OPTIMUM WATER ALLOCATION FOR ABO-ZIRIQ MARSH ECOLOGICAL RESTORATION

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ABSTRACT

Optimum allocation of water for restoration of Iraqi marshes is essential for different related authorities. Abo-Ziriq marsh area about 120 km^2 is situated 40 km east of Al-Nassryia city. After comparing the measured annual water qualities with the Iraqi standards for surface water quality evaluation, Abo-Ziriq marsh water quality was in acceptable limit. Hydro balance computation were done for each month by using interface among the HEC-RAS, HEC-GeoRAS and ArcView GIS software and built a number of eco-hydro relationships to simulate the marsh ecosystem by using HEC-EFM program to estimate water allocation adequate for ecosystem requirement and constructs a GIS hydraulic reference map to show inundation area, depth grid and velocity distribution, the optimal flow result consists of three different scenarios (24, 30.3 and 33.6 m^3/s) for marsh operation during the year. A computer program in MATLAB 7 was developed to simulate the optimization model to determine the optimum flow value entry to lower zone. The priority of each parameter is represented by a weight associated with each of them (penalty factor). The model was used for different scheme of penalty factor value and examines three cases of flow (wet, moderate and dry years). The results obtained from the program run show that the optimum flow values are not affected significantly with changing the scheme of the penalty factors. Hence, any set of solutions can be use for operation the control structure of two inlets in the lower zone that best fits the objective of the system and increase flow release from Abo Jiry inlet to minimum deviation in water quality during the most time of the year

Keywords: Water quality, Ecosystem requirements, Water allocation.

الخلاصة

ان توفير الحصص المائية المثلى بالكميات والنوعيات اللازمة لاعادة الحياه الطبيعية الى سابق عهدها في مناطق الاهوار في جنوب العراق يمثل احدى اهم الاولويات بالنسبة للمهتمين بهذا الموضوع. يتناول هذا البحث دراسة الحصص المائية المثلى لاعادة الانعاش الاحيائي لهور ابوزرك حيث تبلغ مساحته مايقارب 120 كم^2 ويقع في محافظة ذي قار على مسافة 40 كم شرق مدينة الناصرية. بعد مقارنة نوعية المياه المقاسة مع المحددات القياسية العراقية تبين ان مياه هور ابو زرك مازالت في حالة مقبولة وكذلك تم عمل موازنة مائية لكل شهر من خلال الاستتباع الهيدرولوجي بأستخدام التداخل بين البرامج التالية HEC-RAS، ArcView GIS، HEC-GeoRAS حيث تضمن إعداد منحنيات المساحة-المنسوب والحجم-المنسوب وتمثيل المساحة السطحية المغمورة لكل شهر وتخمين التبخر والاستهلاك والحصص المائية في الجزء الجنوبي والشمالي من الهور. لتحقيق متطلبات الانعاش الاحيائي لهور ابوزرك توجب بناء عدة علاقات لتمثيل النظام الاحيائي ووصف علاقة النظام الاحيائي بطبيعة نظام الجريان في الهورمن خلال تطبيق برنامج HEC- EFM حيث اختيرت ثلاثة سيناريوهات للتشغيل على طول السنة المائية وهي (24، 30.3 ، 33.6) م^3\ثا وتم تمثيل تلك القيم والحصول على خرائط لاعماق المياه وسرعة الجريان والمساحة المغمورة. تم تطوير برنامج (MATLAB 7) يهدف لتقليل المجموع الكلي لانحرافات التصريف ومعاملات نوعية المياه عن القيم المسموح بها وحسب برنامج EFM والمواصفات العراقية لتقييم نوعية المياه السطحية. استخدم النموذج عدة حالات مختلفة من قيم معاملات الجزاء ولثلاث حالات من الجريان (رطب وطبيعي وجاف) لكل فرع يدخل الى الجزء الجنوبي، وبعد ملاحظة النتائج تبين ان تغير معاملات قيم الجزاء لاتؤثر بصورة مباشرة على النتائج لكل حالة من حالات الجريان وامكانية اجراء مناقلة بكميات المياه الداخلة الى فرع (ابو الجري) وزيادتها بحيث تحقق افضل نوعية للمياه داخل الجزء الجنوبي للهور من خلال التحكم بمنشاة السيطرة للجزء الجنوبي على مداخل فرعي (ابو الجري و ابو سميسم).

1. Introduction

The Mesopotamian Marshlands of South Iraq represents one of the largest wetland ecosystems in all of Asia and covered more than 15,000 Km^2 (UNEP, 2002), The Mesopotamian marshland has wide ecological and environmental importance. It represents habitats for biodiversity, wildlife, and cultural richness; a 5000 year old culture, heir to the ancient Sumerians and Babylonians (Ochsenschlager, 2004). These marshes are considered by many to be the "cradle of western civilization" and are often referred to as the Garden of Eden (Nicholson et al., 2002).

Around 85% of the Mesopotamian Marshlands have been lost mainly as a result of drainage and damming, (UNEP, 2002). Most of the damage was done between 1991 and 1995; the vegetation cover was reduced by 79 % (Munro and Touron, 1997). The scale and speed of land cover changes in the marshes has resulted in effectively destroying over 90 percent of the ecosystem of one of the most important wetlands in the world in less than 10 years (UNEP, 2002).

In May 2003, water began to return to the marshlands through the actions of local marsh dwellers and Iraq's Ministry of Water Resources. As of May 2004, up to 40% of the former marshlands have been refolded. On the ground, some of the reflooded areas have experienced rapid regrowth of marshland vegetation; other areas are slowly recovering; while some reflooding areas remain barren. The recovery of the ecosystem has yet to be fully assessed.
The main problem that faces the enhancement of the ecosystem in Iraqi marshland is the lack of management and efficient operation systems for controlling the water inputs and outputs.

In such a way to make these enhancements to ensure restoration of the ecosystem in the marshes, most of the previous studies concerning the optimum allocation and operation of the Iraqi marshes deal with water quantity parameter only. Few models had been considered before, to adopt criteria in the optimum operation model that covers both quality and ecosystem requirements, in this research an attempt to reach this goal.

The main objectives of the present work are Assessment of the improvements in water quality using comparison before drying and after flooding (after April 2003) and building a hydrological routing model for the marsh by using topographical survey and hydrological data to implement hydro-balance inside the marsh

Computing the required water quantities that should be recharge to the marsh and adequate for ecosystem requirements by using the Ecosystem Functions Model EFM software. EFM analyses involve statistical analyses of relationships between hydrology, hydraulics, and ecology, and implement hydraulic model, and also GIS programs to display results and other relevant spatial data to visual form to show the different operation scenario's by using interface between HEC-RAS, ArcView GIS and HEC-GeoRAS programs.

Building an optimization model for the lower part of the marsh to minimize the penalty sum of the water quality parameters and ecological factors deviation from its allowable values as mentioned in the Iraqi standards for surface water quality evaluation.

2. Abo-Ziriq Marsh Description

Abo-Ziriq marsh is situated about 40 km east of Al-Nassryia city.

The main source of water supply to the marsh is through Shatt Abo-Lihia and the channel of this river runs through the marsh until it dissipates at the tail end into the central marsh.

The two main towns around the marsh are Al-Islah in the north and Al-Fuhod in the south of Thi-qar governorates shows in Fig. 1. Scattered villages of fishermen are located all along the embankments that surround the marsh (IMET and IF, 2005). The area of the marsh is about 120 km^2 which is 3% of the total marshes area in Iraq, the monitoring of Abo-Ziriq marsh started since late of 2003.

The marsh divided into two sectors namely Upper zone between Islah village and Islah-Fuhod (Said Yousha'a) road embankment and lower zone between the road and Al Fuhod village

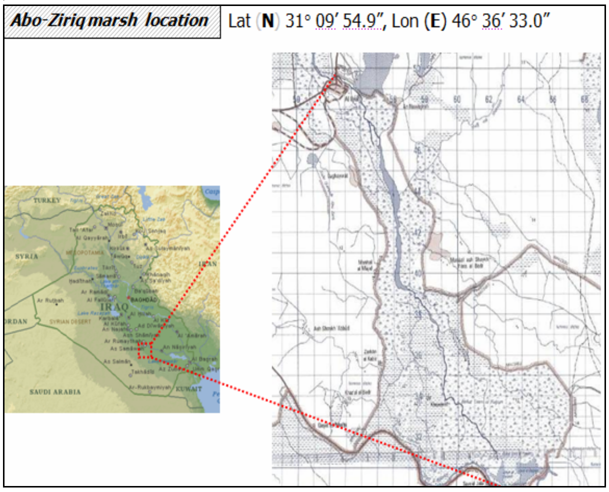

Figure 1: General location of Abo-Ziriq marsh (IMET and IF, 2005).

3. Field Work Monitoring Stations

The number of monitoring stations adopted for the field work is 6 represent upstream of the marsh (feeding point), entrance to lower zone and outflow from of the marsh, Fig. 2 shows the names and locations of the stations. The monitoring of the marsh required to extend more than one season, therefore, the period of data collected extends one year started on October 2009 to September 2010 with one monthly test for each station, Table 1 represent The parameters measured with a method and location.

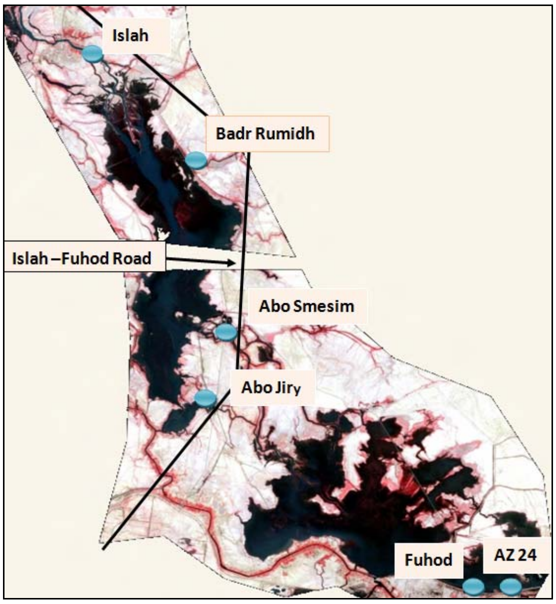

Figure 2: Monitoring station in Abo-Ziriq marsh

Table 1: Parameters measured with a method and location.

Parameters No.	Data measurement	Units	Location measurement	Instruments used
1	pH	-	On site	Multi-Meter
2	D.O	mg/l	On site	Multi-Meter
3	Water temp.	°C	On site	Multi-Meter
4	E.C	µS/cm	On site	Multi-Meter
5	T.D.S	mg/l	On site	Multi-Meter
6	NO_3	mg/l	Lab.	UV- Visible spectrophotometer
7	PO_4	mg/l	Lab.	UV- Visible spectrophotometer
8	Turbidity	NTU	On site	Turbidity meter
9	Discharge	m^3/s	On site	Flow Meter

4. HEC-EFM Relationship

The Ecosystem Function Model (HEC-EFM) is a planning tool that aids in analyzing ecosystem response to change in flow regime. Through using HEC-EFM program the amount of water required to recharge into Abo-Ziriq marsh can be estimated according to ecosystem requirements. In this study, historical flow data for the period from water year (2003-2004) to water year (2009-2010). HEC-EFM relationships are statistical representations of links between hydrology and ecology, and these relationships were selected to demonstrate how the channel restoration would affect ecosystem habitat in the marsh. Each scenario described below represents' information about an aspect of the ecosystem of the marsh. The statistical and geographical queries used to define each as an HEC-EFM relationship, and the logic used to craft those criteria (HEC, 2009).

4.1 Wetland Health

Water exchange between river and marsh areas has also been noted as a key component of wetland health. With frequent exchange, water quality in the wetlands remains good, but with isolation, dissolved oxygen levels drop, wetland areas become anoxic and aquatic species die. This is only an issue in the warm summer months, mid-May to mid-September. The healthy conditions are created when active exchange between the river and wetlands occurs 30% of the time (HEC, 2009).

HEC-EFM Relationship:

Season: 5/15 to 9/15, Duration: 1 day, Percent exceedance: 30% (of time), Flow duration

4.2 Benthic Macro Invertebrate Biodiversity

Reservoirs tend to reduce high flows and increase low flows, which creates a more stable flow regime. In these regulated systems, communities of benthic macro invertebrates often have reduced biodiversity because the few species that thrive in the more stable flow conditions out compete all of the others. Flooding initiates a return to more natural conditions which encourages the community to rebound to its original biodiversity, the timing is not important, but the high flows should occur once every two years, on average (HEC, 2009).
HEC-EFM Relationship:
Season: 10/1 to 9/30, Duration: 1 day, Means and then Maximum, Percent exceedance: 50% (2 year), Flow frequency

4.3 Riparian Shrub Recruitment and Inundation

Reservoir influence and transition of floodplain lands to agriculture has proved a destructive combination for riparian tree and shrub. Through scientific study, riparian shrub establishment has been tied to high flows that occur and recede during germination periods. After germination, survival is a function of water level. If inundated, seedlings are prone to drowning and, conversely, if water levels recede too rapidly, roots desiccate and seedlings are lost germination periods that occurs between mid-Junes through July, after germination, if water levels drop by more than 0.176 m per week then riparian shrub seedlings will have a lower chance of survival. A high stage needs to occur at least once every 5 years to keep sustainable riparian shrub establishment (HEC, 2009).
HEC-EFM Relationship:
Season: 06/15 to 07/31, Duration: 1 day, Rate of change: 0.176 m per weeks - falling (stage), Percent exceedance: 20% (5 year) - Flow frequency

4.4 Fish Spawning Habitat

Fish is important economic source for the Mesopotamian dweller, they are 12 type of fish recorded in the marsh belong to 6 families, the most common family are *Cyprinidae*, the main type is *Cyprinus carpio* (carp), *Barbus luteus* (himmry) and *Barbus sharpeyi* (benny) (MOE, 2008). Most of little fish spawn in shallow, vegetated floodplain areas between February and May. Eggs require sustained high flows for approximately 21 to 28 days before hatching; the successful spawning depends on having a sustained inundation long enough for the eggs to incubate. The fish reach sexual maturity in their first or second year and have a lifespan of approximately 4years, the good spawning conditions do not need to occur every year - it would be sufficient if there were good conditions in 25% of years, so that, on average, each little fish would have a chance to spawn in their lifespan (HEC, 2009).
HEC-EFM Relationship:
Season: 02/01 to 05/31, Duration: 24 days, Minimums (sustained highs) and then Maximum Percent exceedance: 25% (4 year) - Flow frequency

4.5 Macrophytes Habitat

Macrophytes divided according water level to 3 types; emergent plant, submerged plant and floating plant, consider *Phragmites australis* (reed) and *Typha domengns* (barrdi) are often macrophytes found in Iraqi marsh specially Abo-Ziriq marsh, it have high ability afford against salinity and make self-purification of water inside marsh. Macrophytes have economic important for marsh dwellers, there widely used in many workmanship industry of them such as homes, mats, furniture and using as livestock feeding specially buffalo (MOE, 2008).
HEC-EFM Relationship:
Season: 01/01 to 04/31, Duration: 1 day, Percent exceedance: 15% (time) - Flow duration.

5. Optimization Analysis

A MATLAB program was used to find the optimum flow values for lower part of Abo-Ziriq marsh using direct search method. Search methods consist of iteratively determining improved values for the decision variables as measured by an objective function. Most nonlinear problems following the manner; choose some point to start with; find the function value there; take a tentative short step in some direction; find the function value at new

point; if the values is less than the previous value, discard the first point in favor of the second, otherwise stay at the first; go on doing this till you find a point where the value is least within some prescribed tolerable limits.
The proposed optimization model in this study represented by the following function:

$$Min(f)=\sum_{k=1}^{nk}\left[\frac{\sum_{i=1}^{2}Q_{i,j}C_{i,j,k}}{\sum_{i=1}^{2}Q}-C_k\right]*P_k+\sum_{i=1}^{2}(Q_{i,j}-Qe_{i,j})...(1)$$

Subject to the following constraints:

$$Q_{i,j}\le Q_{i,j\max}\cdots(2)$$ During wet years

$$Q_{i,j}\ge Q_{i,j\min}\cdots(3)$$ During dry years

$$Q_{i,j\max}\ge Q_{i,j}\ge Q_{i,j\min}...(4)$$ During normal years

$$Q_{i,j\max}\ge Qe_{i,j}\ge Q_{i,j\min}\cdots(5)$$

Where: - C_k = Acceptable limit for water quality parameter (k), P_k = Different Relative penalty weight for each quality parameter (k), J = 1, 2 .12, represent the month starting from October and ending on September, respectively, as the water year, n = No. of water quality parameters, i =1, represent Abo Smesim inlet, i =2 Abo Jiry inlet, $Q_{i,j}$: Optimum water release from the inlet i, at month j, $Q_{i,j\max}$: Maximum flow from inlet i at month j, $Q_{i,j\min}$.: Minimum flow from inlet i at month j, $Q_{i,j\,avr}$: Average flow from inlet i at month j, $C_{i,j,k}$: Average parameter concentration of the inlet i, at month j of the water quality parameter k, $Qe_{i,j}$: Flow result from ecosystem relationship of the inlet i, at month j.
For the upper limit acceptable of the water quality parameter P_k will be:

$$P_k=\begin{bmatrix}greater\ \ than\ \ 0, less\ or\ equal\ \ 1\\ o\end{bmatrix}_{C^*_{k,j}\ge 0}^{C^*_{k,j}<0}$$

For the lower limit acceptable water quality parameter P_k will be:

$$P_k=\begin{bmatrix}greater\ \ than\ \ 0, less\ or\ equal\ \ 1\\ o\end{bmatrix}_{C^*_{k,j}\le 0}^{C^*_{k,j}>0}$$

$$C^*_{k,j}=\frac{\sum_{i=1}^{2}Q_{i,j}C_{i,j,k}}{\sum_{i=1}^{2}Q}-C_k$$

The objective function was adopted by assuming complete mixing of water at the lower part of the marsh, The above formulated optimization model requires the monthly flow values of the two inlet in the lower zone of the marsh, monthly flow result from EFM and the average value of EC, TDS, NO3,PO4,TUR, DO and pH for each inlets.

6. Results and Discussions

6.1 Water Quantity Data Analysis

The water quantity analysis during the onsite monitoring in the study area of Abo-Ziriq marsh during the water year 2009-2010 consist of three stages represents the discharge of upstream of the marsh, flow entrance to lower zone and outflow from of Abo-Ziriq marsh as show in Fig. 3, where the maximum flow entering the marsh is 17.75 m³/s in May, and the minimum value of flow in January was 3 m³/s .The average inflow entrance to the marsh was 8.19 m³/s. The inlet flow to the lower zone of the marsh represents the outflow passes from the upper zone via the road embankment opening; it mainly consists of flow from Abo Smesim and Abo Jiry control structure stations. The average flow rate passing to the lower zone was 6.14m³/s. The outlet flow from lower zone of the marsh represents the total outflow from the marsh; this flow is computed as the summation of all flows measured along the southern zone including AZ 24 and Fuhod stations, the average flow passing from the marsh was 2.27m³/s.

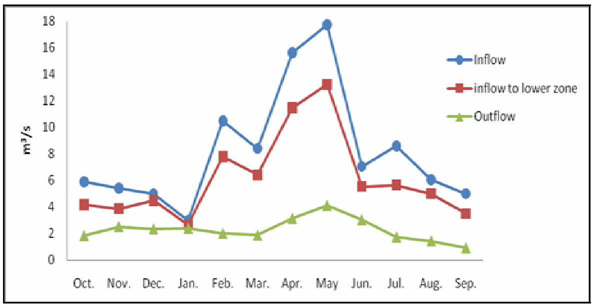

Figure 3: Flow measured in Abo-Ziriq marsh.

6.2 Water Quality Result

It presents the results gathered during the onsite and laboratory monitoring; water quality monitoring activities are divided into two types.

- Physical properties
- Chemical properties

The results present in Fig. 4 below for each parameter were compared with the allowable limits according to the law No.25/1967 (Protection of Rivers and Water from Pollution, Standards of lakes and pools and any collection of water, Ministry of Environment) for each monitoring station in Abo-Ziriq marsh shows more acceptable limits especially in TDS, EC and nutrients measurements along the water year 2009-2010 with respect of allowable value.

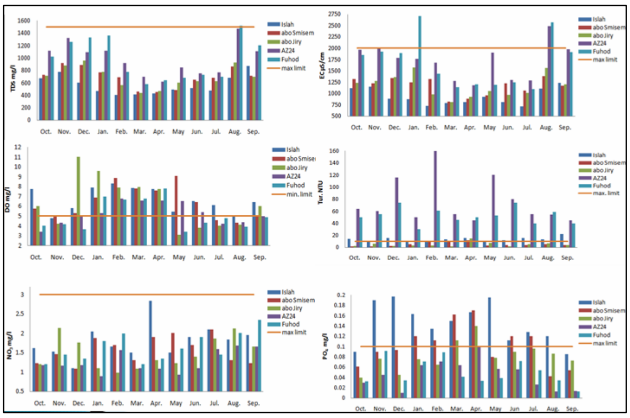

Figure 4: Water quality measurements

6.3 Hydro Balance Result

The overall hydro-balance modeling approach is depended on the following steps:

1. Available Digital Elevation Models (DEM) was used to create the updated digital elevation model concerning the marsh. The different existing obstructions such as: agricultural areas, small towns, hydraulic structures, etc… were considered in the construction of the DEM.

The updated DEM provided a powerful background for the analysis, particularly the stage-volume curve of the marsh area within any scenario of inundation.

2. Applying HEC-RAS and GIS programs to satisfy hydraulic routing in the marsh

3. Construct the Area-Elevation and Volume-Elevation curves to estimation Evapotranspiration (ET) from the surface area of the marsh.

4. Specifying the inflow and outflow from the marsh.

The achieved DEM according to the collected topographical data, surveyed data, cross sections of the Abo Lihia feeder and the marsh area are the major tool in the construction of the required geometric data in HEC-RAS Software. The constructed cross sections are obtained from the DEM through the Arc-View GIS with HEC-GeoRAS extension. The total numbers of cross sections were 22 sections; manning N (roughness coefficient) was taken equals 0.04. The hydrologic data of the recent years have been used in the implementation of the hydraulic model. This model was used to account area and storage curve and find the best solution for marsh restoration during the drought season with the results of hydrologic routing and GIS program.

Management of the hydro-balance model requires construction of Area and Volume-Elevations curves to estimation (ET) from marsh surface area. The interface between hydraulic models in HEC-RAS and graphical user interface with Arc-View GIS through HEC-GeoRAS software were used with the help of DEM to account the area inundation and the volume of water in the marsh at any elevation. The Area-Elevation and Volume-Elevation curves were show in Fig. 5.

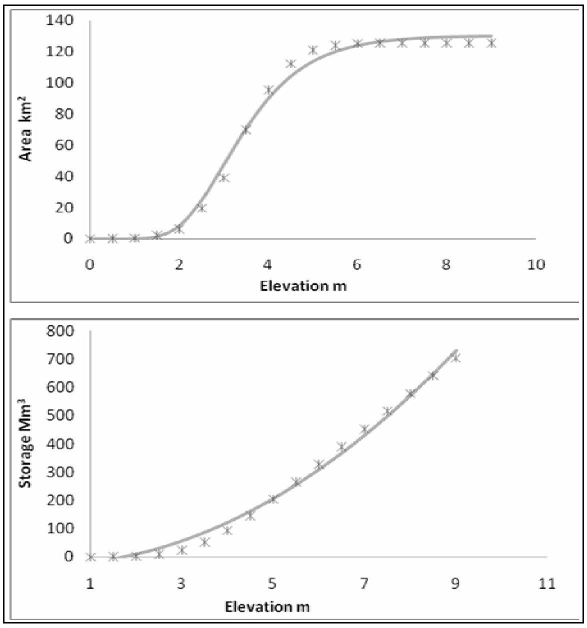

Figure 5: Volume and area elevation Curves.

The result of hydro-balance for Abo-Ziriq marsh can expressed as percentage of inlet flow (Islah station) for each month as shown in the equations below:

Inflow = Outflow

Inflow (100%) = % ET + % Water allocation in Upper and lower zone + % Outflow

Where:

Inflow (100%): Represents the total monthly flow entrance to the marsh for each month in (Islah) station as 100% percentage.

% ET: Represents the amount of water loss from the marsh as percentage from the total inflow to the marsh. % (ET) was calculated by substituted the inlet flow as volume per month in Storage-Elevation curve, then computed the elevation produced through this flow and substituting in Area-Elevation, through the surface area and mean value of ETo, the ET can be computed as apercentage of the total inflow in the marsh for each month during water year.

% Water allocation in Upper and lower zone: Represents the amount of water remaining and using in the upper and lower zone, it was computed by subtraction losses of evapo-transpiration and outflow, from total inflow entrance to the marsh.

%Outflow: Represents the percentage of total monthly flow outlet from the marsh for each month in (Fuhod and AZ24) stations.

The final results of hydro-balance distribution percentage of flow entrance in the marsh for each month are shown in Table 2. Fig. 6 shows the schematic diagram of the total hydro-balance distribution along water year 2009-2010. The percentage of allocation flow in upper zone always less than the lower zone for all the study time because of the large area of the lower zone compared with the upper zone, and there are more chanals provided water for irrigation, drinking and other requirment. Fig. 7 shows the storage and surface area produced from the inlet inflow.

Table 2: Percentage distribution of water entrance in the marsh

Hydro-balance percentage												
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.
Inlet (Islah)	100	100	100	100	100	100	100	100	100	100	100	100
Total Evapo-transpiration	21.9	9.5	5.5	2.5	6.5	10.7	19.2	31	40	37.5	34.3	31.6
Sharing upper zone	20.1	23.5	9.2	10.9	23.7	20.3	20.1	15.2	6.5	18.2	9.6	18.5
Sharing lower zone	27	20.7	38.7	7.0	50.7	46.6	40.6	30.7	10.8	24.2	32.4	31.7
Outlet (Fuhod+AZ24)	31	46.3	46.6	79.5	19	22.3	19.9	23.1	42.8	20.1	23.6	18.3

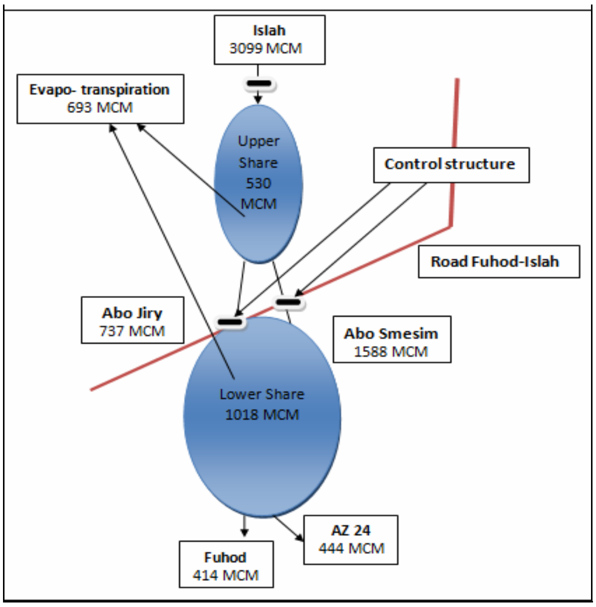

Figure 6: Schematic of the total hydro-balance distribution

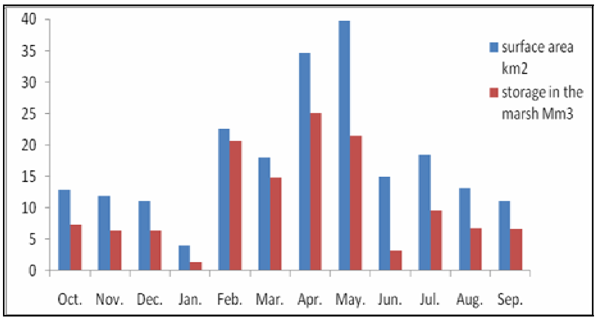

Figure 7: Storage and surface area in the marsh

6.4 HEC-EFM Results

The HEC-EFM output depended upon relationship demonstrate the eco-hydro relationships in the marsh restoration ecosystem, there are many scenarios allow to operate and monitor the ecological restoration inside the marsh, these scenarios depend on the time along the water year and relationship at that time, Table 3 shows each relationship during water year

Table 3: HEC-EFM optimum flow result for each relationship (m^3/s)

Relation	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.
Average. flow	18.5	19.5	20.7	20.4	20.2	25.3	26	21.4	21.7	22	16	19
Marsh health								23	23	23	23	23
Fish					33.6	33.6	33.6	33.6				
Benthic biodiversity	24	24	24	24	24	24	24	24	24	24	24	24
Macrophytes				30.3	30.3	30.3	30.3					
Riparian shrub									19.6	19.6	19.6	19.6
Max. Optimum	24	24	24	30.3	33.6	33.6	33.6	33.6	24	24	24	24

In order to graphically display the inundation area, velocity distribution and depth grid; the computed water surface elevations and flow velocities from the HEC-RAS model were exported into HEC-GeoRAS to construct water surface and velocity distribution. The water surface and velocity data were then compared with terrain data by HEC-GeoRAS to delineate floodplains and flow velocity distributions. The floodplains generated by the various flows from the hydrologic analysis were overlain with substrate characteristics to predict zones that would be suitable for different ecosystem functions. The net required inflow to satisfy ecological restoration in the marsh contains three suggested scenarios was depended on the HEC-EFM results, these scenarios were divided according to time along the water year:

A) First Scenario: Represent flow on January 30.3 m^3/s. Fig. 8, show inundation area, water depth and velocity distribution respectively. In addition to satisfy ecosystem requirement in January, this scenario make sure that the inundation area about 67 km^2 with velocity range 0-0.64 m/s.

Figure 8: First scenario

B) Second Scenario: Represent high flow in the marsh 33.6 m^3/s, extent from February to May. Fig. 9, shows inundation area, water depth and velocity distribution respectively. In addition to satisfy ecosystem requirement during spring season, this scenario make sure inundation area about 72 km^2 with velocity range 0-0.85 m/s.

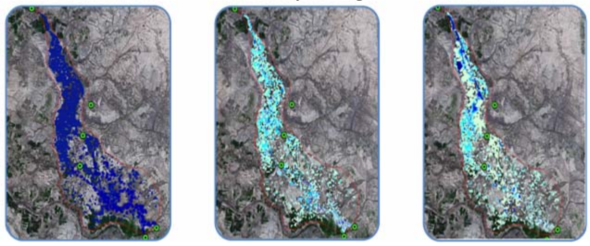

Figure 9: Second scenario

C) Third Scenario: Represent low flow duration, extent from June to December, it was 24 m^3/s. Fig. 10, shows inundation area, water depth and velocity distribution respectively. In addition to satisfy ecosystem requirement during the summer season, this scenario make sure that the inundation area about 52 km^2 with velocity range 0-0.4 m/s

Figure 10: Third scenario

6.5 Optimization Result

The optimum monthly flows of the lower zone system for Abo-Ziriq marsh were calculated by a MATLAB 7.0 program using the monthly data for both quantity and quality to formulate an optimization model. The program used the following data for obtaining the optimum flow entrance to the lower zone:

1. Monthly historical flow data for many years of the two inlets for wet, normal and dry cases.
2. Monthly flow data for EFM and hydro-balance results of each inlet to the mixing zone.
3. Water quality measurements data.

MATLAB 7.0 program used in the present study to minimize the objective function by using the allowable values (pH between 6.5-8.5, EC < 2000 µS/cm, TDS < 1500 mg/l, DO > 5 mg/l, TUR < 10 NTU, NO3 < 3 mg/l, and PO4 < 0.1 mg/l) in equation (1) and applying a penalty factor on the values of $C^*_{K,J}$ as follow:

a. For the upper limits (EC, TDS, TUR, PO4, NO3 and pH=8.5):

$If \quad C^*_{K,J} \geq 0 \Rightarrow p_k = 0$

$If \quad C^*_{K,J} < 0 \Rightarrow 0 < p_k \leq 1$

b. for the lower limits (DO and pH=6.5):

$If \quad C^*_{K,J} \leq 0 \Rightarrow p_k = 0$

$If \quad C^*_{K,J} > 0 \Rightarrow 0 < p_k \leq 1$

The Different schemes of the penalty factors assignment were used in order to evaluate its effect on the results of the optimum flow. These schemes depend on the ecological effect of each parameter on aquatic system in the marsh:

a. scheme 1 (salinity effect):

$p_k Ec = 1$
$p_k TDS = 1$
$p_k NO_3 = 0.5$
$p_k PO_4 = 0.5$
$p_k DO = 0.6$
$p_k pH = 0.6$
$p_k TUR = 0.8$

b. scheme 2 (nutrient effect):

$p_k Ec = 0.7$
$p_k TDS = 0.7$
$p_k NO_3 = 1$
$p_k PO_4 = 1$
$p_k DO = 0.8$
$p_k pH = 0.8$
$p_k TUR = 0.6$

c. scheme 3 (DO effect):

$p_k Ec = 0.6$
$p_k TDS = 0.6$
$p_k NO_3 = 0.7$
$p_k PO_4 = 0.7$
$p_k DO = 1$
$p_k pH = 0.7$
$p_k TUR = 0.7$

The optimum flow calculated for 3 schemes and 3 cases of flow wet, normal and dry years.

6.5.1 Optimum Wet Flow

For the wet years the optimum flow values for Abo Smesim and Abo Jiry inlet showed low flow variations comparing to the values of each scheme effect as shown in Fig. 11. The most optimum flow for Abo Smesim inlet more than Abo Jiry obvious to reduce flow values with respect to values of the wet flow case because the water quality in these months more acceptable from Abo Jiry inlet, it occurs at the range 6-18 m^3/s for Abo Smesim inlet and 3-10.5 m^3/s for Abo Jiry inlet, while wet flow ranges 9.5-22 m^3/s and 4.5-10.5 m^3/s for Abo Smesim and Abo Jiry inlets respectively.

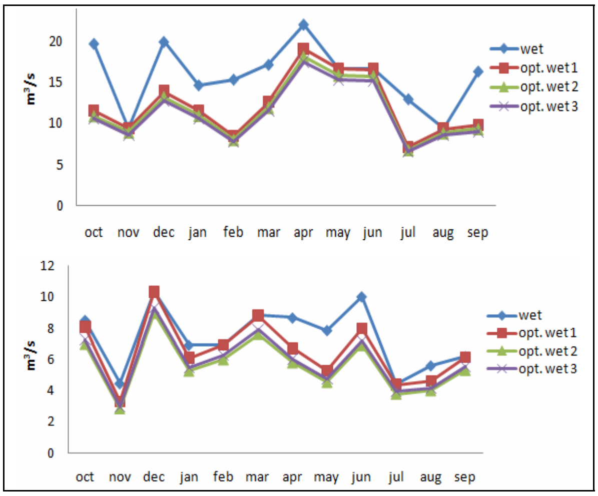

Figure 11: Optimum wet flow for different schemes.

6.5.2 Optimum Normal Flow

The optimum flow for the normal case represent the more flow values and it can be depend for controlling of the water passes through control structure in each inlet. The most probable flow for Abo Smesim inlet occurs in the range 7-17 m^3/s and 3.27-8 m^3/s for Abo Jiry inlet, comparing optimum flow values of the two inlets with those values, shows that the most optimum flow values fall in the same range, for Abo Smesim inlet flow occurs in the range 4.5-20.5 m^3/s and 2-9.5 m^3/s for Abo Jiry inlet. The optimum normal flow values show low flow variations comparing to the values of each scheme effect as shown in Fig. 12.

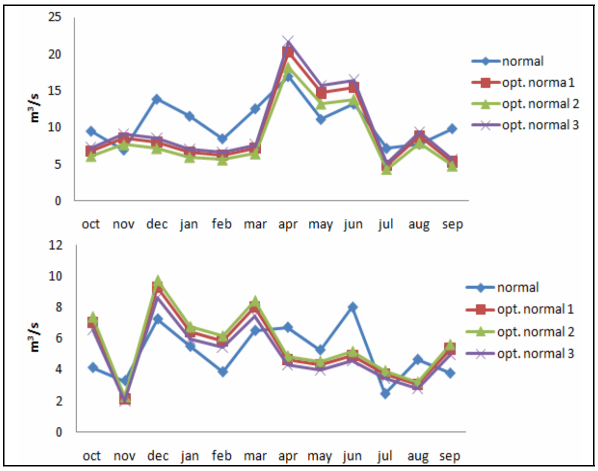

Figure 12: Optimum normal flow for different schemes.

6.5.3 Optimum Dry Flow

For the dry years the optimum flow for Abo Smesim and Abo Jiry inlet showed various flow variations comparing with the values of the dry flow in each inlet, especially in Abo Jiry inlet as shown in Fig. 13, optimum dry result appears most optimum flow for Abo Smesim inlet than Abo Jiry obvious to reduce flow values with respect to values of the dry flow case except April and August because the water quality in these months more acceptable from Abo Jiry inlet which have high optimum dry flow extend from December to May and September to October, the optimum dry flow occurs at the range 3-15 m^3/s and 1.6-8 m^3/s for Abo Smesim and Abo Jiry inlets respectively.

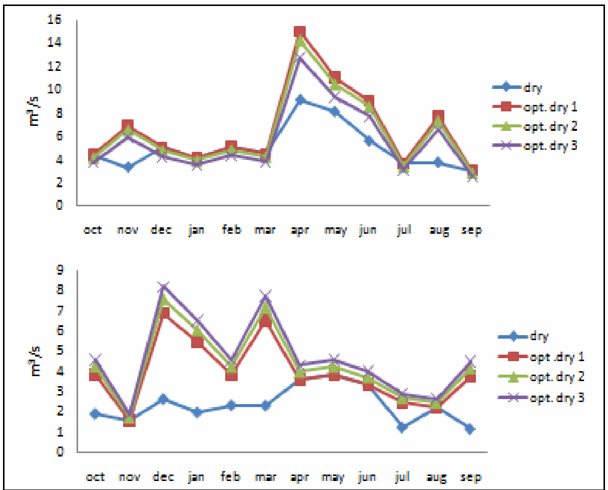

Figure 13: Optimum dry flow for different schemes.

7. Conclusion

Comparison of water quality parameters of the marsh for the present period, reflooded period, and that before drying indicate no significant changes in water quality and all are within the acceptable limits were TDS 784 mg/l, pH 8.05, E.C 1330 µS/cm, DO 5.95 mg/l, Turbidity 30.3 NTU, NO_3 1.55 mg/l, and PO_4 85 µg/l.

Evapotranspiration in the marsh is the main reason of water loss, about 22.33% of total inflow. The present annual storage with the marsh is 46.42% from inlet inflow, which remains inside the marsh and contribute to enhance the ecological restoration in the marsh.

The HEC-EFM software application indicates three optimum operations scenarios along the water year 24, 30.3 and 33.6 m^3/s. Implementation of these scenarios to produce and illustrate graphically inundation area ranging 52-72 km^2, water depth grid in the range 0-3.45 m, and a velocity distribution of a range 0-0.85 m/s, for each scenario.

The changing in schematic penalty factor has no significant effect on the optimum flow value.

Increase the inflow into the lower zone of the marsh from Abo Jiry control structure to minimize the deviation of water quality within this part.

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