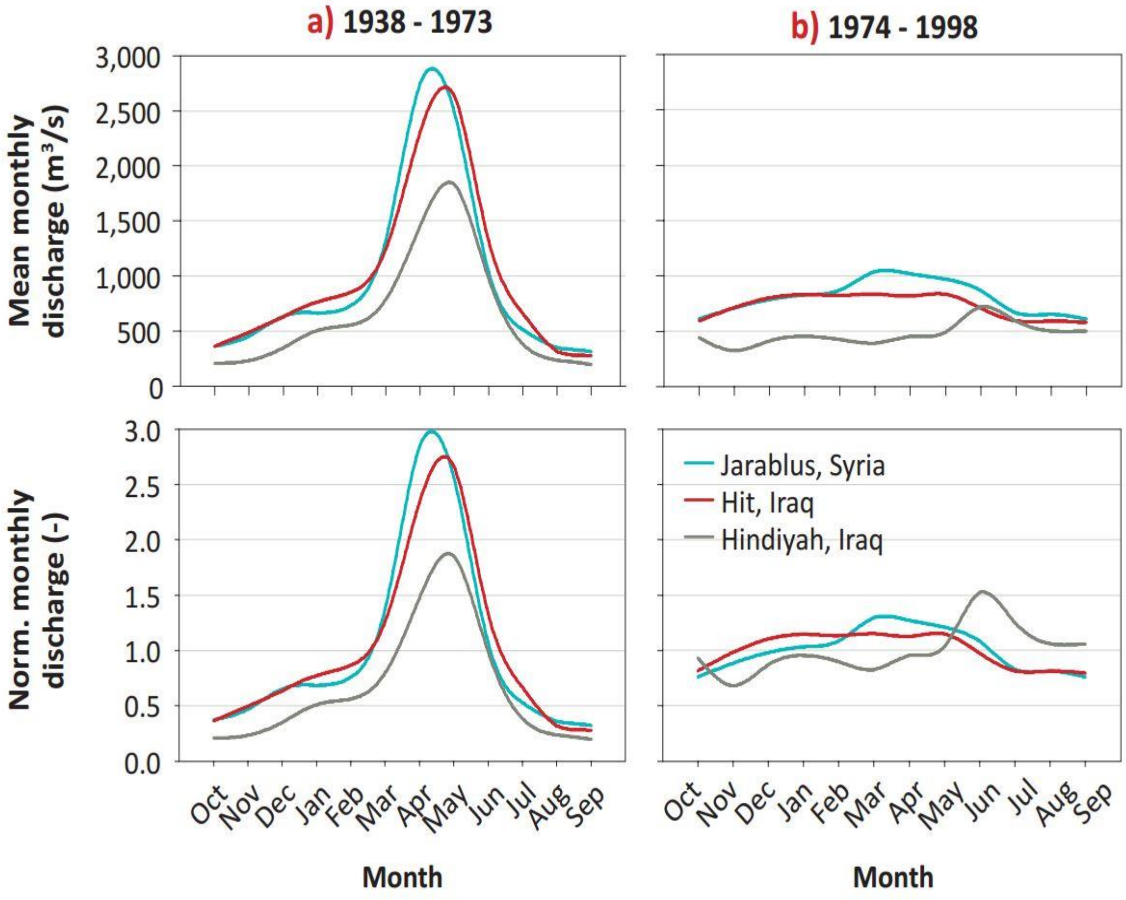

Figure 5. Mean monthly flow regime of Euphrates River for different periods [4].

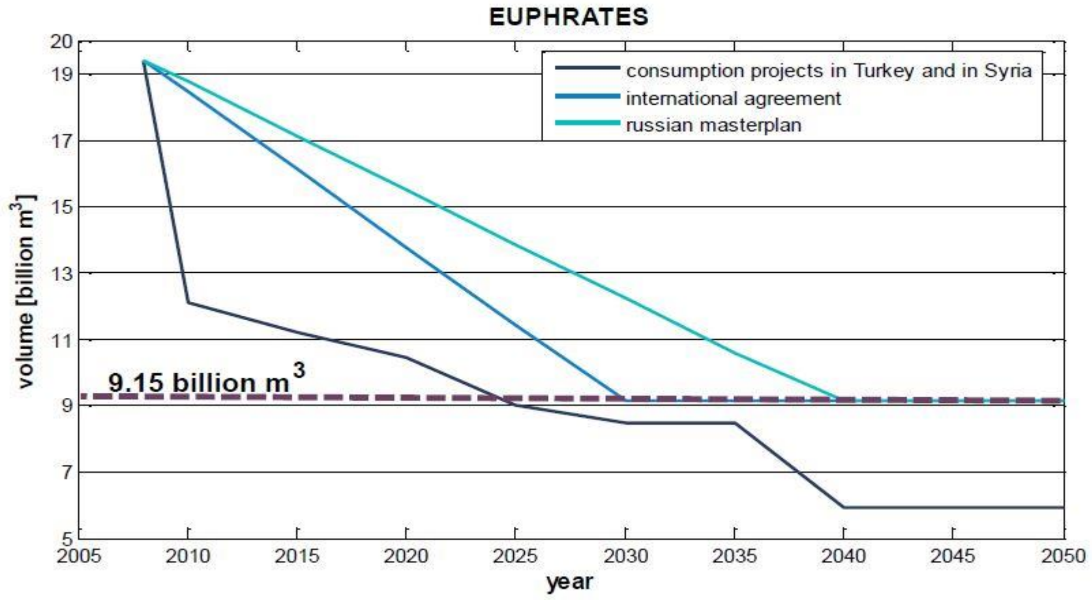

Figure 6. Water demand of the Euphrates River from upstream countries [12].

1.8 Draining of the Iraqi Marshes

Historically, the Iraqi marshes were the floodplain of the Tigris and the Euphrates rivers in the high-flow seasons. The marshes were considered the mouth of these rivers because the area of the marshes is flat and its elevation is close to the mean sea level. The draining campaign of the Iraqi marshes by Saddam's regime took place due to geopolitical and military reasons, and it included many phases. Firstly, during the Iraqi-Iranian war in the 1980s, the Iraqi regime started constructing embankments around the southeastern border with Iran. The embankments divided the marshes into many compartments which were easier to access and made the draining process of the marsh faster. In addition, the Iraqi army used the embankments as military roads during the war. Secondly, after the 1991 Gulf war, the Shiites in the south rebelled against the Saddam regime, and they used the marsh regions as a harbor. Therefore, Saddam's regime carried out a military operation in the marsh regions. During this operation, the regime burned and bombed the marsh villages to eliminate rebellion against his rule and built massive drainage canals to drain the marshes. In the Al-Hammar marsh, the regime constructed the embankments to the Euphrates River from south of the city of Suq Al-Shuyukh to Al-Qurnah city. These embankments helped to divert the entire flow of the Euphrates River away from the Al-Hammar marsh. Consequently, the Al-Hammar marsh converted from the mouth of the Euphrates river to dry land. The other impact of the embankments was to change the path of the Euphrates river. The Euphrates river joined the Tigris river in Al-Qurnah city instead of Karmet Ali, which is located in southern Al-Qurnah city about 70 Km at Al-Basrah province. Thirdly, in 1992, the Saddam regime completed the last sector of the Main Outfall Drain (MOD) which was used to deliver the water from the marshes into the Arabian Gulf. MOD is the canal that was originally designed to collect the drainage water from irrigation projects spanning from the North of

Baghdad until the Arabian Gulf in order to reduce the salinity concentrations of the soil in Iraq [13]. Finally, at the same time as the draining campaign, there was a negative trend in the water quantity of the Tigris and Euphrates rivers [4], [5]. This trend caused a water shortage that was dramatically increased by the construction of dams in upstream countries. In spite of these facts, the regime tried to give a reasonable explanation for draining the marshes, such as land reclamation designed to achieve national self-sufficiency through agricultural crops (especially with the International sanctions against Iraq in 1991). Figure 6 shows the impacts of the draining campaign and the construction of dams in upstream countries on the Iraqi marshes.

Figure 7. Photos of the snails in the dried marshlands at Al Nasiriya city, taken by Ali Al-Quraishi in 2010.

1.9 Degradation of the Marshlands Ecosystem

The draining of the Iraqi marshes caused an obvious disruption in the marshland’s ecosystem when the tremendous change in the distribution of marshland occurred between 1992 and 1994 [12]. The collapse of the marshland’s ecosystem was represented by the reduction of vegetation cover. For example, the reduction in the vegetation cover was measured through the Normalized Difference Vegetation Index (NDVI) as follows: Al-Hawizah marsh -38%, Al-Hammar marsh -82%, and Central marsh -92 % [14].

Declining water flow into the marshes, the reduction of land cover, increasing drought periods, and increasing water salinity led to the destruction of many flora and fauna species. The loss of habitat for migratory birds caused some species to go extinct. Milk products and fish were the main resources collected from the marsh ecosystem. These products supported the local Iraqi markets. Moreover, 60% of all fish consumed in Iraq came from the marshes [15]. The decline in vegetation cover and land quality indicate the variation in water and nutrients influx to the marsh regions due to water management projects by upstream countries [14]. Table 1 and Figure 7 show the reduction of land cover in the Iraqi marshes between 1973 and 2000. As a result of losing the marsh region, the death of the water buffalo and the reduction of the fish occurred, which had a negative economic effect in the Iraqi market [15].

Table 1. Statistics of the land cover changes of the Al-Hammar marsh [15].

Land cover Category	1977(Km^2)	1985(Km^2)	2000(Km^2)
Permanent Marsh	1632	2347	60
Seasonal Marsh/ Agriculture	286	339	210
Open Water	1933	694	112
Total Wetland	3565	3041	172

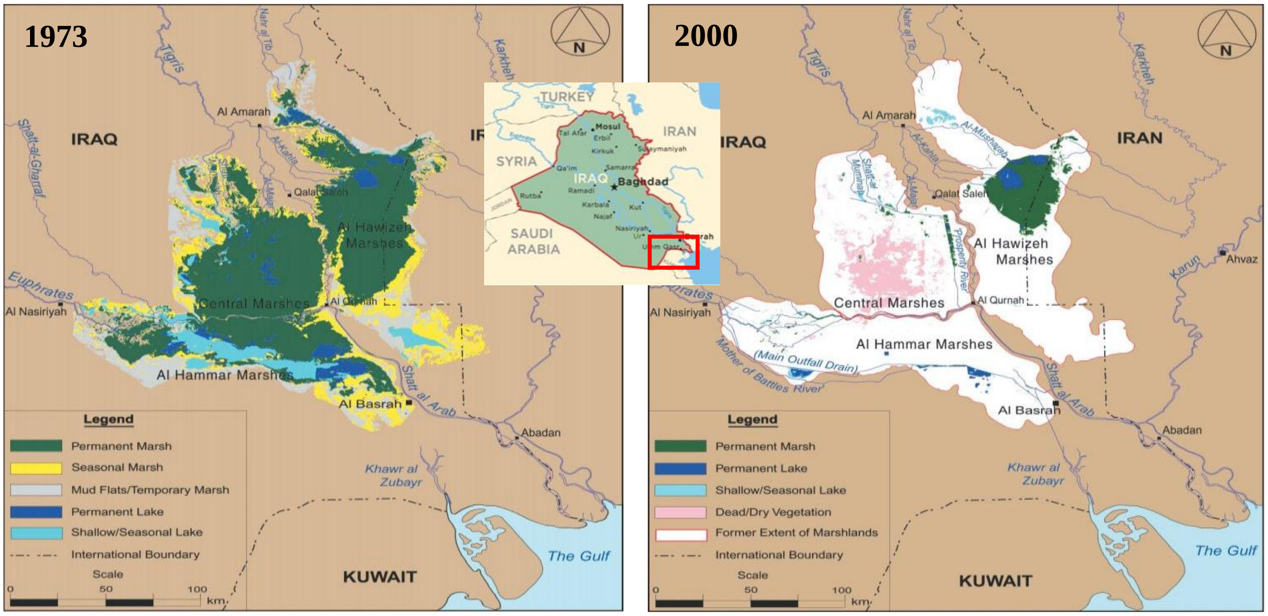

Figure 8. Land cover of the Iraqi marshes between 1973 and 2000 [3].

1.10 Water Resource Challenges in Iraq

1.10.1 Climate Change Impact

A predictive model for Iraq, alongside the Middle East and North Africa (MENA) regions, simulated the average monthly measurements of temperature and rainfall for the historical period from 1900 to 2009 [16]. The results of the simulation prediction model for the temperature and rainfall showed that by the end of the century the average temperature will increase from 3C° to 5C°, and the precipitation rates will decrease about 20% [16]. These results show that the effects of climate change will become more erratic and devastating through increasing temperatures and receding rainfalls in Iraq and MENA regions. Figures 8 and 9 show the prediction model of the temperature and precipitation in Iraq by 2099[16].

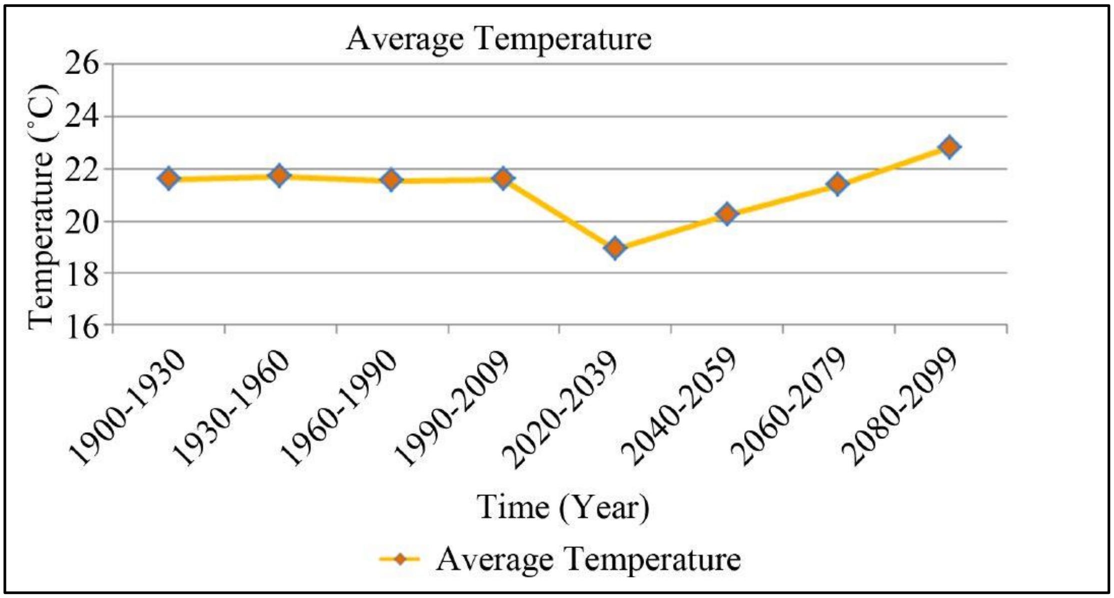

Figure 9. Prediction of the temperature in MENA regions by 2099 [16].

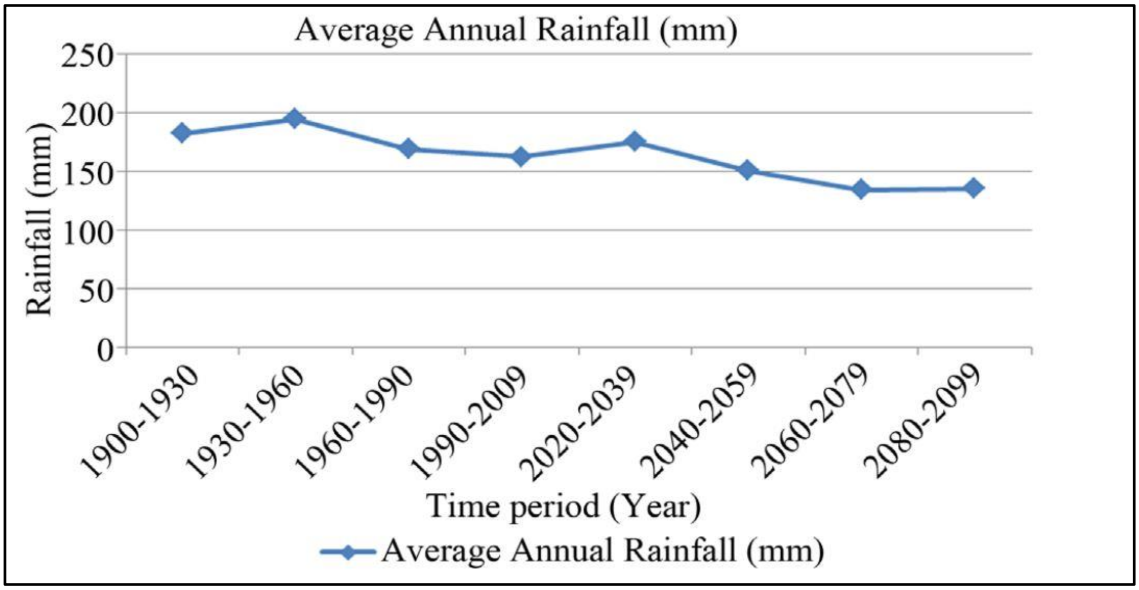

Figure 10. Prediction of the rainfall in MENA regions by 2099 [16].

1.10.2 External Factor: Upstream Management

In mid-1980s, Turkey started the hydroelectric development program which aimed to regulate the Tigris and Euphrates rivers' flow as well as produce electricity. Turkey changed the approach of the program from a hydroelectric program to an integrated regional development program. The new approach included giant irrigation projects in addition to the hydroelectric program. This project is called GAP, the Southeastern Anatolia Irrigation Project. GAP has greatly affected water quantities in downstream river basins. For example, GAP reduced the flow from the Tigris by one-third and flow from the Euphrates was reduced by half. As a result, the marshes were shrinking due to the water management of upstream countries [2]. Furthermore, according to a UNESCO study, Iraq is facing a severe water shortage. About 100,000 Iraqis have left their communities since 2005, and 70% of the Karez (water canals) in Northern Iraq were dried up by 2009. As a result, 36,000 people were displaced. The water levels in the Tigris and Euphrates have dropped by more than two-thirds their original discharge, and this decline is expected to completely dry up the Tigris and Euphrates by 2040 [15].

1.10.3 Internal Factor: Absence of the Restoration Strategy

The challenge of managing water resources in order to meet the needs and growing demands in different sectors has crucial importance to the development of Iraq. Many decades of instability in Iraq are important considerations as they have had profound effects on the water strategy. It is clear that, despite the projects in the water resources sector in Iraq, finding a clear and suitable strategy to achieve a sustainable management of water resources is a formidable challenge because of the linkages between external factors and internal disturbances, such as the absence of international coordination, and the security situation in Iraq. Therefore, to develop a plan for building a water resources strategy, some points should have top priority. Firstly, cooperative work, whether external or internal, should be viewed as critical to the project. Currently, the cooperation between the ministries and centers of the research or international organizations is still in the first stages. The other factor of vital importance is increasing awareness of the value of water in Iraq. The Iraqi people have no clear idea about the consequences of the water shortage on food security and the local economy. Consequently, increasing awareness is important in order to build an effective and fruitful strategy for water resources management in Iraq. For example, this strategy might include identifying the impacts of the flood irrigation method, such as the waste of water and the increasing soil salinity. Also, another element of the strategy may be to use different media to reduce daily water demand by the people and put appropriate regulations on reusing and recycling the waste water.

1.11 Review of Literature

Al-Ansari (2016) model predictions suggest that the future of water resources in the Middle East and North Africa (MENA) region is gloomier than the current situation. This region is vulnerable to the impacts of climate change and as such, drought periods, average temperature rises and low precipitation rates are the most significant potential challenges. For example, the average temperature will increase from 3C° to 5C° and the precipitation will decrease 20% from the current values. Consequently, water run-off will be reduced by 20-30% in the MENA region by 2050. There is a possibility of conflict over water issues between the riparian countries in the Middle East for many reasons: (1) increasing of the population growth rate will affect the water allocation per capita negatively. For example, the population growth in Syria and Iraq is about 3.7 which is greater than the population growth in Turkey which is 1.6. This growth in population has significant influence on food security through growing demands for food. At the same time, there is a reduction of agricultural lands due to the water shortage. (2) Energy security is one of the main goals of the headwater countries which desire to reduce their dependency on expensive imports of foreign oil. For example, Turkey uses hydropower to produce their required energy. (3) Economic development causes increasing water demands for domestic and industrial activates. (4) Water availability and water management play a main role in the water crisis. Using inefficient irrigation systems in the lower basin of the Tigris and Euphrates wastes a huge amount of water and exacerbates the water shortage. (5) Public awareness will have a great effect on the preservation of future water supplies, and it is emerging as an issue of global importance on the road to achieving sustainable management for current water resources and future water need. Finally, Iraq and Syria will have a severe water shortage due to the water management of Turkey, which controls the headwaters of the Tigris and Euphrates. The Southern Anatolia Project (GAP) in Turkey includes 22 dams and 19 hydraulic power plants, which cause severe water shortages for the downstream countries, Syria and Iraq [16].

Al-Ansari (2012) addressed the possibilities of restoring the Iraqi marshes. Water quality was evaluated at several marshes for potential restoration. To evaluate the water quality of the marshes, 154 water samples were taken from 48 stations during the summer. The water quality index (WQI) was calculated to examine the suitability of the water for aquatic organisms. Many of the measurements were taken in WQI, such as temperature, PH, dissolved oxygen, total dissolved solid, and others. The result of the WQI of the marshes showed that the water quality was fluctuating during the seasons and the best water quality was in spring or winter, while the summer had poor water quality. The Al-Hammar marsh had the worst WQI results for every season due to the poor water quality of its feeders as well as the drop of the Euphrates river's level, which is the main source of water into the Al-Hammar marsh. The central marshes also had bad water quality for every season except the north part. Generally, the summer produces poor water quality because of the high evaporation the reduction of the dilution factor in the Tigris and Euphrates rivers. To improve the water quality in the marshes, water should flow into the marshes continuously [15]. The expected result of restoration showed that 70-75 % of the original Iraqi marshes can be restored.

Marco (2004) addressed the New Eden Project, which was supported by the Italian Ministry of Environment and aimed to overcome the challenges in the water resources sector in Iraq. The reconstruction process of water resources management was achieved by these goals: (1) preserve and manage the national water resources; (2) provide safe drinking water to the Iraqi people; (3) restore the Iraqi environment. These goals were implemented in southern Iraq especially in Basrah and Thi Qar governorates, because they have the Iraqi marshes and have experienced large scale destruction in different sectors caused by the continued wars in Iraq. The work plan had many phases. The first phase was data gathering and modeling to create a comprehensive database in different sectors, such as water control structures and sanitation and environment. The second phase was the on-site evaluations to obtain a better understanding about what actions have been taken to address the problems of pollution and poorly maintained of the water structures along the Tigris and Euphrates rivers. Therefore, Abu-Zareg marsh was addressed as a wetland pilot project to monitor the response of re-flooding and the rehabilitation processes. Consequently, optimization of water resources can be developed based on the results of the pilot project. Hence, the New Eden Project represents a powerful tool for water resources management and resolving water issues in southern Iraq, providing a general vision for numerous sectors: such as water resources, water quality and quantity, data on population, water consumption, and drinking water projects [17].

Abdul Raheem (2015) developed an approach for allocating water quality monitoring stations in the Al Hammar marsh using hydrodynamic and water quality simulation of patterns of water quality distribution. The simulation was implemented by the Surface Modeling System (SMS), such as RMA2 and RMA4 models for 27 selected cases representing differential marsh water quality. They found total dissolved solids (TDS) to be the biggest concern and presented variation in TDS in thematic maps using the spatial analysis tool in the Geographic Information System (GIS). The results showed a lack of water quality monitoring efficiency caused by the random distribution of monitoring stations in the marsh. The simulation model results explained that the variation of water quality near the inlet zone is higher than the other areas of the marsh. The study suggested setting up 46 and 15 monitoring stations in the western and eastern portions of the Al Hammar marsh, respectively [18].

Al-Hamdani (2014) chose the optimal outlet location for the western part of the Al Hammar marsh in order to reduce the accumulation of salts (caused by brackish water from the MOD through Al Khamissiya canal). TDS in the Khamissiya Canal was 6300 mg/l in 2012 January and 8100 mg/l in July 2012. In contrast, the Euphrates River, which feeds the western marsh through many feeders, had TDS concentrations of 2020 to 305 0mg/l in January and 2380 to 3700mg/l in July. Many factors played significant roles in identifying the optimal outlet location, such as marsh topography, water depth, water velocity, and TDS concentration distribution. The suggested outlet reduces TDS concentration because it allows salts to be pushed out of the marsh. Therefore, the main path of water flow that this study chose is located at the centerline of the marsh [8].

Munro and Touron (1997**)** estimated the rate of the Iraqi marshlands degradation using satellite data. The Landsat TM and the band 1 to 5 were used to find the Vegetation Index (NDVI) which represents the vegetation distribution. NDVI results showed that 90% of the marshlands dehydrated between 1992 and 1994, such as the Al Hammar marsh and the Al Amarah marsh (Central marshes). The most significant collapse of vegetation occurred between 1992 and 1993 due to the drainage operations in the region. For instance, the changes in vegetation coverage between 1992 and1994 were –92% in the central marshes, –82% in the Al Hammar marshes, and –38% in the Al Hawizeh marsh. On the other hand, the major changes in the water coverage between 1992 and 1994 were –96% in the central marshes, –79% in the Al Hammar marshes, and +3% in the Al Hawizeh marsh. However, there was great difficulty in accessing the field data which makes accuracy assessment impossible [14].

Al-Quraishi and Ziboon (2006) conducted a study of the aquatic environment of the Iraqi marshes, focusing on the western Al Hammar marsh. This study aimed to determine the total area of inundation after the restoration of the western Al-Hammar marsh by using Remote Sensing and GIS Techniques. The classification of the satellite data, particularly supervised classification, was used to determine the area of each land cover category by multiplying the number of pixels in each category by the ground resolution of the satellite imagery, which was MODIS 250 m. The second goal was a study of water quality characteristics of the inundated area of the marsh. The water quality measurements included a wide range of the physical measurements, chemical measurements, nutrients, and heavy metals. The results of the water quality study showed that the water quality was between medium and poor based on the location of the sample and the concern about Total Dissolved Solid (TDS) concentrations, which ranged from 900 to 4240 mg/l in January and from 1250 to 3680 mg/l in August 2005. Also, there was intensive growth of aquatic plants within the marsh, such as submerged plants, floating plants, and reeds. The abundance of nutrients in the water, such as phosphorous and nitrogen come from human activities, such as agriculture and wastewater which contribute to the increase in nutrient levels within the marsh [19].

Salman and Ziboon (2006) measured many parameters in the Al Hammar marsh's soil, such as Organic Matter (OM), Total dissolved Solids (TDS), and soil texture. The study showed the relationship between the parameters and the spectral reflectance in the satellite image classification. The measurements showed the minimum and maximum concentrations of TDS for 25 samples of soil were 3.69 and 7.75 mg/l, respectively. The main source of soil salinity was the water of marsh, which has relatively high salinity concentrations [20].

2. Assessing Surface Water Resources

2.1 Introduction

After the Iraqi marshes were listed as a world heritage site in 2016, updating the water budget for the Iraqi marshes became necessary and is currently a top priority of the Iraqi government. As a result of surface water shortages, estimating the water from the Tigris and Euphrates rivers required for different purposes is one of the most important of the new budget elements. In 2014, the Iraqi government, through the MoWR together with an Italian consulting firm, finished the last Master Plan for Iraqi water resources. The Iraqi government needs to negotiate with the upstream countries, such as Turkey, Iran, and Syria, in order to reveal the amount of water needed for different sectors. These countries have the most headwaters and the watershed of the Tigris and Euphrates rivers, so their water management has affected downstream countries, particularly Iraq. In addition, a water budget must be evaluated in order to restore and maintain the wetland through the available water during each season [21]. Therefore, this study will calculate the water budget for the western part of the Al-Hammar marsh by using the general water balance equation without focusing on the details of the inundation process. For example, we will not focus on the number of shoots needed to achieve restoration requirements and the length of time needed to complete the inundation process). The monthly data for the water budget components are provided by the Iraqi Ministry of Water Resources, including precipitation, surface water inflow, and evapotranspiration. The general equation for the water budget can be expressed [21]:

$$\Delta S = P - E\text{-}ET \pm SW \pm SRO \pm GF \tag{2-1}$$

Where: $\Delta S =$ change in storage, $P =$ precipitation, $E =$ evaporation of open water, $ET =$ evapotranspiration, $SW =$surface water flow, $SRO =$ surface runoff, $GF =$ groundwater flow.

In this study, the change of storage (ΔS) will be calculated under different circumstances as shown below:

1- The threshold of the storage change $(\Delta S)_{\text{threshold}}$: this storage represents the minimum amount of water required to restore the marsh and meet the requirements for aquatic biota to survive and maintain the marsh ecosystem. The $(\Delta S)_{\text{threshold}}$ can be calculated by using total area of the marsh and the optimal water depth of the marsh. The optimal water depth will be obtained from the historical hydroperoid records when the marshes were in good condition before 1980. The area of the marsh was provided by MoWR in Iraq as a shapefile that includes area of the marsh and farmlands.

2- The actual storage change $(\Delta S)_{\text{actual}}$: the actual storage will depend on the monthly inflow field measurements of the feeder canals. Because of the variation in the inflow per month, the storage of the marsh will change. Therefore, the actual storage will show the fluctuation in storage over time. Figure 10 illustrates the threshold and actual storage in the marsh.

3- The data provided by MOWR in table 1 is discontinuous due to the looting of the official building in 2003. Although CRIMW was established in 2004, they did not begin the field measurements until 2009 because they did not possess sufficient instruments and technicians. The climatological data includes precipitation and evapotranspiration obtained from Iraqi climatological department for Al-Nasiriyah station from 2009-2016, which consists the period of the flow measurements as shown in tables 2, 3 and the missing data of the evapotranspiration was calculated by using interpolation (**) and extrapolation (*).

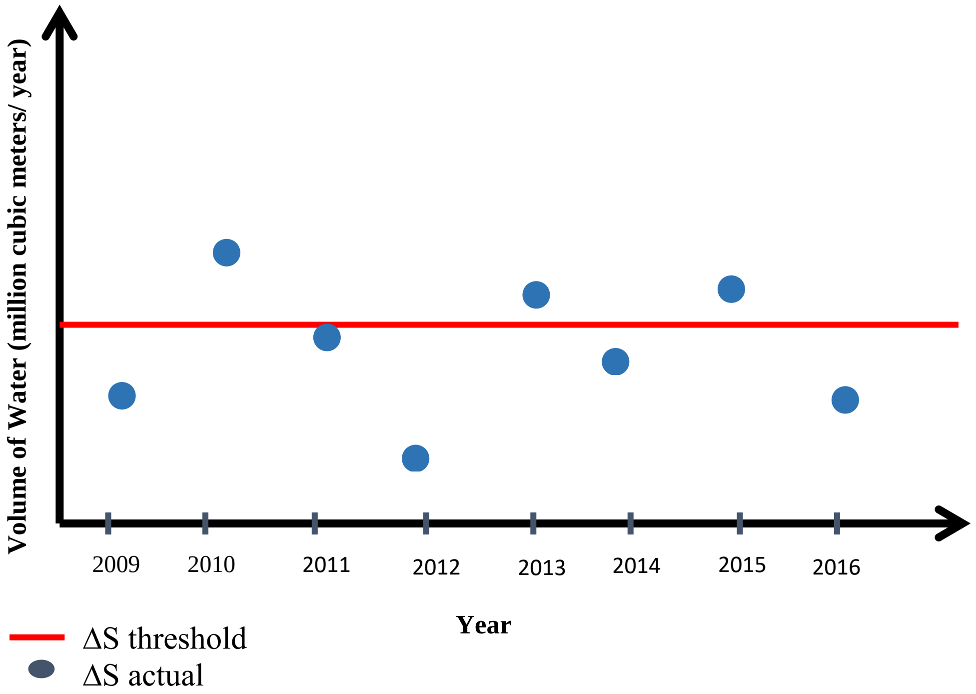

Figure 11. Assumed data to explain the threshold and actual storage.

The measurements of the main variables in the water balance equation were found from different sources, such as CRIMW and Iraqi meteorological department. The missing data were calculated by using interpolation and extrapolation. The ground filtration value assumed depends on the soil texture of the marsh, which is silty clay [15], [20] as shown in Table 2. According to many studies, the type of soil of the Al-Hammar marsh is impermeable and has a range of values depending on the ground slope. The value of the infiltration rate has neglected in the calculation because it is small. While the area of the marsh calculated from the satellite images for the same period. It is important to mention that the area of the marsh was considered the inundated area and not the entire area of the shape file of the western Al-Hammar marsh (Figure 3).

Table 2. Soil characteristics of the Al-Hammar marsh [15].

Location	Organic Matter OM %	Silt %	Sand %	Clay %
Eastern Al-Hammar (Al-Shafi project)	5.5	40	18	42
Western Al-Hammar (Al-Malha project)	7	35	18	47

Table 3. Monthly rainfall measurements (mm) at Al-Nassiriyah meteorology station [22].

yr./mo.	2009	2010	2011	2012	2013	2014	2015	2016
Jan	0.3	2.6	7.5	6.2	8.8	9.3	3.3	1.2
Feb	7.1	2.7	19.9	21.6	0.2	1.3	17.6	23.0
Mar	18.6	0.5	13.8	1.3	0.3	59.7	24.4	8.4
Apr	4.6	29.2	21.2	6.7	5.1	20.1	1.0	15.8
May	1.5	14.8	9.7	0.0	36.0	0.0	0.6	3.6
Jun	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
Sep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct	0.2	0.1	2.6	2.6	1.8	8.4	14.3	0.0
Nov	1.7	0.4	13.0	58.5	126.4	23.5	8.2	0.0
Dec	22.3	7.3	0.0	19.3	1.7	2.6	36.1	9.2

Table 4. Monthly evapotranspiration measurements (mm) at Al- Nassiriyah meteorology station [22].

yr./mo.	2009	2010	2011	2012	2013	2014	2015	2016
Jan	88.3*	120.1	95.9	96.8	83.7	61.0	75.6	72.9
Feb	197.0*	152.4	114.5	129.7	125.0	95.0	91.8	103.9
Mar	284.6*	279.5	242.2	235.3	239.8	136.5	137.4	148.2
Apr	351.1*	338.5	307.3	335.3	288.8	183.8	199.0	180.7
May	396.4*	442.3	474.4**	498.5	362.5	247.7	241.4	259.3
Jun	420.5*	423.9**	641.6	627.1	517.6	260.0	334.1	274.1
Jul	632.6	405.5**	592.6**	587.2**	506.2**	273.0	326.8	312.4
Aug	597.7	387.1**	543.5**	547.4**	494.8	239.0	304.8	281.5
Sep	454.1**	368.7**	494.5	507.5	289.6	217.0	220.3	229.4
Oct	310.5	350.3	314.7	286.9	258.1	156.0	150.9	157.1
Nov	185.0	181.8	139.1	101.3	104.4	105.0	83.1	100.9
Dec	92.2	129.8	110.8	71.8	67.7	71.2	64.7	65.2

2.2 Water Budget and the Main Assumptions

According to the hydrological situation of the western Al-Hammar marsh, some of the terms in the water budget equation will be neglected as shown in Figure 11 below;

$(-\mathrm{E})$ The evaporation will be neglected to avoid calculating the evaporation (E) twice, one with the (E) and one with evapotranspiration (ET).

$(+\mathrm{SRO})$ Surface runoff will be neglected because most of the areas around the marsh are drylands with low rainfall rates; therefore, no runoff generates.

$(-\mathrm{SW})$ There is no outflow of surface water in the western part of the Al-Hammar marsh.

$(\pm\ \mathrm{GF})$ There is no recharge from ground water to surface water. Also, the discharge value is very small.

(+) unmeasured water flow, such as drainage water from the agricultural lands around the marsh.

Consequently, the general water budget equation will be;

$$\Delta \mathrm{S} = \mathrm{P} - \mathrm{ET} + \mathrm{SW} \qquad (2\text{-}2)$$

Where: $\Delta\mathrm{S}$ = change of storage, P= precipitation, ET= evapotranspiration, SW= surface water.

The questions will be used in the calculation as below:

1- Calculate $(\Delta\mathrm{S})_{\text{threshold}}$ which represents

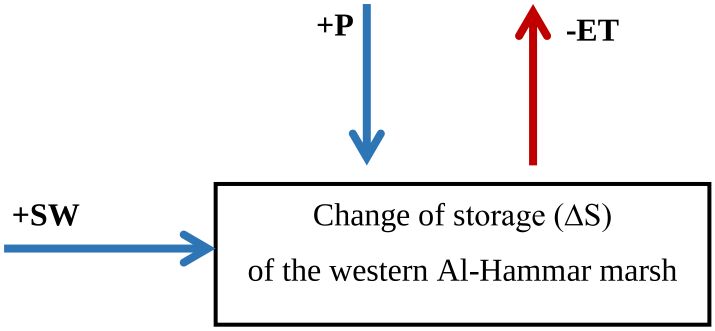

Figure 12. Main drivers to calculate the water budget of the western Al-Hammar marsh.

$$(\Delta S)\text{threshold} = \text{Area of the marsh(min)} \times \text{waterdepth(min)} \qquad (2\text{-}3)$$

2- Calculate the $(\Delta S)_{\text{actual}}$ which represents

$$(\Delta S)\ \text{actual} = P - ET + SW \qquad (2\text{-}4)$$

3- Calculate the needed water (+SW) by plugging all the terms in the water balance equation when the change in the storage ΔS=0 as shown below

$$\Delta S = P - ET + SW \qquad (2\text{-}5)$$

$$SW = ET - P \qquad (2\text{-}6)$$

The water budget was calculated using flow measurements [23] and many assumed variables based on the local conditions (described as follows):

1- The ideal storage area is located in a depression between upland areas and is assumed to be about 500 km^2 depending on the satellite images used for the western Al-Hammar marsh. This area was determined by measuring the average permanently inundated area throughout the study period (2009-2016). This area was used to calculate the storage threshold, which considers the minimum volume of water that must be maintained within the marsh to preserve its ecosystem. The other benefits of using 500 km^2 as a goal (minimum area) out of the 1,345 km^2 total area, according to the shape file of the western Al-Hammer, are as follows:

   A- Submitting a reasonable amount of the water needed to restore the marsh, encouraging the riparian countries to release a sufficient amount of water to restore the marshes as one of the UNESCO world heritage sites.

   B- Using the available alternative water resources in the marsh regions, such as drainage water and municipal wastewater to restore the marshes. This step will show serious efforts to reuse water in light of the severe water shortage in the region exacerbated by an increasing population and demand for water resources. Also, using a certain area of the marsh as a permanent inundated area, which is 500 km², will decrease the water loss by evaporation and evapotranspiration.

C- Using the difference in the areas, permanent inundated area (500km²) and total area 1,345 km², as a flood plain during the flood-time or as agricultural lands because the marshlands are fertile lands for agriculture.

D- Preserving the minimum area of the marsh will ease difficulties for both management and operations as well as protect the species of flora and fauna from extinction.

2- Many studies have shown that the water depth of the marsh varies with the water level of the Euphrates river, which is influenced by seasonal variations. The Al-Hammer marsh is riverine marsh and the flow from the Euphrates river to the marsh depends on the energy gradient between them. The water depth within the marsh fluctuate between 0.5 to 3.5 meters annually [24], and in order to calculate the threshold for water storage, the water depth is assumed to be no less than 1m to preserve the marsh ecosystem and maintain the health of the marsh. In addition, many species of aquatic animals require a certain depth of water to survive, such as fish, otters, and water buffalo.

2.3 Results of the Storage Calculation

The water storage within the western part of the Al-Hammer marsh is driven by the Euphrates river flow. Therefore, the inundation area and hydroperiod of the marsh is related to seasonal fluctuations of the Euphrates river. According to satellite data, the storage and inundation area have changed throughout the study period: 2009-2016. The greatest inundation areas of the marsh occurred in 2013, 2014, and 2016 and the lowest in 2009 and 2015 (Figure 12). During these periods alternative water resources, such as brackish water and wastewater, were used dramatically in addition to the fresh water from the Euphrates river. However, the surface water within the marsh reaches peak heights of 0.5- 3.5 meters annually, which helps to maintain the survival of certain species of plants and animals [25]. The other key component is precipitation, which occurred in less than ½ of the year's months. The average annual precipitation does not exceed 150 mm [26] with harsh local conditions, such as air temperature, sunshine duration, and humidity. Moreover, the drainage water from the agricultural lands discharges into the marsh, and this amount of water was not considered in the water budget by the CRIMW for the discharge measurements of the western Al-Hammar. In contrast, evapotranspiration (ET) and ground infiltration represented the output of the water budget model. The Al-Hammar area is situated in a zone with dry and hot summers and cool winters [26]. Therefore, with these dry conditions, the average annual evapotranspiration (ET) is 2909 mm, and it is considered the main reason for water loss within the marsh. The other source of outlet is ground filtration, which depends on the water table and soil texture. The soil texture of the Iraqi marshes varies between medium to heavy (i.e. silt) and is influenced by the alluvial deposits at flood-time and absence of course-textured soils, which makes the ground have a slow rate of filtration [26]. Figures 13, 14 show the results of the water balance of the western Al-Hammar through the study period.

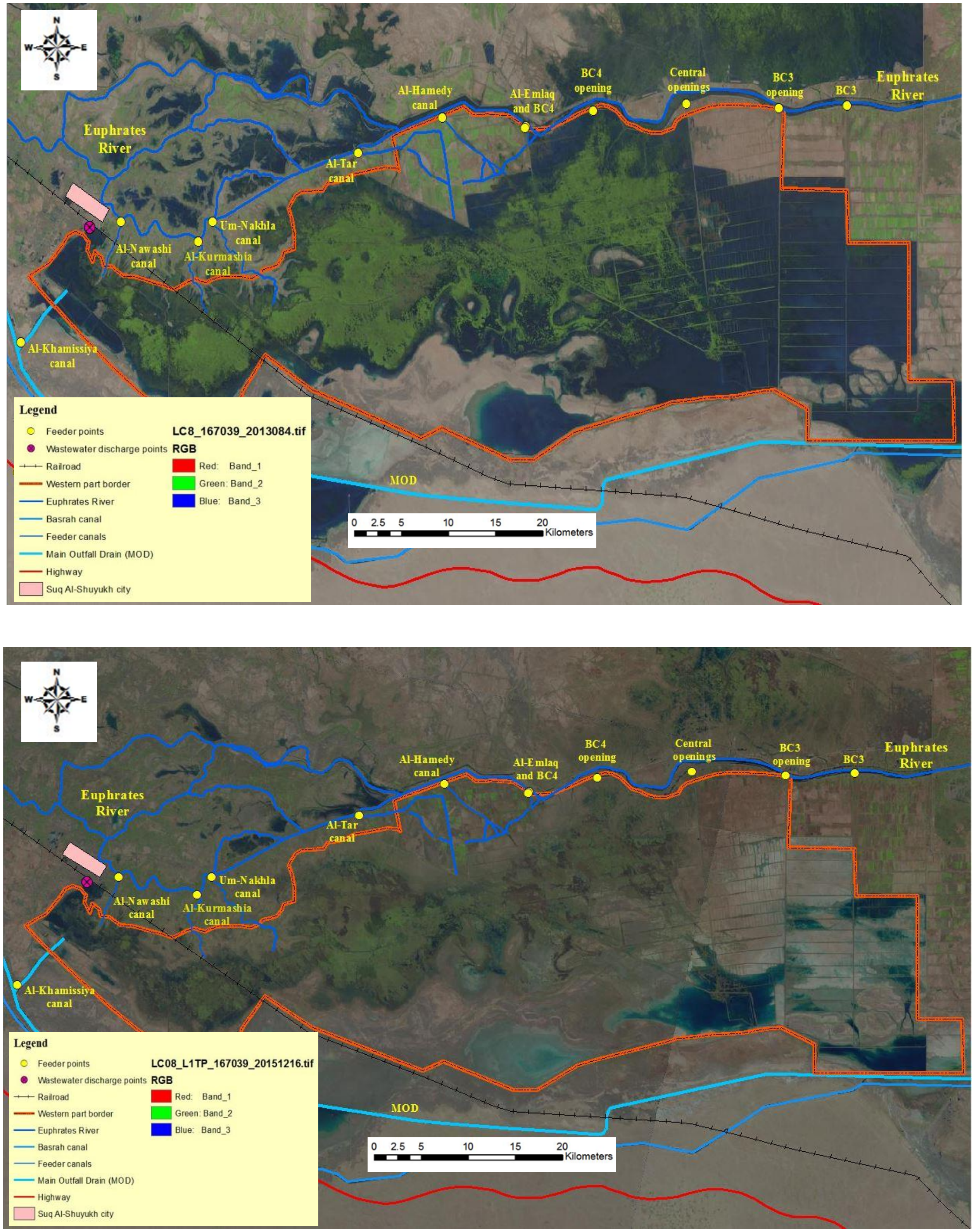

Figure 13. Variation in the storage area of the western Al-Hammar marsh in 2013(top) and 2015(bottom).

Table 5. The water balance of the western Al-Hammar marsh in 2009 with storage area about 267 km² and flow in (m³/sec).

Month	Al-Nwashi canal	Al-Kurmashia canal	Um-Nakhla canal	Euphrates-Right canals	Al-Khamissiya canal	WW pump stations	BC3 canal	BC4 canal	BC3 opening	BC4 opening	Central openings
Jan	6.43	0.907	3.72	10.9	0	0.416	1.80	2.20	1.9	2	2.1
Feb	6.5	0.606	1.008	7.4	0	0.416	1.80	2.20	1.9	2.0	2.1
Mar	5.95	0.35	0.852	1.2	0	0.416	1.64	2.00	1.73	1.82	1.91
Apr	5.41	0.65	1.932	9.7	0	0.416	1.49	1.82	1.57	1.65	1.74
May	8.99	0.56	2.16	3.8	0	0.416	3.90	3.80	4.60	5.50	10.00
Jun	8.17	2.50	2.53	3.4	0	0.416	3.55	3.45	4.18	5.00	9.09
Jul	8.10	2.55	2.8	3.03	0	0.416	3.25	3.25	3.80	4.5	7.93
Aug	8.02	0.96	1.6	24.3	0	0.416	2.96	3.04	3.42	4.0	6.76
Sep	7.94	0.85	1.5	25.7	0	0.416	2.67	2.83	3.04	3.5	5.60
Oct	7.86	0.95	1.9	28.1	0	0.416	2.38	2.62	2.66	3.0	4.43
Nov	7.79	0.65	1.35	31.6	0	0.416	2.09	2.4	2.28	2.5	3.27
Dec	7.71	1	1.7	36.2	0	0.416	1.80	2.20	1.9	2	2.1

Continued table 5.

P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	∑SW m³/mo.	ΔS actual Mm³	water depth (m)
0.3	88.3	80100.0	23576100	84010000	60.5	0.2
7.1	197	1895700.0	52599000	67370000	16.7	0.1
18.6	284.6	4966200.0	75988200	46380000	-24.6	-0.1
4.6	351.1	1228200.0	93743700	68330000	-24.2	-0.1
1.5	396.4	400500.0	105838800	113360000	7.9	0.0
0.6	420.5	160200.0	112273500	109670000	-2.4	0.0
0	632.6	0.0	168904200	102690000	-66.2	-0.2
0	597.7	0.0	159585900	143880000	-15.7	-0.1
0	454.1	0.0	121244700	140080000	18.8	0.1
0.2	310.5	53400.0	82903500	140870000	58.0	0.2
1.7	18.5	453900.0	4939500	140900000	136.4	0.5
19.3	92.2	5153100.0	24617400	147700000	128.2	0.5

Table 6. The water balance of the western Al-Hammar marsh in 2010 with storage area about 415 km² and flow in (m³/sec).

Month	Al-Nwashi canal	Al-Kurmashia canal	Um-Nakhla canal	Euphrates-Right canals	Al-Khamissiya canal	WW pump stations	BC3 canal	BC4 canal	BC3 opening	BC4 opening	Central openings
Jan	6.7	0.57	3.37	44.4	0	0.416	1.9	2.5	1.9	2.5	2.1
Feb	6.79	0.5	3.2	38.4	27	0.416	1.89	2.47	1.97	2.48	2.1
Mar	6.17	0.5	2.95	33.4	26.9	0.416	1.72	2.25	1.79	2.26	1.91
Apr	5.61	0.55	3.8	29.5	24.2	0.416	1.56	2.04	1.63	2.9	1.74
May	7.80	3.85	4.4	26.6	26.1	0.416	3.7	3.2	3.10	4.7	1.58
Jun	7.09	1.66	2.93	24.8	24.5	0.416	3.36	2.91	4.50	4.27	1.43
Jul	7.19	2.4	3.85	24.0	25.7	0.416	3.10	2.79	4.2	3.94	2.9
Aug	7.30	2.05	3.65	24.3	25.74	0.416	2.84	2.67	3.9	3.62	2.74
Sep	7.40	2.4	4.1	12.9	25.78	0.416	2.63	2.55	3.6	3.29	2.58
Oct	7.50	2.5	4.5	17.05	25.82	0.416	2.36	2.44	3.3	2.96	2.42
Nov	7.61	1.6	2.5	13.1	25.86	0.416	2.08	2.32	3	2.63	2.26
Dec	7.71	1.13	2.3	9.87	25.9	0.416	1.8	2.2	2.7	2.3	2.1

Continued table 6.

P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	∑SW m³/mo.	ΔS actual Mm³	water depth (m)
2.6	120.1	1079000	49841500	172070000	123.3	0.3
2.7	152.4	1120500	63246000	226040000	163.9	0.4
0.5	279.5	207500	115992500	208000000	92.2	0.2
29.2	338.5	12118000	140477500	1915780000	63.2	0.2
14.8	442.3	6142000	183554500	221440000	44.0	0.1
0	423.9	0	175918500	201800000	25.9	0.1
0	405.5	0	168282500	208710000	40.4	0.1
0	387.1	0	160646500	205430000	44.8	0.1
0	368.7	0	153010500	175350000	22.3	0.1
0.1	350.3	41500	145374500	184700000	39.4	0.1
0.4	181.8	166000	75447000	164250000	89.0	0.2
7.3	129.8	3029500	53867000	151440000	100.6	0.2

Table 7. The water balance of the western Al-Hammar marsh in 2011 with storage area about 618 km² and flow in (m³/sec).

Month	Al-Nwashi canal	Al-Kurmashia canal	Um-Nakhla canal	Euphrates-Right canals	Al-Khamissiya canal	WW pump stations	BC3 canal	BC4 canal	BC3 opening	BC4 opening	Central openings
Jan	6.22	1.5	2.7	15.1	18.2	0.416	1.8	2.3	1.90	2.00	1.90
Feb	6.26	1.85	3.35	33.3	31.53	0.416	1.83	2.28	1.91	1.95	1.92
Mar	5.69	0.97	1.2	15.73	25.83	0.416	1.66	2.07	1.74	1.78	1.74
Apr	5.18	1.65	2	15.55	46.8	0.416	1.51	1.89	1.58	1.62	1.59
May	4.71	1.3	1.3	18.13	32.7	0.416	1.73	1.71	1.43	1.47	1.44
Jun	6.80	1.35	1.8	17.2	18.3	0.416	2.90	2.56	3.00	3.40	1.70
Jul	6.78	2.22	3.6	20.5	19.7	0.416	2.77	2.48	2.83	3.08	1.77
Aug	6.36	2.15	3.65	40.9	23	0.416	2.63	2.41	2.67	2.77	1.83
Sep	6.45	1.85	3.15	26.35	24.55	0.416	2.50	2.33	2.50	2.45	1.90
Oct	6.39	2.6	3.75	25.9	23.9	0.416	2.37	2.25	2.33	2.13	1.97
Nov	6.55	0.9	1.2	10	12.5	0.416	2.23	2.18	2.17	1.82	2.03
Dec	6.7	1.6	2.8	16.8	12.5	0.416	2.1	2.1	2.00	1.50	2.10

Continued table 7.

P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	∑SW m³/mo.	ΔS actual Mm³	water depth (m)
7.5	95.9	4635000	59266200	140060000	85.4	0.1
19.9	114.5	12298200	70761000	224470000	166.0	0.3
13.8	242.2	8528400	149679600	152490000	11.3	0.0
21.2	307.3	13101600	189911400	206760000	29.9	0.0
9.7	474.4	5994600	293179200	171950000	-115.2	-0.2
0	641.6	0	396508800	154030000	-242.5	-0.4
0	592.6	0	366226800	171470000	-194.8	-0.3
0	543.5	0	335883000	230120000	-105.8	-0.2
0	494.5	0	305601000	192950000	-112.6	-0.2
2.6	314.7	1606800	194484600	191830000	-1.0	0.0
13	139.1	8034000	85963800	108830000	30.9	0.1
0	110.8	0	68474400	1311200000	62.7	0.1

Table 8. The water balance of the western Al-Hammar marsh in 2012 with storage area about 670 km² and flow in (m³/sec).

Month	Al-Nwashi canal	Al-Kurmashia canal	Um-Nakhla canal	Euphrates-Right canals	Al-Khamissiya canal	WW pump stations	BC3 canal	BC4 canal	BC3 opening	BC4 opening	Central openings
Jan	7.30	1.45	2.55	21.85	18.8	0.416	1.90	2.2	2.1	2.45	2.3
Feb	7.46	1.83	2.93	23.73	23.17	0.416	1.88	2.20	2.06	2.37	2.25
Mar	7.62	0.85	1.8	14.05	20.05	0.416	1.71	2.00	1.87	2.16	2.05
Apr	7.78	1.55	2.4	20.8	22.65	0.416	1.56	1.82	1.70	1.96	1.86
May	7.94	1.53	3.1	19.87	22.6	0.416	2.50	1.95	2.55	2.70	1.69
Jun	8.10	1.35	2.85	18.85	27.2	0.416	2.27	2.30	2.95	3.18	2.10
Jul	8.04	3.4	6.85	29.85	23.2	0.416	2.18	2.28	2.73	2.92	1.9
Aug	7.97	2.15	4.3	27.25	35.05	0.416	2.08	2.27	2.52	2.65	1.88
Sep	7.91	2.6	4.35	28.83	39.57	0.416	1.99	2.25	2.30	2.39	1.86
Oct	7.84	2.35	3.9	28.35	37.65	0.416	1.92	2.23	2.08	2.13	1.84
Nov	7.78	1.35	1.95	18.35	22.1	0.416	1.81	2.22	1.87	1.86	1.82
Dec	7.71	2.13	3.2	23.87	27	0.416	1.70	2.2	1.65	1.6	1.8

Continued table 8.

P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	∑SW m³/mo.	ΔS actual Mm³	water depth (m)
6.2	96.8	4154000	64856000	164120000	103.4	0.2
21.6	129.7	14472000	86899000	182230000	109.8	0.2
1.3	235.3	871000	157651000	141460000	-15.3	0.0
6.7	335.3	4489000	224651000	167170000	-53.0	-0.1
0	498.5	0	333995000	173270000	-160.7	-0.2
0	627.1	0	420157000	185510000	-234.7	-0.4
0	587.2	0	393424000	217110000	-176.3	-0.3
0	547.4	0	366758000	229480000	-137.3	-0.2
0	507.5	0	340025000	244830000	-95.2	-0.1
2.6	286.9	1742000	192223000	235120000	44.6	0.1
58.5	101.3	39195000	67871000	159450000	130.8	0.2
19.3	71.8	12931000	48106000	189930000	154.8	0.2

Table 9. The water balance of the western Al-Hammar marsh in 2013 with storage area about 927 km² and flow in (m³/sec).

Month	Al-Nwashi canal	Al-Kurmashia canal	Um-Nakhla canal	Euphrates-Right canals	Al-Khamissiya canal	WW pump stations	BC3 canal	BC4 canal	BC3 opening	BC4 opening	Central openings
Jan	8.3	2.85	4.1	46.95	56.55	0.416	2.2	2.4	1.8	2.2	2.5
Feb	8.26	2.45	3.2	43.65	40.6	0.416	2.15	2.37	1.81	2.18	2.43
Mar	7.51	0.85	1.8	21.2	22.47	0.416	1.95	2.16	1.64	1.98	2.21
Apr	6.83	2.15	3.5	33.05	36.15	0.416	1.77	1.96	1.50	1.80	2.01
May	9.45	2.5	3.8	26.85	27.75	0.416	1.90	2.72	2.4	2.64	1.82
Jun	9.2	2.3	3.53	21.77	20.1	0.416	1.73	2.95	2.35	2.40	1.90
Jul	9.0	2.9	5.27	23.55	17.58	0.416	1.71	2.81	2.28	2.80	1.87
Aug	8.79	2.8	6.3	22.9	25.43	0.416	1.68	2.67	2.20	2.64	1.83
Sep	8.56	2.57	4.47	29.47	37.4	0.416	1.66	2.53	2.13	2.48	1.80
Oct	8.34	2.6	5.75	32	31.65	0.416	1.64	2.38	2.05	2.32	1.77
Nov	8.12	2.65	6.2	37.3	38.15	0.416	1.62	2.24	1.98	2.16	1.73
Dec	7.9	2.55	4.7	28.25	25.4	0.416	1.6	2.1	1.9	2	1.7

Continued table 9.

P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	∑SW m³/mo.	ΔS actual Mm³	water depth (m)
8.8	83.7	8157600	77589900	337650000	268.2	0.3
0.2	125	185400	115875000	283870000	168.2	0.2
0.3	239.8	278100	222294600	166380000	-55.6	-0.1
5.1	288.8	4727700	267717600	236220000	-26.8	0.0
36	362.5	33372000	336037500	213190000	-89.5	-0.1
0	517.6	0	479815200	178000000	-301.8	-0.3
0	506.2	0	469247400	181900000	-287.3	-0.3
0	494.8	0	458679600	201290000	-257.4	-0.3
0	389.6	0	361159200	242310000	-118.8	-0.1
1.8	258.1	1668600	239258700	235670000	-1.9	0.0
126.4	104.4	117172800	96778800	265860000	286.3	0.3
1.7	67.7	1575900	62757900	203510000	142.3	0.2

Table 10. The water balance of the western Al-Hammar marsh in 2014 with storage area about 960 km² and flow in (m³/sec).

Month	Al-Nwashi canal	Al-Kurmashia canal	Um-Nakhla canal	Euphrates-Right canals	Al-Khamissiya canal	WW pump stations	BC3 canal	BC4 canal	BC3 opening	BC4 opening	Central openings
Jan	8.1	2.9	5.23	17.6	25.5	0.416	1.8	2.1	2	1.85	2.1
Feb	7.97	1.97	3.6	15.27	26.45	0.416	1.77	2.07	1.99	1.84	2.05
Mar	7.25	1.45	2.35	12.8	9.7	0.416	1.61	1.88	1.81	1.67	1.87
Apr	6.59	1.87	2.73	11.53	28.93	0.416	1.47	1.71	1.64	1.52	2.70
May	7.50	1.9	2.85	15.17	27.65	0.416	2.33	2.49	1.80	2.36	2.45
Jun	6.82	1.55	2.15	19.25	15.35	0.416	2.12	2.26	2.30	2.15	2.23
Jul	6.80	2.5	4.27	23.7	12.93	0.416	2.02	2.19	2.23	2.07	2.13
Aug	6.78	2.37	4.43	25.83	31.3	0.416	1.91	2.11	2.15	2.00	2.02
Sep	6.76	1.8	3.95	22.5	22.65	0.416	1.81	2.03	2.08	1.93	1.92
Oct	6.74	1.7	4	22.9	31.9	0.416	1.71	1.95	2.00	1.86	1.81
Nov	6.72	1.83	2.53	14.15	11.85	0.416	1.60	1.88	1.93	1.79	1.71
Dec	6.7	1.4	1.9	8.65	26.35	0.416	1.5	1.8	1.85	1.72	1.6

Continued table 10.

P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	∑SW m³/mo.	ΔS actual Mm³	water depth (m)
9.3	61	8928000	58560000	180390000	130.8	0.1
1.3	95	1248000	91200000	169530000	79.6	0.1
59.7	136.5	57312000	131040000	110950000	37.2	0.0
20.1	183.8	19296000	176448000	158380000	1.2	0.0
0	247.7	0	237792000	173460000	-64.3	-0.1
0	260	0	249600000	146690000	-102.9	-0.1
0	273	0	262080000	158740000	-103.3	-0.1
0	239	0	229440000	210780000	-18.7	0.0
0	217	0	208320000	175840000	-32.5	0.0
8.4	156	8064000	149760000	199550000	57.9	0.1
23.5	105	22560000	100800000	120260000	42.0	0.0
2.6	71.2	2496000	68352000	139670000	73.8	0.1

Table 11. The water balance of the western Al-Hammar marsh in 2015 with storage area about 327 km² and flow in (m³/sec).

Month	Al-Nwashi canal	Al-Kurmashia canal	Um-Nakhla canal	Euphrates-Right canals	Al-Khamissiya canal	WW pump stations	BC3 canal	BC4 canal	BC3 opening	BC4 opening	Central openings
Jan	6.7	0.3	1.3	2.6	33.25	0.416	1.4	2.3	1.4	2	1.7
Feb	6.65	1.53	2.55	3.13	28.88	0.416	1.38	2.26	1.37	1.95	1.67
Mar	6.04	1.33	2.23	3.05	22.57	0.416	1.26	2.05	1.25	1.78	1.52
Apr	5.49	1.6	2.9	3.8	47.7	0.416	1.14	1.87	1.13	1.62	1.38
May	4.99	1.15	2.5	3.25	25.1	0.416	1.40	1.70	1.30	1.74	1.80
Jun	5.54	0	0	1.95	14.5	0.416	1.27	1.54	1.18	1.58	2.14
Jul	5.63	0	0	0.6	0.3	0.416	1.26	1.59	1.17	1.57	2.02
Aug	5.73	0.9	1.95	2.55	0	0.416	1.25	1.65	1.15	1.55	1.89
Sep	5.82	1.3	2.2	3.4	0	0.416	1.24	1.70	1.14	1.54	1.77
Oct	5.91	0.95	1.75	2.5	7.55	0.416	1.22	1.75	1.13	1.53	1.65
Nov	6.0	1.2	2.25	3.75	7.6	0.416	1.21	1.80	1.11	1.51	1.52
Dec	6.1	1.6	2.55	6.7	0	0.416	1.2	1.85	1.1	1.5	1.4

Continued table 11.

P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	∑SW m³/mo.	ΔS actual Mm³	water depth (m)
3.3	75.6	1079100	24721200	138320000	114.7	0.4
17.6	91.8	5755200	30018600	134250000	110.0	0.3
24.4	137.4	7978800	44929800	112730000	75.8	0.2
1	199	327000	65073000	178980000	114.2	0.3
0.6	241.4	196200	78937800	117540000	38.8	0.1
0	334.1	0	109250700	78080000	-31.2	-0.1
0	326.8	0	106863600	37730000	-69.1	-0.2
2	304.8	654000	99669600	49350000	-49.7	-0.2
0	220.3	0	72038100	53190000	-18.8	-0.1
14.3	150.9	4676100	49344300	68310000	23.6	0.1
8.2	83.1	2681400	27173700	73570000	49.1	0.2
36.1	64.7	11804700	21156900	63290000	53.9	0.2

Table 12. The water balance of the western Al-Hammar marsh in 2016 with storage area about 640 km² and flow in (m³/sec).

Month	Al-Nwashi canal	Al-Kurmashia canal	Um-Nakhla canal	Euphrates-Right canals	Al-Khamissiya canal	WW pump stations	BC3 canal	BC4 canal	BC3 opening	BC4 opening	Central openings
Jan	8.3	2.15	3.45	25.7	22.7	0.416	1.8	2.6	2.3	2.2	2.3
Feb	8.23	1.85	3.25	18.2	14.2	0.416	1.80	2.51	2.26	2.13	2.24
Mar	7.48	1.3	2.3	18.1	26.7	0.416	1.64	2.28	2.06	1.93	2.03
Apr	6.80	1.8	2.7	22.15	34.3	0.416	1.49	2.07	1.87	1.76	1.85
May	6.18	1.3	2.27	17.57	27.17	0.416	1.85	1.89	2.10	1.60	1.68
Jun	7.62	1.55	2.8	16.5	19.2	0.416	1.68	1.95	1.91	1.45	1.53
Jul	6.93	3.4	3.8	23	18.03	0.416	1.53	1.77	1.74	1.32	1.80
Aug	6.30	2.7	3.45	23.2	6.7	0.416	1.39	1.61	1.58	1.20	1.64
Sep	5.73	2.8	3.65	24.65	20.1	0.416	1.26	1.50	1.43	1.48	1.49
Oct	5.20	2.8	3.7	26.95	14.25	0.416	1.51	1.65	1.30	1.35	1.35
Nov	4.73	1.6	2.4	10	0	0.416	1.37	1.50	1.19	1.22	1.23
Dec	7.55	1.85	2.85	17.05	7.1	0.416	1.8	1.6	1.9	1.4	1.6

Continued table 12.

P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	∑SW m³/mo.	ΔS actual Mm³	water depth (m)
1.2	72.9	768000	46656000	191590000	145.7	0.2
23	103.9	14720000	66496000	147960000	96.2	0.2
8.4	148.2	5376000	94848000	171700000	82.2	0.1
15.8	180.7	10112000	115648000	200120000	94.6	0.1
3.6	259.3	2304000	165952000	165950000	2.3	0.0
0	274.1	0	175424000	146730000	-28.7	0.0
0	312.4	0	199936000	165190000	-34.7	-0.1
0	281.5	0	180160000	130070000	-50.1	-0.1
0	229.4	0	146816000	167200000	20.4	0.0
0	157.1	0	100544000	156770000	56.2	0.1
0	100.9	0	64576000	66510000	1.9	0.0
9.2	65.2	5888000	41728000	116940000	81.1	0.1

Table 13. The water needed for the 2009.

Month	P mm/mo.	ET mm/mo.	P m^3/mo.	ET m^3/mo.	SW needed Mm^3
Jan	0.3	88.3	150000.0	44150000	44.0
Feb	7.1	197	3550000.0	98500000	95.0
Mar	18.6	284.6	9300000.0	142300000	133.0
Apr	4.6	351.1	2300000.0	175550000	173.3
May	1.5	396.4	750000.0	198200000	197.5
Jun	0.6	420.5	300000.0	210250000	210.0
Jul	0	632.6	0.0	316300000	316.3
Aug	0	597.7	0.0	298850000	298.9
Sep	0	454.1	0.0	227050000	227.1
Oct	0.2	310.5	100000.0	155250000	155.2
Nov	1.7	18.5	850000.0	9250000	8.4
Dec	19.3	92.2	9650000.0	46100000	36.5

Table 14. The water needed in 2010.

Month	P mm/mo.	ET mm/mo.	P m^3/mo.	ET m^3/mo.	SW needed Mm^3
Jan	2.6	120.1	1300000	60050000	58.8
Feb	2.7	152.4	1350000	76200000	74.9
Mar	0.5	279.5	250000	139750000	139.5
Apr	29.2	338.5	14600000	169250000	154.7
May	14.8	442.3	7400000	221150000	213.8
Jun	0	423.9	0	211950000	212.0
Jul	0	405.5	0	202750000	202.8
Aug	0	387.1	0	193550000	193.6
Sep	0	368.7	0	184350000	184.4
Oct	0.1	350.3	50000	175150000	175.1
Nov	0.4	181.8	200000	90900000	90.7
Dec	7.3	129.8	3650000	64900000	61.3

Table 15. The water needed in 2011.

Month	P mm/mo.	ET mm/mo.	P m^3/mo.	ET m^3/mo.	SW needed Mm^3
Jan	7.5	95.9	3750000	47950000	44.2
Feb	19.9	114.5	9950000	57250000	47.3
Mar	13.8	242.2	6900000	121100000	114.2
Apr	21.2	307.3	10600000	153650000	143.1
May	9.7	474.4	4850000	237200000	232.4
Jun	0	641.6	0	320800000	320.8
Jul	0	592.6	0	296300000	296.3
Aug	0	543.5	0	271750000	271.8
Sep	0	494.5	0	247250000	247.3
Oct	2.6	314.7	1300000	157350000	156.1
Nov	13	139.1	6500000	69550000	63.1
Dec	0	110.8	0	55400000	55.4

Table 16. The water needed in 2012.

Month	P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	SW needed Mm³
Jan	6.2	96.8	3100000	48400000	45.3
Feb	21.6	129.7	10800000	64850000	54.1
Mar	1.3	235.3	650000	117650000	117.0
Apr	6.7	335.3	3350000	167650000	164.3
May	0	498.5	0	249250000	249.3
Jun	0	627.1	0	313550000	313.6
Jul	0	587.2	0	293600000	293.6
Aug	0	547.4	0	273700000	273.7
Sep	0	507.5	0	253750000	253.8
Oct	2.6	286.9	1300000	143450000	142.2
Nov	58.5	101.3	29250000	50650000	21.4
Dec	19.3	71.8	9650000	35900000	26.3

Table 17. The water needed in 2013.

Month	P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	SW needed Mm³
Jan	8.8	83.7	4400000	41850000	37.5
Feb	0.2	125	100000	62500000	62.4
Mar	0.3	239.8	150000	119900000	119.8
Apr	5.1	288.8	2550000	144400000	141.9
May	36	362.5	18000000	181250000	163.3
Jun	0	517.6	0	258800000	258.8
Jul	0	506.2	0	253100000	253.1
Aug	0	494.8	0	247400000	247.4
Sep	0	389.6	0	194800000	194.8
Oct	1.8	258.1	900000	129050000	128.2
Nov	126.4	104.4	63200000	52200000	-11.0
Dec	1.7	67.7	850000	33850000	33.0

Table 18. The water needed in 2014.

Month	P mm/mo.	ET mm/mo.	P m³/mo.	ET m³/mo.	SW needed Mm³
Jan	9.3	61	4650000	30500000	25.9
Feb	1.3	95	650000	47500000	46.9
Mar	59.7	136.5	29850000	68250000	38.4
Apr	20.1	183.8	10050000	91900000	81.9
May	0	247.7	0	123850000	123.9
Jun	0	260	0	130000000	130.0
Jul	0	273	0	136500000	136.5
Aug	0	239	0	119500000	119.5
Sep	0	217	0	108500000	108.5
Oct	8.4	156	4200000	78000000	73.8
Nov	23.5	105	11750000	52500000	40.8
Dec	2.6	71.2	1300000	35600000	34.3

Table 19. The water needed in 2015.

Month	P mm/mo.	ET mm/mo.	P m^3/mo.	ET m^3/mo.	SW needed Mm^3
Jan	3.3	75.6	1650000	37800000	36.2
Feb	17.6	91.8	8800000	45900000	37.1
Mar	24.4	137.4	12200000	68700000	56.5
Apr	1	199	500000	99500000	99.0
May	0.6	241.4	300000	120700000	120.4
Jun	0	334.1	0	167050000	167.1
Jul	0	326.8	0	163400000	163.4
Aug	2	304.8	1000000	152400000	151.4
Sep	0	220.3	0	110150000	110.2
Oct	14.3	150.9	7150000	75450000	68.3
Nov	8.2	83.1	4100000	41550000	37.5
Dec	36.1	64.7	18050000	32350000	14.3

Table 20. The water needed in 2016.

Month	P mm/mo.	ET mm/mo.	P m^3/mo.	ET m^3/mo.	SW needed Mm^3
Jan	1.2	72.9	600000	36450000	35.9
Feb	23	103.9	11500000	51950000	40.5
Mar	8.4	148.2	4200000	74100000	69.9
Apr	15.8	180.7	7900000	90350000	82.5
May	3.6	259.3	1800000	129650000	127.9
Jun	0	274.1	0	137050000	137.1
Jul	0	312.4	0	156200000	156.2
Aug	0	281.5	0	140750000	140.8
Sep	0	229.4	0	114700000	114.7
Oct	0	157.1	0	78550000	78.6
Nov	0	100.9	0	50450000	50.5
Dec	9.2	65.2	4600000	32600000	28.0

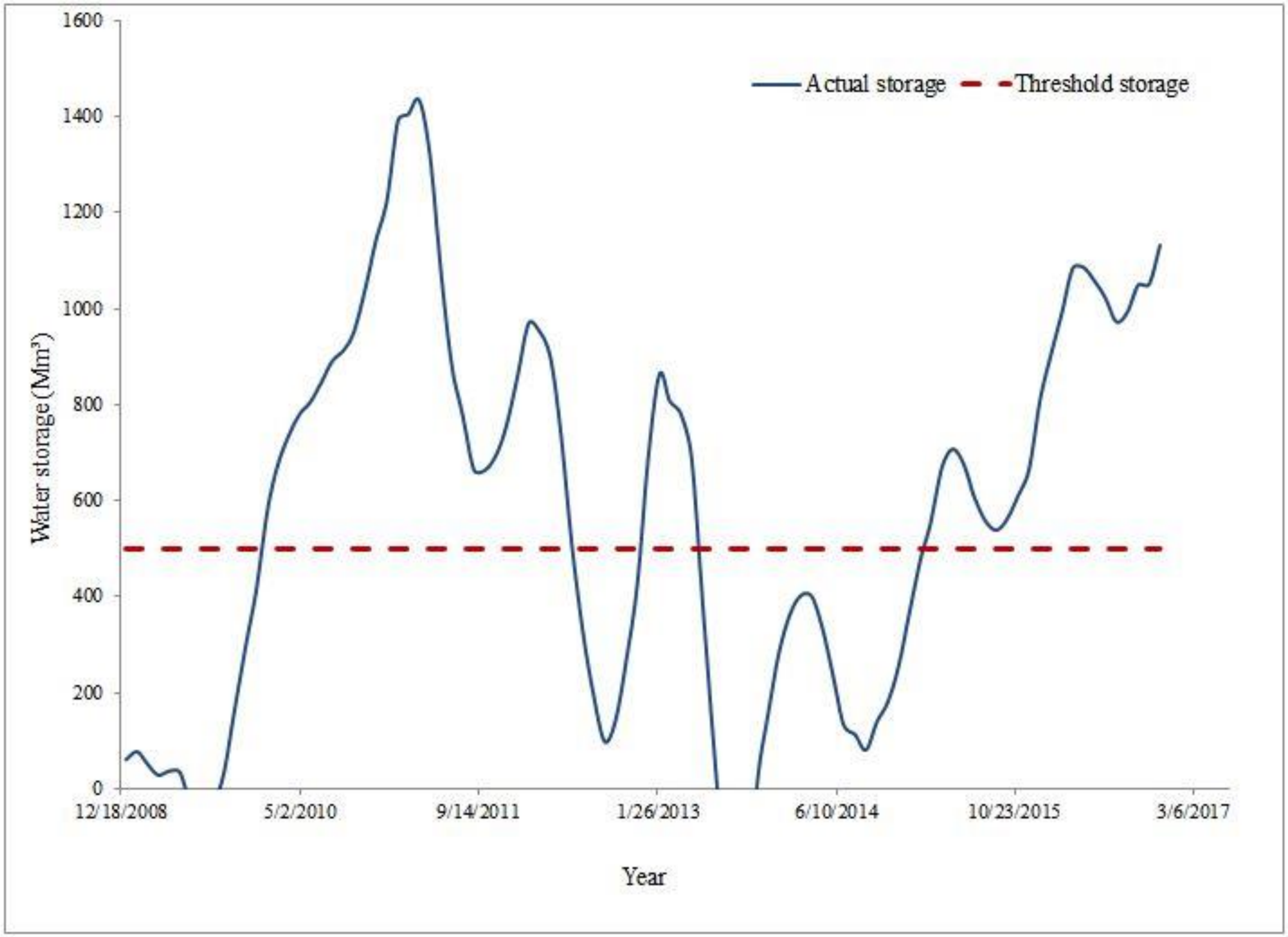

Figure14. The progress of the western part of the Al-Hammar marsh recovery between 2009 and 2016.

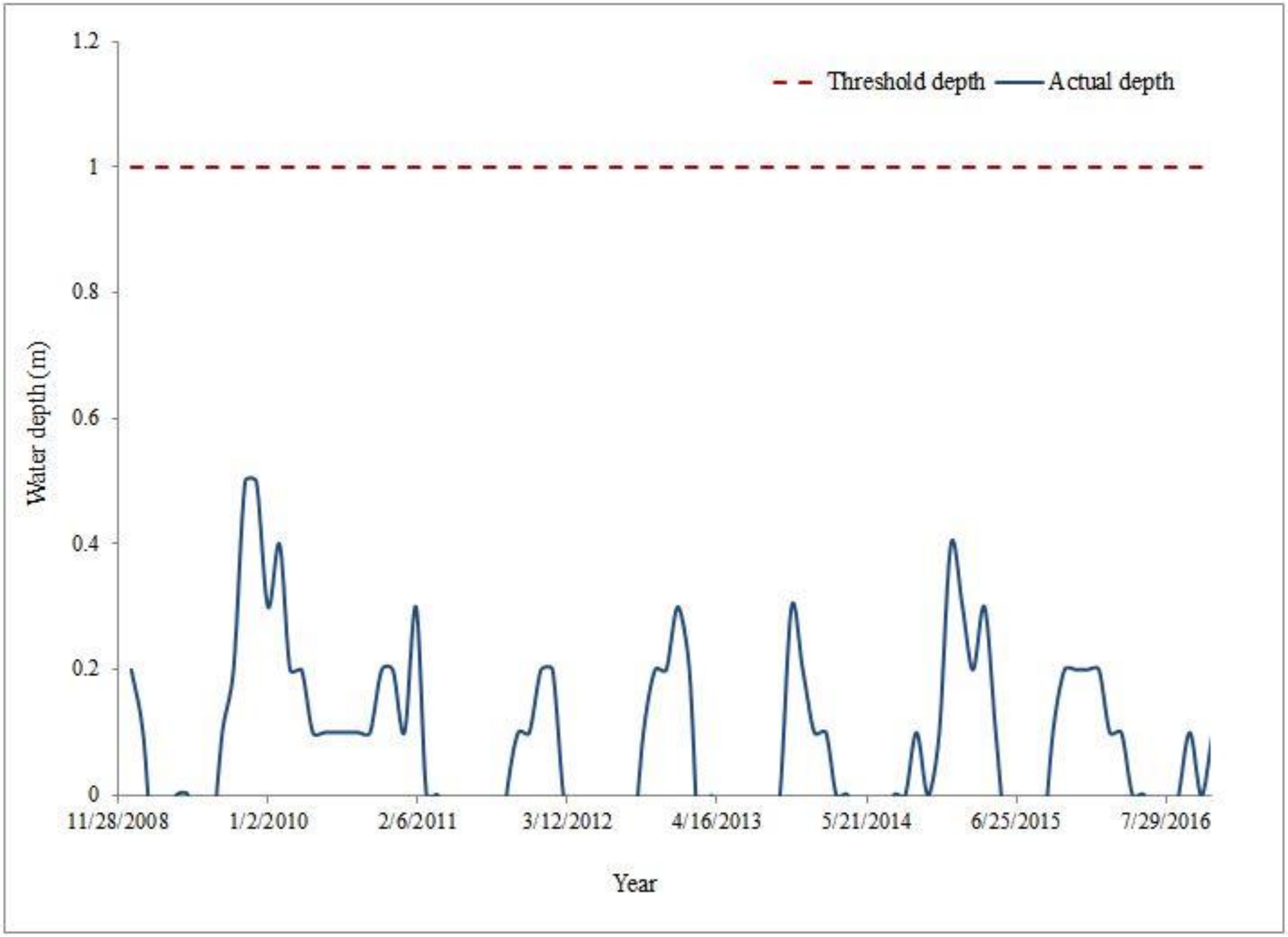

Figure15. Water depth of the western Al-Hammar marsh between 2009 and 2016.

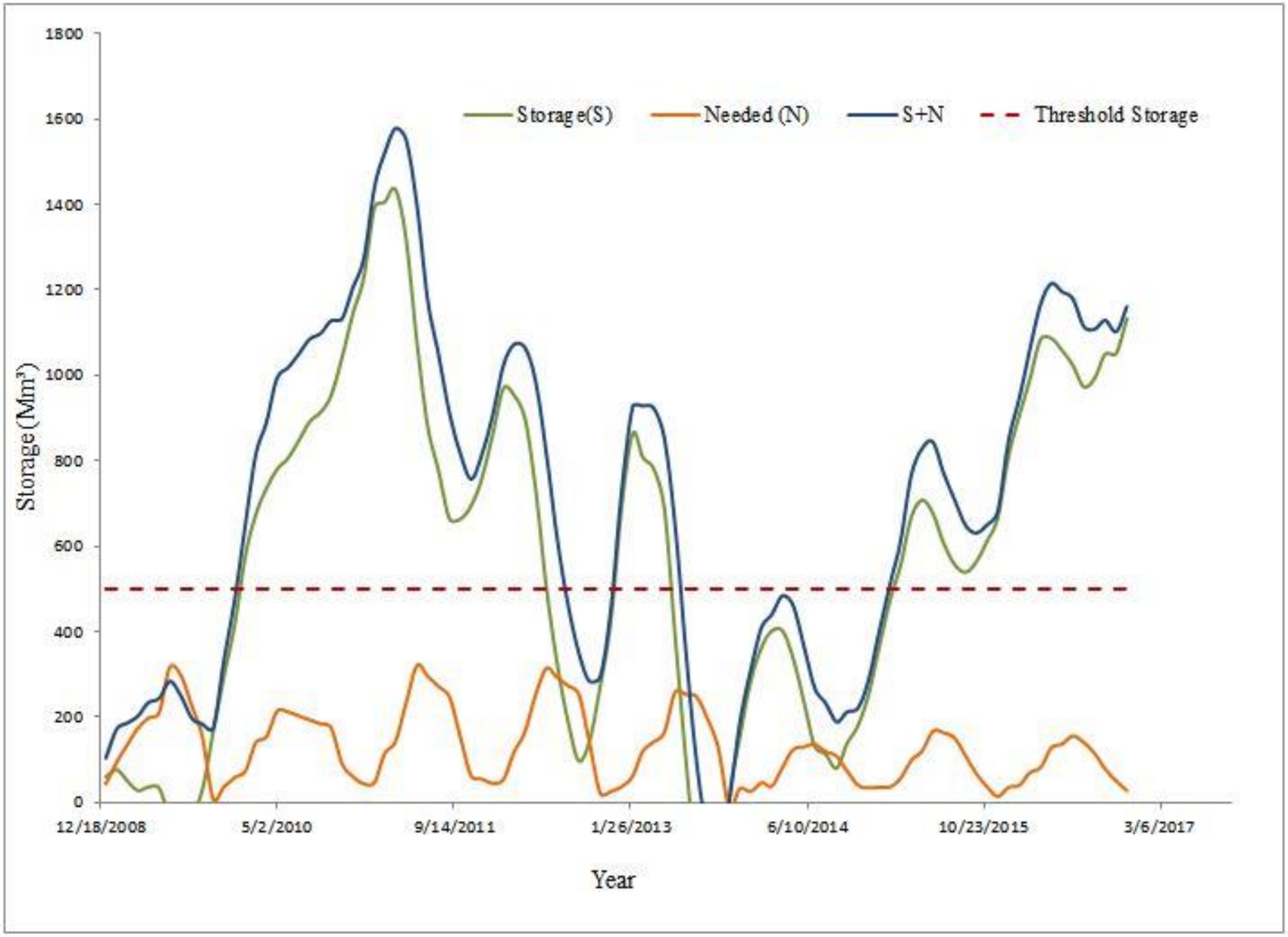

Figure16. Effects of needed water on the water budget between 2009 and 2016.

3.Evaluating the Water Conveyance System

3.1 Introduction

After the draining campaign in 1991-1994 by Saddam's regime, the Al-Hammar marshlands were used as agricultural lands through reclamation projects. These projects included most of the areas in the western and eastern Al-Hammar marshlands. In addition to agricultural uses, the draining of the Al-Hammar marsh opened the land for oil exploration. For example, the supergiant oil field, Al-Rumaila, is located in the Al-Hammar marshland. Therefore, in 1985 the Iraqi government drained the eastern part of the Al Hammar marsh for oil exploration [2]. The reclamation of the marsh included two projects: the Al-Malha project and the Al-Shafi project. The Al-Malha project extends from southeastern Al-Nassiriyah to the northwestern Al-Basrah governorates. The total area of the reclaimed lands in the Al-Malha project was 305,000 dunam (30,500 hectare). In contrast, the Al-Shafi project covers most of the eastern part of the Al-Hammar marsh, and its total area was 122,000 dunam (12,200 hectare). The reclamation included building networks of irrigation canals in both projects Al-Malha and Al-Shafi [27]. This chapter will address the network of feeder canals serving the western part of the Al-Hammar marsh, which is the study area of this project.

Um-Nakhla and Al-Kurmashia are the main irrigation canals that serve the Al-Malha agricultural project, and they deliver the water from the Euphrates river into the agricultural lands. The Um-Nakhla canal was completed in 1996 and serves about 80,000 dunam (8,000 hectare) of the total area of the Al-Malha project. Therefore, the lands that are served by the Um-Nakhla canals are called the Um-Nakhla Agricultural Project. The other main irrigation canal is the Al-Kurmashia canal which serves the lands north of the Um-Nakhla canal but with less capacity for water distribution. Also, many small canals branch out of the Um-Nakhla and

Kurmashia canals when they cross the farm lands. The small canals serve small areas or orchards and usually bear the name of the land's owners [27].

The Al-Malha agricultural project is used to produce cereals, such as wheat, barley, rice, and corn. These crops are important to farmers and were labeled high priority crops by the previous government after the international sanctions in 1991. Furthermore, different types of vegetables and fruits were produced through the project as well as date palms. The land's productivity and crop yield in the Al-Malha project were high due to numerous factors. Firstly, the soil of the marsh is fertile, and it has high nutrient concentrations due to the annual sediment deposits in the marsh. Secondly, the drying of the marsh led to low ground water levels which reduced salinity concentrations in the soil. Finally, the low water table increased the efficiency of the drainage system, further reducing ground water levels, and consequently improving the land's productivity.

In the present day, the agricultural lands and orchards have been affected by the restoration of the Al-Hammar marsh after 2003 for many reasons. Returning water back into the marsh increases the water table level which raises salinity concentrations in the soil, hence reducing the land's productivity. Also, the reduction of the surface water in the Euphrates has decreased the arable land. Finally, the reduction of government support for the agriculture sector in Iraq has had a negative impact on this sector in general.

3.2 The Irrigation Canals to the Feeder Canals

In the present day, the Al-Malha agricultural lands have been returned to marshlands within The Restoration of the Iraqi Marshes Plan. Returning the water into the marsh after 2003, and the inundation of wide areas of the western Al-Hammar marsh, converted the region from agricultural land back to its original state as marshland. Therefore, the irrigation canals that used to irrigate the Al-Malha agricultural lands are used today to feed the western Al-Hammar marsh. The restoration of the western Al-Hammar marsh after 2003 did not inundate all of the marsh area due to a lack of water available for the restoration. Therefore, some of the original marsh area continues to be used for agricultural purposes. However, these agricultural lands have been affected by the restoration of the marsh for many reasons: (1) Returning the water into the marsh causes the water table level in the region to increase, which subsequently increases the salinity concentrations in the soil and reduces the land productivity. (2) Reduction of the water in the Euphrates river has affected the land farms significantly. (3) The production costs of agriculture have increased (such as energy, labor, and fertilizers) with the reduction in government support. As a result, many farmers left this sector in Iraq.

3.3 The Feeder Canals of the Western Al-Hammar Marsh

The Euphrates River is the main water source for the western part of the Al-Hammar marsh while the eastern part of the Al Hammar marsh is fed by the Shatt Al-Arab from the Al-Shafi canal as shown in figure 3. After the draining of the western Al-Hammar, the marshlands were used for agricultural purposes. Therefore, the irrigation canals were designed to serve the agricultural lands and the orchards within the marshlands. The irrigation canals included main and sub-main canals that deliver water from the Euphrates river into the Al-Malha agriculture lands, as shown in table 21. There are two main sources of water for the western part of the Al-Hammar marsh: the Euphrates river and the Main Outfall Drain (MOD).

3.1.1 Feeders from Euphrates River

The feeder canals come from the Euphrates river. They feed the marsh and deliver water to the agricultural lands and orchards before they reach the boundary of the marsh. Um Alwada opening is divided into eight canals, which are Al Nawashi, Al Gassid, Al Zaeelia, Khatlaan, Um Altobool, Al Ramlia, Mahood, and Al Had.

3.1.2 Feeders from Main Outfall Drain (MOD)

The Al Khamissiya canal comes from the MOD which contains brackish water. In 2010, CRIMW tried to find alternative water resources to reduce the water shortage in the Euphrates River. In consequence, they diverted MOD water, and they chose the path of the Al-Khamissiya canal with adequate slope for water flow in order to ensure the flow of water toward the marsh [8]. The use of gravity to move water through the canal was chosen to avoid pumping and the cost of power. Table 21shows the feeder canals and water resources of the west part of Al-Hammar marsh [8]. There are two classifications of water resources of the marsh; the first depends on the water resources type, such as fresh water, brackish water, and wastewater. The second depends on formal or informal canals when some canals have made by the government, such as the canals 1 to 8, but the others by the marsh dwellers, such as BC_3 and BC_4 openings which do not have continues uniform flow over all seasons.

3.4 Water Resources and the Main Canals

Different types of water resources are currently in use to restore the western part of the Al-Hammar marsh. The main source is the fresh water from the Euphrates river. Because of the drop in the water level of the Euphrates river, brackish water has been used as temporary solution to treat the water deficit. At the same time, the sewage department discharges wastewater into the marsh as well. Consequently, fresh, brackish, and wastewater are the main water sources of the marsh, as shown in the table 21 and Figure 15. The amount of water is out of the control of the CRIMW; therefore, there are no real measurements of the inflow towards the marsh. For example, the marsh dwellers made some openings along the right embankment of the Euphrates river, such as BC_3 and BC_4. The purpose of the openings was to make ponds for their water buffalo because there is no feeder canal in this region, and the existing water depth was too shallow for them to survive. No measurements can be taken for the flow of these openings, so they are therefore considered illegal. However, the local government does not want to face these people at this time due to other more pressing responsibilities. In addition, the wastewater from the Suq Al-Shuyukh city discharges from three pump stations but with only estimated measurements because the sewerage department refuses to provide the daily discharges of the pump stations. Furthermore, water from the farmlands is drained into the marsh because of the topography of the region. This water inflow is not measured as well, even though it affects the water budget of the mash. The following are the water resources of the marsh:

Table 21. The main feeder canals and water resources of the western part of the Al-Hammar marsh [8], [18].

No.	Name of the canals	Source	Water type	Types of flow	Purposes
1	Um Al- Nwashi	Euphrates	Fresh	Gravity flow	Agriculture, Drinking, Feeding of the marsh
2	Al Kurmashia	Euphrates	Fresh	Gravity flow	Agriculture, Drinking, Feeding of the marsh
3	Um Nakhla	Euphrates	Fresh	Gravity flow	Agriculture, Drinking, Feeding of the marsh
4	Al Hamedy	Euphrates	Fresh	Gravity flow	Agriculture, Drinking, Feeding of the marsh
5	Al Tar	Euphrates	Fresh	Gravity flow	Agriculture, Drinking, Feeding of the marsh
6	Al Emlaq	Euphrates	Fresh	Gravity flow	Agriculture, Drinking, Feeding of the marsh
7	BC_3, BC_4	Euphrates	Fresh	Gravity flow	Agriculture, Drinking
8	Al Khamissiya	MOD	Brackish	Gravity flow	Feeding of the marsh
9	BC_3, BC_4 Openings	Euphrates	Fresh	Gravity flow	Feeding of the marsh (Informal)
10	Central openings	Euphrates	Fresh	Gravity flow	Feeding of the marsh (Informal)
11	Pump stations	Suq Al-Shuyukh city	Wastewater	Lift pumps	Feeding of the marsh

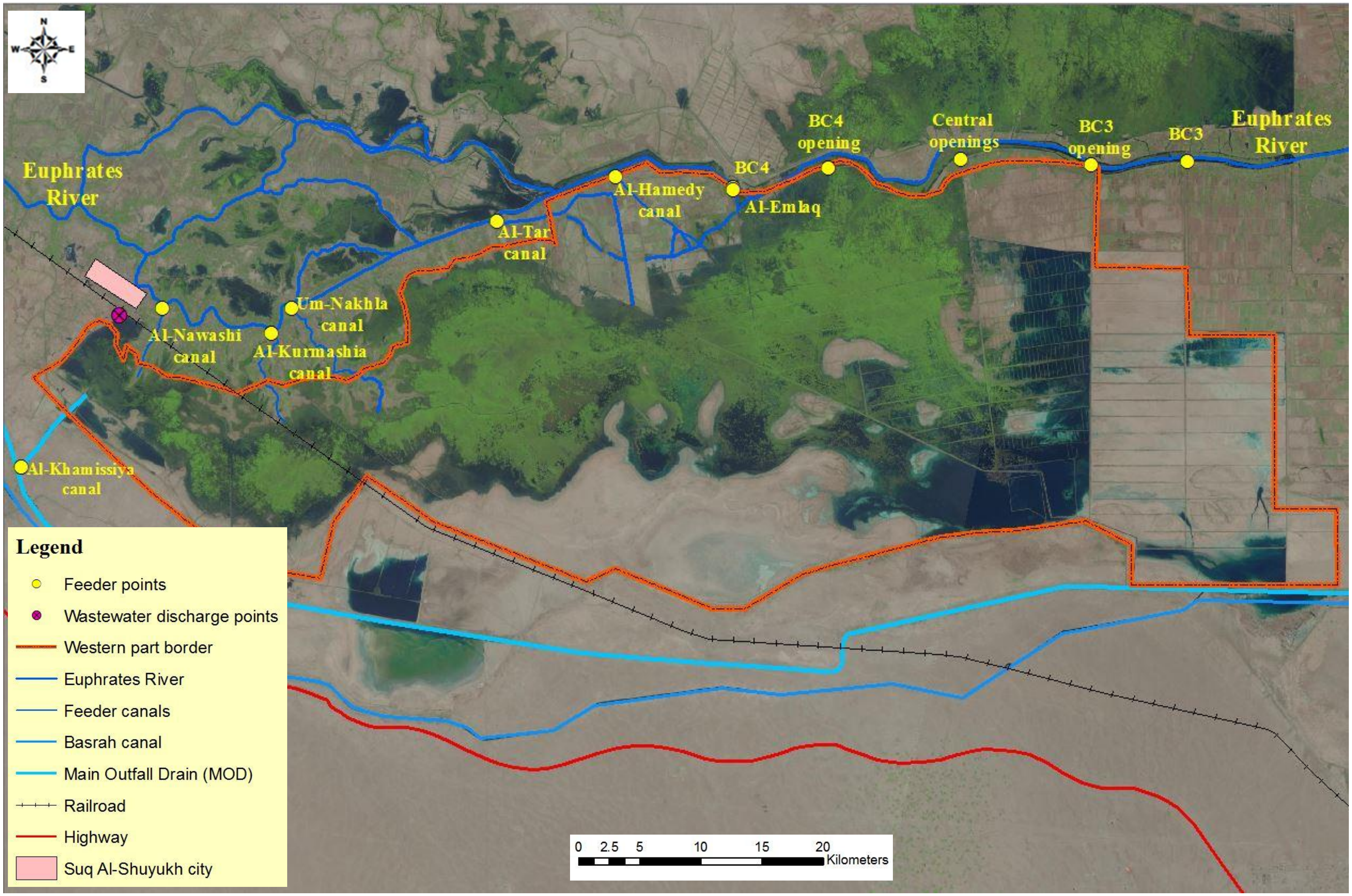

Figure 17. Feeder canals of the Al-Hammar marsh (scale1:250,000).

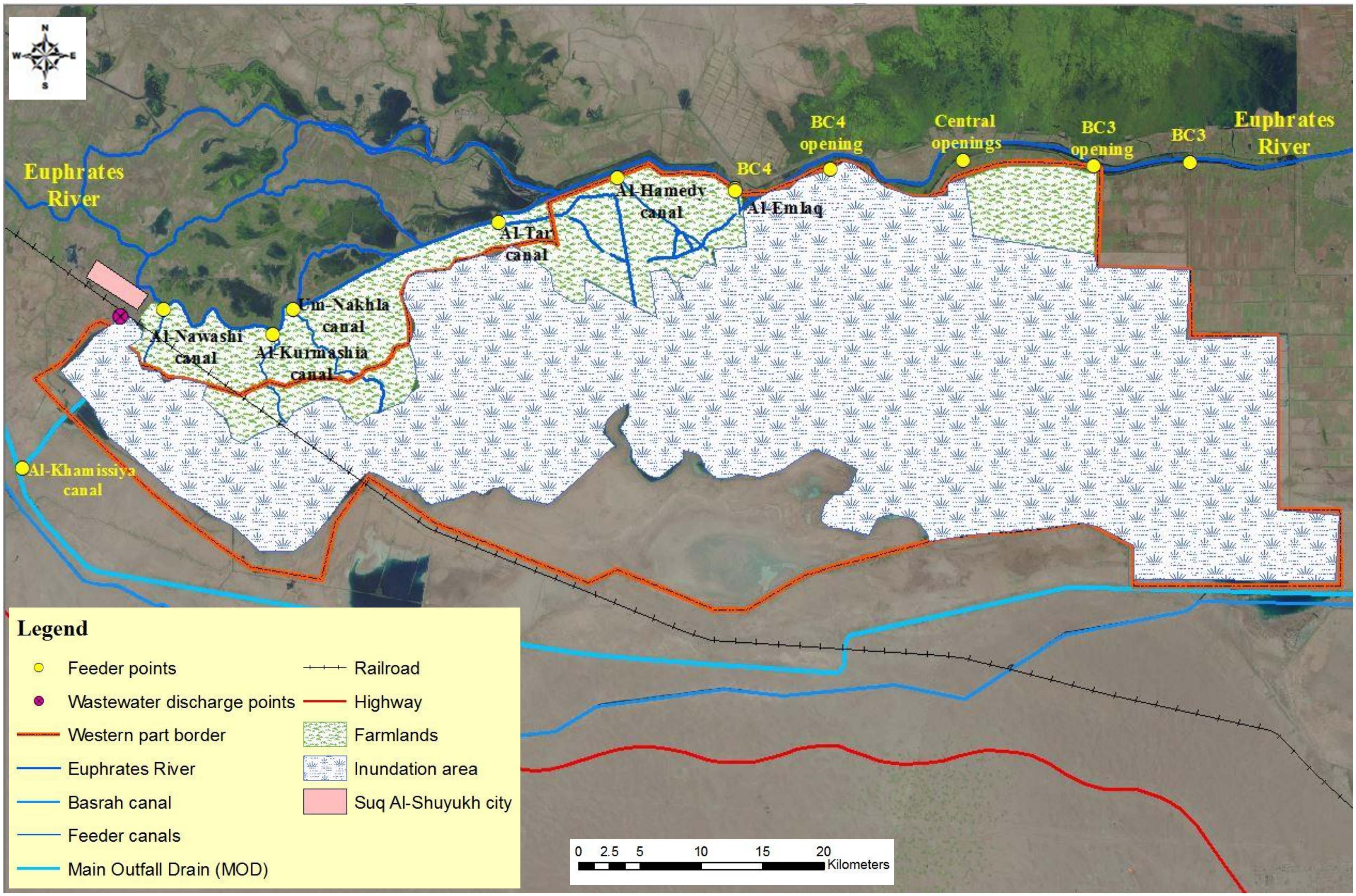

Figure 18. Storage area and agriculture lands in the western Al-Hammar marsh (scale1:250,000).

3.4.1 Al-Nwashi Canal (Um Alwada opening)

The first canal is located in southern Suq Al-Shuyukh city and its total length is 6 km. The canal is intended to supply an irrigated area of about 8 km^2 of cereal farms and orchards using gravity. The intake structure is on the Euphrates river (i.e. a head regulator with a flat gate of 3.0×2.5m). The discharge of flow differs with the variation of the water level in the Euphrates river; there is not a pump station to keep the water level in the canal constant. Therefore, the discharge is not consistent. The consumption of water for irrigation and drinking along the canal causes the upstream discharge is to be greater than the downstream discharge that is delivered into the marsh. In addition, the analysis of the annual flow for these canals is weak due to insufficient data concerning the characteristics of the canals. For example, the measurement of flow is taken downstream of the canals to measure the discharge of water into the marsh while the upstream discharge is not taken into account. Also, some details about the canals are not updated, such as the width and slope of the canals, which makes the real capacity of the canal more difficult to calculate. Figure 17 shows the photos of the regulator and the Al-Nwashi canal.

Figure 19. Photos for Al-Nwashi regulator and canal, taken by Samir Najeeb Makki, May 2017.

3.4.2 Al-Kurmashia Canal

This canal is intended to supply another sector of the marshlands. The main canal is 8 km long and supplies an area of 14 km^2. The head regulator is located on the Euphrates river, and it has a flat gate of 3.0×2.0 m and supplies water by gravity. After a few kilometers, the main stem of the Al-Kurmashia canal is divided into another canal which is called the Jasim irrigated canal. These canals irrigate two parts of the Um-Nakhla irrigation project, which has three sub-parts Um-Nakhla, Al-Kurmashia, and Jasim. Typically, the part of the project has the same name as the feeder that passes through it. For these canals, the main consumer of water is agriculture, such as rice plantations and orchards in addition to drinking purposes. Hence, the amount of water that accesses the marsh, which is located on edges of the farmlands, is limited and does not exceed a few cubic meters per second, and in some instances, the flow is zero. The other issue is that there is no pump station to keep the water level constant. The flow is controlled by a regulating gate to reduce the cost of maintenance and operating; therefore, the flow is determined by gravity. Figure 18 shows photos of the regulator and the Al-Kurmashia canal.

Figure 20. Photos for Al-Kurmashia regulator and canal, taken by Samir Najeeb Makki, May 2017.

3.4.3 Um Nakhla Canal

This canal is intended to supply the Um-Nakhla irrigation project. It is a main stem with a total length of 9 km and an irrigated area of about 40,000 dunam (4000 ha). Also, it splits into several branches. The intake structure is on the Euphrates river with two flat gates of 3.00× 3.00 m. The Um-Nakhla canal does not differ from the other canals in the region and suffers from the same issues: water losses, low hydraulic efficiency, and poor maintenance as well as water level changes determined by the variation of the water level in the Euphrates. The regulating gate regulates the discharge of flow in the canal, and it two flat gates that have mechanical issues. Hence, the flow is influenced and this leads to intervention by the farmers in the canal's management. Using gravity to produce the flow of water has some disadvantages; one of which is water variation which impacts agricultural production and produces conflicts between farmers. Also, there is no doubt that the insufficient hydrological data makes the development of the canal and the irrigation project a difficult undertaking and requires an even greater effort in order to optimize the new plans. Figure 19 shows photos of the Um Nakhla canal.

Figure 21. Photos for Um Nakhla regulator and canal, taken by Samir Najeeb Makki, May 2017.

3.4.4 Al-Tar Canal

Al-Tar contributes to the irrigation of some farmlands in the Al-Malha irrigation project. The head regulator of the canal has one gate of 3.0×1.5 m, and the downstream discharge of this canal does not access the marsh directly. After supplying the agricultural areas, the Al-Tar canal as well as the Al-Hamady canal discharge into a single canal called Al-Qausy canal (Figure 15). Then, a pump station lifts the water from the arcane canal and discharges it into the marsh. The main problems with this canal are the same as those of the others and also cause severe limitations in water availability. Therefore, increasing the productivity of agriculture requires improvement of the irrigation system (such as the conveyance network) and improvement on-farm irrigation methods higher production. Regarding the overall inundation of the Iraqi marshes, attention to the water conveyance system is absent, even though the water conveyance system plays a very important role. The water conveyance system influences several critical aspects of the project, including the inundation rate of the marsh and the development of more sustainable agricultural irrigation. Figure 20 shows photos of the regulator and the Al-Tar canal.

Figure 22. Photos for Al-Tar regulator and canal, taken by Samir Najeeb Makki, May 2017.

3.4.5 Al-Hamedy Canal

The Al-Hamedy canal supplies the area of the Al-Malha project that is located south-east of the Um-Nakhla canal, and it is about 5 km^2. The total length of the canal is 3 km, and its intake structure is on the Euphrates river with two flat gates of 3.00× 1.50 m. This canal has the same hydraulic problems that are found in the other canals. Therefore, one of the solutions to supply more of the water from these canals to the marsh is to use a sophisticated irrigation system such as the drip irrigation system because flooding irrigation causes inadvertent soil salinization of the croplands. There are many potential benefits to reduce the soil salinity when using the new irrigation technologies. Using only the exact amount of water needed can reduce the salinity concentration in the soil and ration the water [26]. This not only reduces local soil salinization, but will also improve the crop yield. Another important factor in achieving constant inundation is providing a pump station in the head structure to optimize the hydraulic efficiency of the feeder canals. Figure 21 shows the photos of the regulator and the Al-Hamedy canal.

Figure 23. Photos for Al-Hamedy regulator and canal, taken by Samir Najeeb Makki, May 2017.

3.4.6 Al-Emlaq Canal

Al-Emlaq canal directly supplies the marsh and has a total length of 0.5 km. It is equipped with a hydraulic structure of 3.00×1.50 m enabling the conveyance of water from the Euphrates river to the marsh to be restored. Because the canal is short, it does not supply the croplands, so water loss (such as evaporation and seepage) and water consumption (such as irrigation) can be neglected. Consequently, the discharge entering the marsh is very close the discharge at the canal’s opening. In order to control the variations in water level, which depend on the water level of the Euphrates river, it is important to provide a pump station to achieve a constant water level and uniform flow in the canal. The gates at the head structure are currently not working due to some mechanical issues caused predominantly by insufficient maintenance and the antiquity of the structure. Figure 22 shows photos of the regulator and the Al-Emlaq canal.

Figure 24. Photos for Al-Emlaq regulator and canal, taken by Samir Najeeb Makki, May 2017.

3.4.7 Al-Khamissiya Canal

The decline in available water in the Euphrates river is a big threat to the marsh because it makes the marsh prone to the drying. In order to avoid the drying of the marsh, the CRIMW worked with the Scientific and Engineering Consulting Bureau of the University of Technology, to conduct the study "Possibility of using the Water of the Main Outfall Drain to Restore Al Hammar Marsh after Operating the Pumping Station in Al Nassiriyah". The purpose of this study was to use the drainage water of the Main Outfall Drain (MOD) to feed the western part of the Al-Hammar marsh as a temporary solution. The study included the impacts of the drainage water on the water quality of the marsh and its ecosystem. One of the main outcomes of this study was using Al-Khamissiya canal to supply the marsh, depending on the topographical survey and the hydrologic routing. The average discharge of Al-Khamissiya canal was 40 m^3/sec diverted from the MOD [11]. The flow of Al-Khamissiya canal depends on the water level in MOD and there is no regulator on the stem MOD, as shown in the Figure 23.

Figure 25. Photos of the stem Main Outfall Drain MOD and Al-Khamissiya canal, taken by Ali Al-Quraishi, 2010.

3.4.8 Municipal wastewater pump stations

The Suq Al-Shuyukh city (which is located on the marsh border: Figure 1) provides wastewater to the marsh. The sewage department in the Suq Al-Shuyukh city discharges the municipal wastewater into the marsh due to the absence of infrastructure, such as a wastewater treatment plant and sewage networks, through three pump stations: Al-Nawashi, Al-Ismailia, and Al-Jaafri (as shown in the Figure 24). The capacity of each station is about 380-500 m^3/hour of untreated wastewater through an open drain system. This amount of water is important in the calculation of the water budget for the marsh.

Figure 26. Top- photos of the pipes of the Al-Jaafri pump station, taken by Dr. Jamal Al-Hamdani, 2015. Bottom- photos of the pipes of the Al-Nawashi pump station, taken by Ali Al-Quraishi, 2009.

3.4.9 BC$_3$ and BC$_4$ Canals

The BC$_3$ canal was established in 1998 to serve 24000 dunams of agricultural lands on the right side of the Euphrates river. The head regulator has two gates measuring 5×3.6 m and designed to discharge 25m^3/sec, a rate which has not yet been achieved. The real discharge is about 10m^3/sec and depends on the water level in the Euphrates River. The BC$_4$ canal was constructed in 1997 to supply an irrigated area of 20000 dunams. The head regulator has two gates with dimensions of 5×3m for each gate. The design capacity of the canal is 15m^3/sec, and the actual discharge is 10m^3/sec, a rate which also depends on the water level in the Euphrates river. Currently, both canals do not provide a uniform flow to the marsh and depend on seasonal water flow and water usage for irrigation.

3.5 Problems with the Feeder Canals

Water is distributed to the marsh through many unlined canals. In the few kilometers before the canals reach the marsh, they lose water due to uncontrolled usage from farmers, seepage, and the existence of aquatic plants. In addition, most of the regulating gates and water structures are old and the maintenance of these structures has been poor; therefore, the water reaches the marsh in discontinuous periods. This project will take the water distribution system efficiency into account to achieve a constant flow rate reaching the marsh. This uniform flow will have a significant impact on the sustainable management and the restoration process of the marsh. This chapter will answer these questions: (1) what are the main problems concerning the feeder canals' structures? (2) what are the impacts of the low hydraulic efficiency of the feeder canals?

3.5.1 Water Losses

The flow in these canals depends on the gradient slope between the Euphrates river and the farmland, and the volume of water in the canals is related to the water level in the Euphrates river. The main regulator that helps to raise the water level in the Euphrates river is Beni Si'ed regulator, which is located in southeastern Suq Al-Shuyukh city. The volume of water that supplies the marsh from these canals is different based on the capacity of each canal, and not all the canals deliver water into the marsh.

3.5.2 Proliferation of Aquatic Weeds

The decline of water quantity and the reduction of the dilution factor of the river system in Iraq have negative consequences not only on the water quality but also in the thriving of aquatic plants in the water conveyance systems. The problem plants in the canal systems pose a health risk and clog irrigation canals, impeding water flow [28]. Hence, the vast quantities of aquatic plants have profound effects on the hydraulic operation efficiency of the canals, and technologies for aquatic vegetation removal are needed, such as harvesting, chemical control, and prevention [28]. The feeder canals of the western Al-Hammar contain different types of aquatic plants, including algae and reeds that grow in the edges of the rivers and low current regions. This emerging problem is disrupting the restoration and will threaten the marsh ecosystem if it is not managed properly.

3.5.3 Irregularities and Illegal Manipulation

Public awareness is an important consideration for the development of a sustainable agricultural sector. In Iraq, continued wars over more than three decades contributed to a lack of attention given to the agricultural and other sectors. Hence, the obvious decline in these sectors makes keeping pace with the evolving public concerns difficult. Despite the role agricultural associations play in regulating and developing farming activity, their resources are insufficient to meet the public need. Also, there are many emerging and growing problems in this sector. For example, the water shortage is becoming increasingly important. As a result, the irregularities increase because the farmers try to get on water irrigation without following the regulations for the irrigation. The other issue is that most farmers buy the fuel, fertilizers, and equipment to sustain their farms, which places a greater financial strain on them. Consequently, many farmers lost their farms because farming has become unprofitable. Other farmers, who could not leave, tried to produce vegetables or crops which do not require as much effort in order to make a living. These farmers have also frequently used water from the irrigation canals without rationing according to the available water, and that lead in time to conflicts. So, with these difficult living conditions and the water shortage in Iraq, the marsh dwellers believe it is impossible to restore the marsh with the current amount of water. Also, the government should start negotiations with the headwater countries to achieve development in the agricultural sector.

4. Improving the Water Conveyance System

4.1 Introduction

This chapter details the study of the existing feeder canals and the hydraulic problems that affect the restoration rate. We also present the inundation rate and determine how much inundation can be achieved within the marsh such as limited feeder canals and multiple feeder canals as a function of the feeding system.

Water loss is an important factor to be considered in the restoration of the marshes to identify its effect on the water balance therefore, how much further the restoration could proceed. The main forms of the water loss in the marsh regions are evapotranspiration, evaporation from the open water, and seepage. The high evapotranspiration rate, which is evaporation and plant transpiration, is one challenge in restoring the marsh regions because it is more than ten times the precipitation, and at the same time there is also a lack of surface water.

Hydrodynamics are considered by focusing on the water distribution system in the western Al-Hammar marsh. The feeding system and the amount of water that is delivered to the marsh have a significant effect on the inundation pattern and the inundation rate within the marsh. The limited feeding canals have a different pattern of inundation in comparison with the multiple feeding canals, regardless of the amount of water delivered. Therefore, the creation of a network with multiple feeder canals could improve the inundation rate within entire sections of the marsh. Furthermore, the multiple feeder canals should be paved with concrete to reduce the water losses, whether by evaporation or seepage. Hence, delivering the water by using a multiple feeder canal system has many advantages for the marsh ecosystem. Figures 26, 27, 28 show the advantages of a network of multiple feeder canals.

4.2 Water Losses in the Feeder Canals

Water losses through seepage and evaporation constitute a substantial part of the waste of water resources (Figure 25). The feeder canals of the western Al-Hammar are currently conducted in natural soil, and they are not lined. The seepage and evaporation are occurring at especially high rates because the canals are built within an arid region with a low water table. Thus, these canals work as losing streams in addition to promoting water evaporation and soil evaporation under the effect of the capillary force caused by unsaturated soil [29]. The seepage can be estimated by the equations:

1- Water loss by seepage (q_s) as shown in the Figure 25 [30].

$$q_s = ky_nF_s \tag{4.1}$$

Where: q_s = seepage discharge per unit length of canal (m^2/sec); k = coefficient of permeability (m/s); y_n = normal depth of flow in the canal (m); and F_s = seepage function (dimensionless) [30].

2- The evaporation loss from the irrigation canal (E_o) is as shown in the Figure 25, [31].

$$q_e = TE \tag{4.2}$$

Where: q_e = evaporation discharge per unit length of channel (m^2/s); E= evaporation per unit free surface area (m/s); T= width of free surface (m) [31].

3- The total water losses from the seepage and evaporation can be expressed [31]:

$$q_w = ky_nF_s + TE \tag{4.3}$$

4- Soil evaporation loss from the filtration of water on both sides [29].

$$E_1 = \beta.2t\sqrt{1+m^2}\int_0^h f_o\,dx \tag{4.4}$$

Where: β= Empirical coefficient; t= the water delivery time (day); m= the trapezoidal channels slop coefficient; h = the channel bottom width (m); f= infiltration rate of channel bottom (mm/min) [29].

It is worth mentioning that the geometrical canal shape, such as triangular, rectangular, and trapezoidal, plays an important role in determining water losses in the canals because it governs the surface area of the water [31].

4.3 Improving the Feeder Canal Systems

The existing feeder canals (shown in table17) were designed to serve the dried marshlands in the 1990s. These canals depend on the gradient slope between the water level in the Euphrates and the land’s surface level. Some of the disadvantages with these canals are obvious, such as water loss and low hydraulic efficiency. Therefore, to improve the water conveyance and distribution system within the marsh, the creation of multiple feeder canals could eliminate hydraulic problems and improve water distribution.

Creating a lined water distribution canal network would have a significant positive influence on the entire marsh ecosystem. The network should include main and sub canals alongside the renovated existing structures. Because improving water distribution will increase water access at multiple points in the marsh, it presents many advantages to the entire system. Typically, the longitudinal slope of the marsh is gentle and creating a canal network could enhance the restoration by evening water distribution within marsh. The other advantage would include reducing the evaporation rate by reducing the travel time of the water. In addition, the canals network can serve the agricultural lands and orchards adjacent to the marsh. As a result, this network would have a high economic feasibility through supporting the water distribution in the marsh and the irrigation system in the adjacent area.

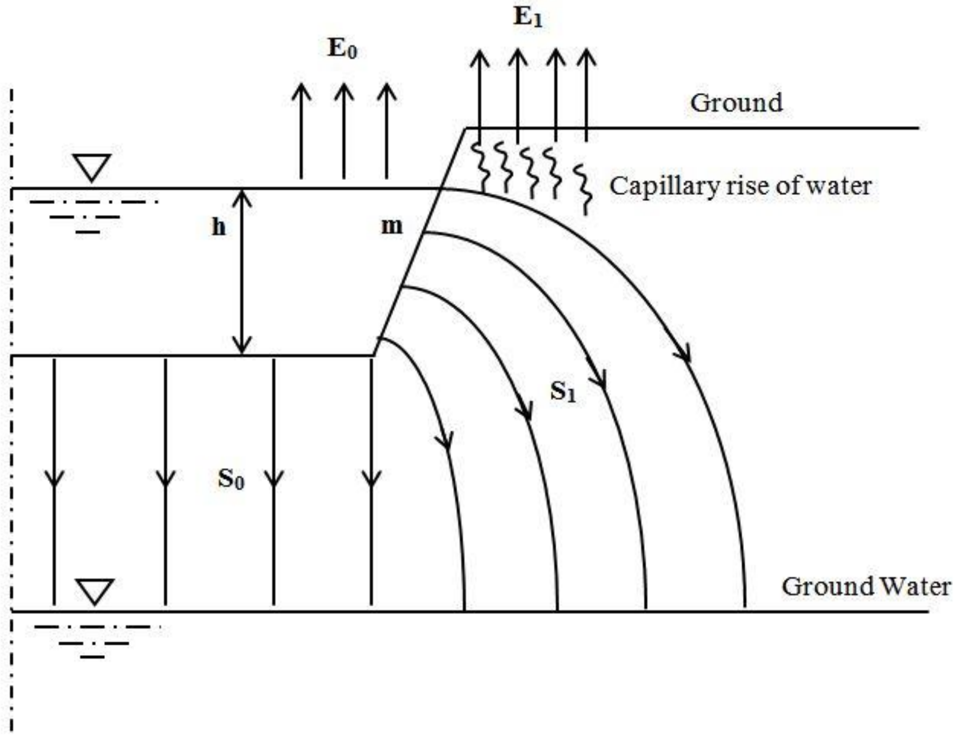

Figure 27. Leakage in irrigation canal, where S = infiltration volume, m= channel slope, h= water depth, E= evaporation [29].

4.4 Advantages of a Multiple Feeder Canals System

The western Al-Hammar marsh is located in a water scarce region. Therefore, managing the water resources is crucial due to the harsh local conditions. Designing a multiple feeder canals network could improve the irrigation as well as the restoration process at the same time. Using this method, water quality can be improved within the marsh by supplying water directly from the Euphrates river.

4.4.1 Improving the Conveyance System and the Marsh Restoration

The existing canals are earthen canals made from removed earth. This type of canal comes with some disadvantages, such as water loss, weed growth, and side slope collapsing. Consequently, this type of canal is not an effective way to deliver water to the marsh. In contrast, using a lined canals network with low water loss would be more effective and has a high hydraulic performance [32]. These canals can be divided into main and branch canals to deliver water through multiple points to the marsh. Delivering a consistent amount of water into the marsh at each of the multiple points would strongly support the restoration of the marsh ecosystem as well as maintain the level of the water in the marsh. Hence, the growth of aquatic life, such as fish, water buffalo, and reeds would be expected. Figures 26- 30 illustrate a schematic of the multiple feeder canals.

4.4.2 Reducing Water Losses

The canals' water losses include seepage and evaporation losses. Seepage depends on the geometry of the channel while evaporation depends on the surface area of the water. It is readily conceivable that a considerable amount of water is lost due to seepage; special consideration is needed for canals carrying small amounts of water in an arid region. Therefore, paving the canals with concrete could decrease the seepage loss into the ground. Moreover, seepage losses are higher at the beginning of the canal's operation, and it gradually decreases over time [29]. For example, the clogging of the canal depends on the suspended sediment content and grain size distribution, so the clogging decreases the seepage loss from the bottom and slopes of the canals [29].

4.4.3 Flush the Accumulated Salt Out

Multiple inflows can create water pathways and avoid a weak circulation within the marsh. Increasing the feeder canals will affect the hydrological regime, degree of mixing of the water, and mass transport. Consequently, this technique is an important hydrological factor that can change the distribution of vegetation communities in the wetland [33]. The multiple feeder canals in the western Al-Hammar will have a great advantage to flush the accumulated salt load out, which continuously accumulates when water from the MOD is used as an alternative water resource. Flushing out salt from the marsh requires not only multiple inflows but also an outlet (Al-Hamdani in 2014 [8]) to achieve an active mixing processes.

Figure 27 shows the current inflows which are insufficient to deliver water to the farmlands and the marsh at the same time. It is obvious that the small amounts of the downstream inflows, which access the marsh, are not sufficient for the restoration of the marsh ecosystem, causing zonation within the marsh. Therefore, there will not be enough water circulation, which has negative effects on the health of the ecosystem, such as decreasing the dissolving oxygen concentration. In contrast, Figure 28 shows a more consistent inundation and flow rate distribution for the entire marsh. Designing multiple feeder canals will deliver more fresh water to many parts, Figure 26, as well as irrigate the orchards and farmlands in the region. In addition, flushing salt out, which is a great challenge to restore the marsh, will reduce the effects of salinity creating acceptable concentrations of the salinity. Thus, the multiple feeder canals are necessary to preserve ecosystem of the western Al-Hammar marsh.

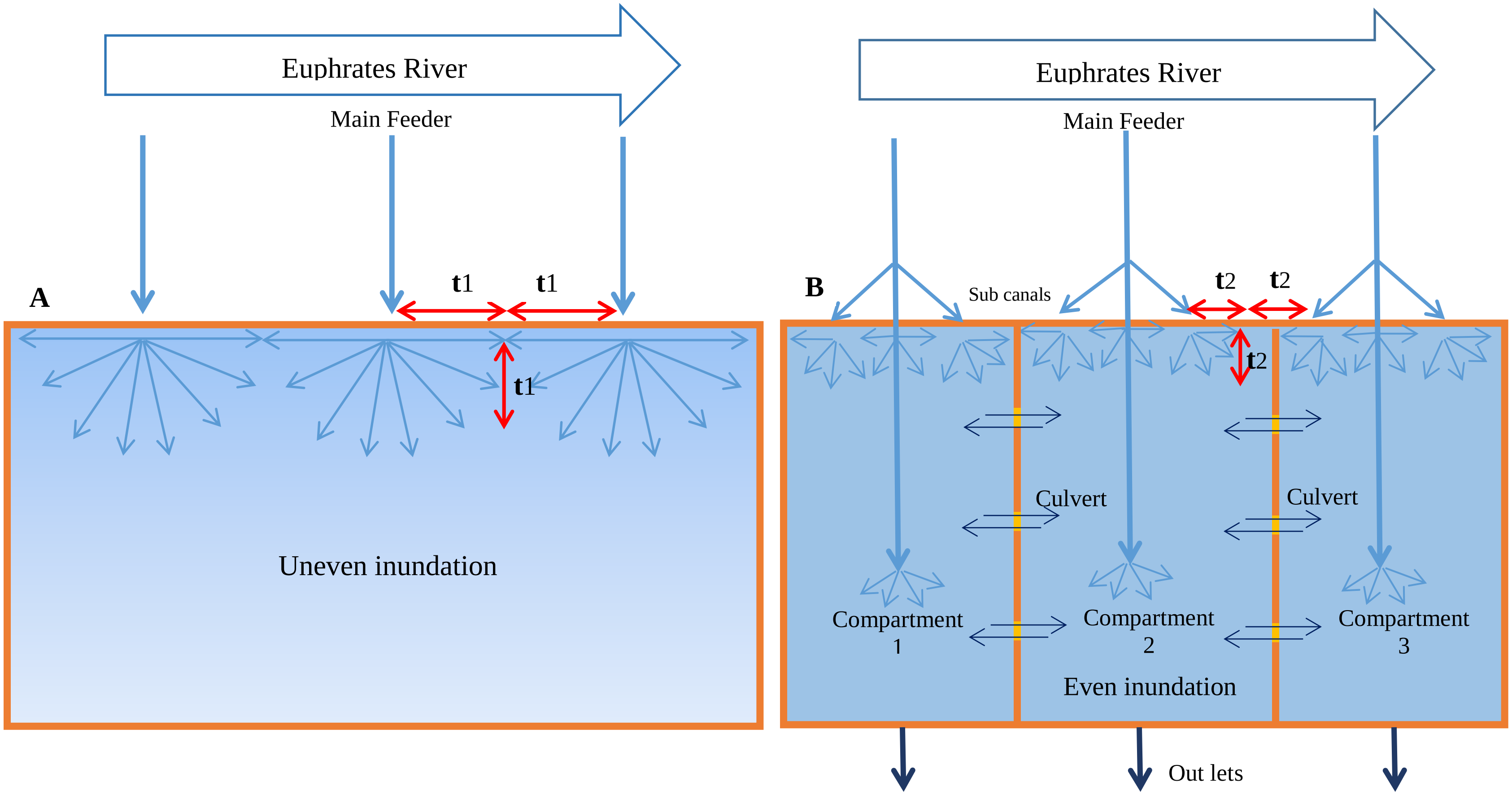

Figure 28. Two different water distribution systems in the marsh. A- The current feeder canals system of surface water distribution. B- The suggested feeder canals and sub canals network of the surface water distribution.

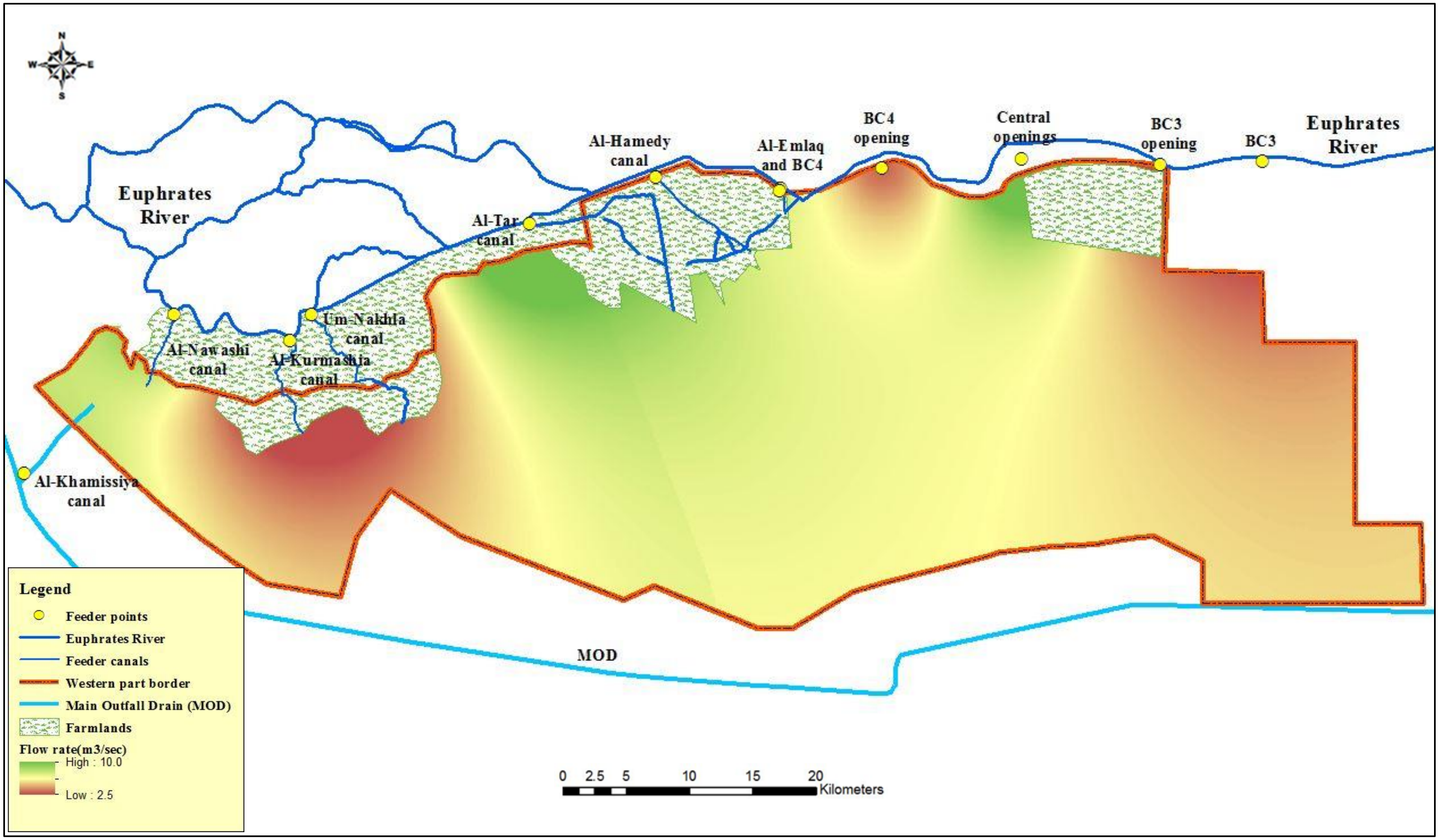

Figure 29. Distribution of the flow rate of the current feeder canals.

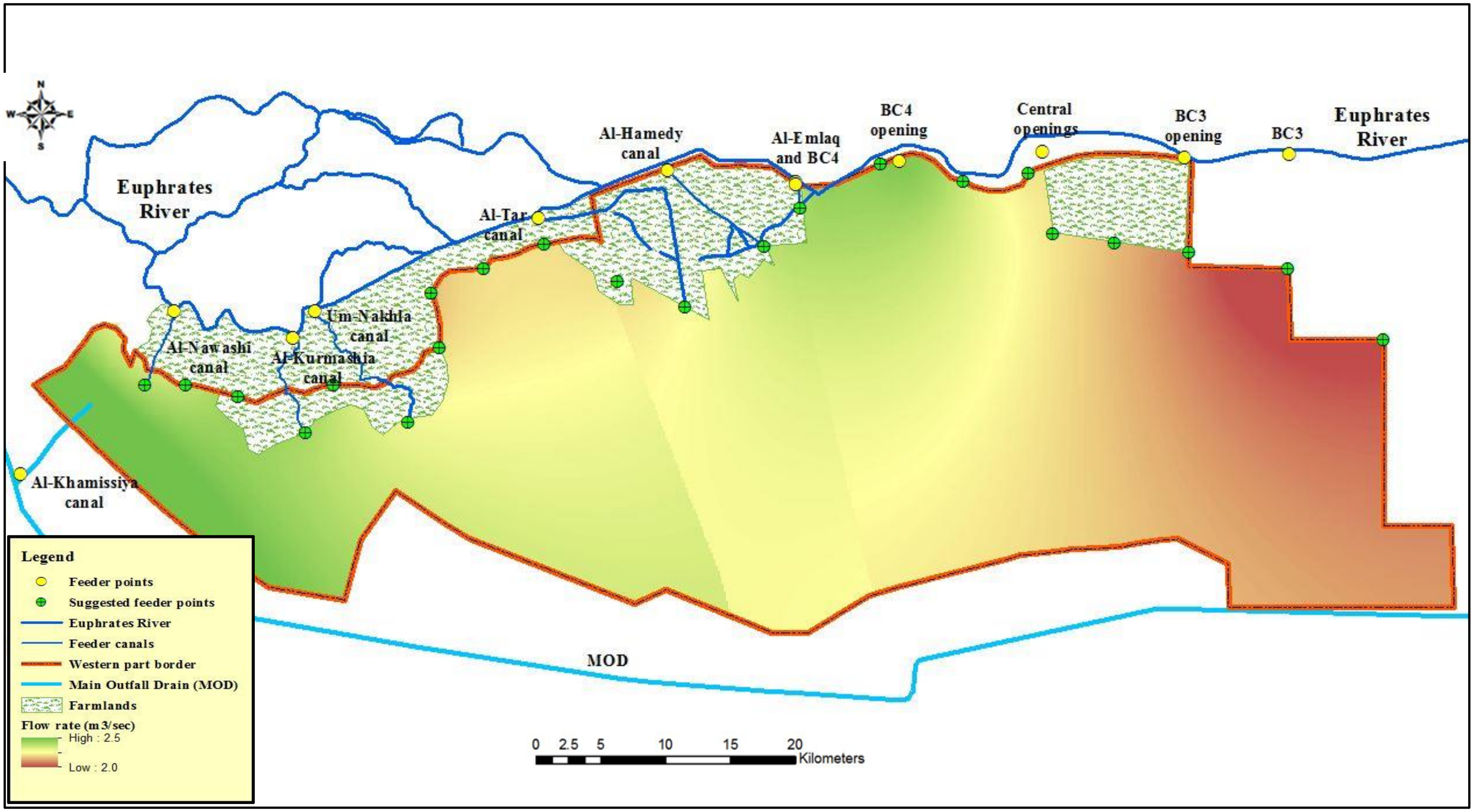

Figure 30. Assumed distribution of the flow rate to the multiple feeder canals.

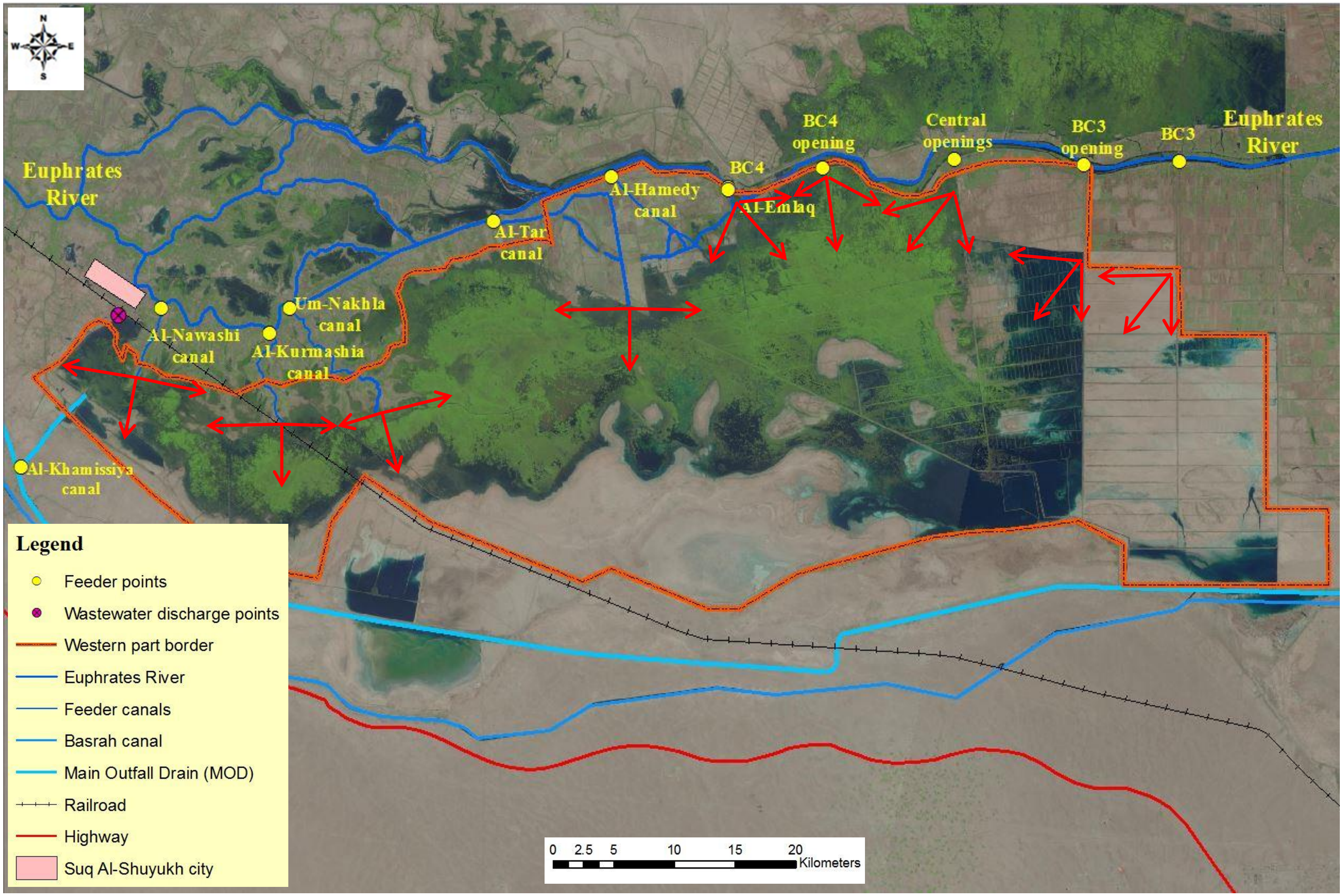

Figure 31. Current feeder points (non-equally spaced points) to the marsh.

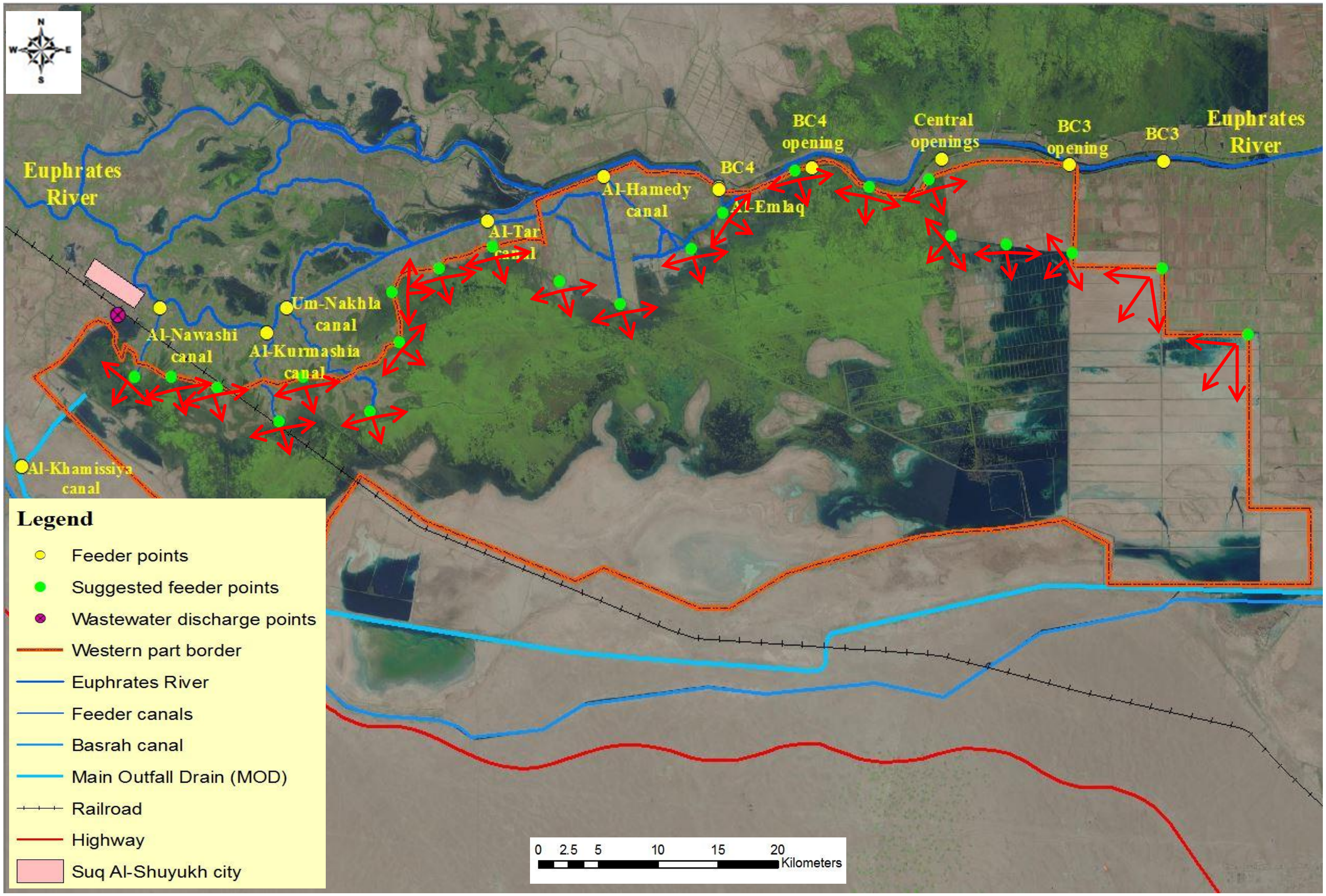

Figure 32. Suggested feeder points (equally spaced points) to the marsh.

4.5 The Main Drivers of the Water Losses in the Marsh

The temperature and surface area of the water are the main drivers that influence the rate of evaporation, and these are strongly present in the marsh regions. They play a main role in the evaporation rate which is proportional to the temperature and the surface area of the water body. The mechanism starts when the water molecules (liquid) get enough energy (temperature) to break free from the surface tension and become water vapor (gas), and this happens only at the water's surface or water-air interface [34]. The relationship between the temperature and the surface area with evaporation is shown in these equations:

1- The amount of evaporation

$$\mathrm{g}_s = \theta A(\mathrm{X}_s - x)/3600 \tag{4.5}$$

$$\mathrm{g}_h = \theta A(\mathrm{X}_s - x) \tag{4.6}$$

Where: g_s: amount of evaporated water per second (kg/s), g_h: amount of evaporated water per hour (kg/h), θ: evaporation coefficient (kg/m^{2}h) $(25 + 19v)$, v: velocity of air above the water surface (m/sec), A: water surface area (m^2), X_s: humidity ratio saturated air (kg/kg) (kg H_2O in kg Dry Air), x: humidity ratio air (kg/kg) (kg H_2O in kg Dry Air).

The required heat supply for evaporation:

$$\mathrm{q} = \mathrm{h}_{we}\, \mathrm{g}_s \tag{4.7}$$

Where: q = heat supplied (kJ/s, kW), h_{we} = evaporation heat of water (2257 kJ/kg) [35].

2- Evapotranspiration

Potential evapotranspiration or reference crop evapotranspiration is one method to calculate the net crop water requirements. Evapotranspiration of crops is determined by the formula:

$$\mathrm{ET\ crop} = \mathrm{ET_o} \times \mathrm{Kc} \tag{4.8}$$

Where $\mathrm{ET_o}$= potential evapotranspiration (mm), Kc= crop coefficient [36].

Potential evapotranspiration (mm/day) is given by:

$$ET_o = c[p(0.46T + 8)] \tag{4.9}$$

Where c= adjustment factor depending upon minimum relative humidity, sunshine hours and daytime wind estimates, p= mean daily percentage of total annual daytime hours for a given month and latitude, T= mean daily temperature in C° over the month considered [26].

The high temperatures and the wide surface area of the water are responsible for the high evaporation rate in the marsh regions. The temperature is a natural cause of evaporation and is related to the global scale. In contrast, the surface area of the water is easier to control. Therefore, this chapter addresses the possible and realistic solutions to reduce the evaporation rate, especially in the feeder canals, including main, branch, and lateral canals. Consequently, the research questions that are answered in this chapter are as follows:

How can the efficiency of the restoration process be improved? And how can the water loss in the water distribution system be reduced?

The answer to question one is that multiple feeding sources could provide water for the marsh regularly, which would have a direct impact on the marsh ecosystems. A uniform flow would allow a rich biodiversity to be obtained and would preserve the habitats which are vitally important to the health of the marsh. Also, this set-up would reduce of the travel time of water by reducing the distance between the feeding points when the travel time is proportional with the flow length as shown in the following equation:

$$Tt = \frac{L}{3600V} \tag{4.8}$$

Where T_t= travel time (hr.); L= flow length (ft.); V= flow velocity (ft./sec); 3600= conversion factor for seconds to hours [36].

5. Conclusion

The water balance of the western part of the Al-Hammer marsh, from 2009 to 2016, has shown a water deficit in the restoration of the marsh especially in the summer when the temperature and evapotranspiration rate are high. Using the Main Outfall Drain (MOD) water, which is drainage water with high salinity as an alternative source of water in 2010, helped to reduce the water shortage in the Euphrates river, but this brackish water also raised the salinity concentration of the marsh, which affected the entire marsh ecosystem: water, organisms, plants, and soil. The water budget calculation shows that the water need to maintain 500 Km^2 with a minimum depth 1 m is 50-100 Mm^3/mo. in winter and 250-300 Mm^3/mo. in summer. Therefore, estimation of the current water usage in the western Al-Hammer has shown a need for a clear strategy, not only for the management of surface water resources but also for the operation of the feeder canals. According to the current condition of the feeders and their feeding points into the marsh, they are not suited for restoration. Based on that, the restoration of the western Al-Hammar for more than 13 years has been a re-flooding process more than a restoration process due to inexistence uniform flow with a good water quality to the marsh. Also, the results have revealed that using multiple feeder canals consistently distribute the water within the marsh. Therefore, the marsh and farmlands require a canal network to be built for feeding, including inlet and outlet canals for discharging and circulating the water within the marsh. In addition, design a multiple feeder canal system with outlets which can change the hydraulic pattern within the marsh, and create an active mixing that can help to reduce the salinity concentration over time then rehabilitate the ecosystem of the marsh through improving the water quality and quantity.

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