Location of the Outlet of the West Part of Al Hammar Marsh

Jamal S. Makki and Riyadh Z. Al Zubaidy

Department of civil engineering, University of Thi-Qar
Department of Water Resources Engineering, University of Baghdad
E-mail: jamal_sahib2000@yahoo.com,

Abstract. The brackish water of the Main Outfall Drain (MOD) is supplied to the west part of Al Hammar Marsh to overcome the shortage of water supply and prevent dryness of the marsh. However, salts started to accumulate in high concentrations in the marsh as the MOD water contains high salt concentrations. This study aims to find an optimal outlet location in the west part of Al Hammar Marsh to drain out the water of the marsh back to the (MOD). Hydrodynamic and water quality distribution mathematical models for the marsh were developed to specify the depths of water, flow velocity profiles, and the distribution of salt concentrations in the marsh. The obtained hydrodynamic properties and the quality of the water within the marsh area were used as indicators for selecting the optimal outlet location among five suggested locations at six operation conditions. Results showed that the water depth, velocity profiles, and concentration of the total dissolved solids (TDS) are affected by the location, discharge, the concentration of the TDS of the feeders, location of the outlet, the topographic characteristics at the upstream of outlet, and evapotranspiration. It is found that the third location of the outlet, located at E=699003 and N=3404760, gives the minimum deterioration in the concentration of the TDS, depending on the overall distribution of TDS concentrations.

Keywords
Marsh, Al Hammar, outlet, TDS.

1. Introduction
The marshes of Iraq cover a relatively wide area (15000-20000 km$^2$) compared with other lakes and water bodies, and they are located in the south of the country [1]. Therefore, it is very important for the economy, climate and environment in Iraq and the population in the south particularly. The area of the Al Hammar Marsh was reduced greatly due to the reduction in the supplied water. The reduction in the supplied water to the marsh is a result of the massive increase in demand for water in Turkey, Syria, and Iraq. To reduce the effects of this problem, a part of the MOD water was suggested to be supplied to the marsh, as a temporary solution in order to prevent the marsh dryness. The MOD water is delivered to the marsh by a canal of 40 m$^3$/s capacity, which is known as Al Khámìssiyá canal. This canal was constructed and started feeding the marsh by the end of 2009, the additional supply of water to the marsh has contributed in maintaining the marsh area. The water of the MOD is classified as brackish water with salinity varying between 4450 and 8381 mg/l, [2]. After four years of uncontrolled supplying MOD water without any outlet to drain out the water, the salt has accumulated in the marsh and reached very high levels of concentration that threatening the ecosystem of the marsh.

The marshes have been affected by the combined action of the upstream damming in Turkry, Syria, and Iraq, and the massive intended drying (by the regime) that was performed in south of Iraq during the 1980s and 1990s [3]. These actions have resulted in reducing the marsh areas by 10%-15% from the original area in the year 2001 according to the official records of the Iraqi ministry of irrigation [4]. Regarding the modelling analysis, Sharp [5] has made the first attempt of using topographical techniques for specifying the optimum locations for sampling stations. Then, the Dynamic...
Programming Approach (DPA) technique was introduced by Bellman [6] as an integrated method for maximizing and minimizing mathematical formulas to solve problems MCDM. In addition, several authors have studied the DPA such as Harmancioglu et al. [7], Park et al. [8], Shamsuddin et al. [9].

The main problem in Al Hammar Marsh is an accumulation of salt in it; this is because of feeding the marsh from MOD that has a high concentration of TDS without an outlet. This study aims to obtain an optimal outlet location of the west part of Al Hammar Marsh for draining out the water from the marsh to the MOD. This would decrease the concentration of TDS within the marsh. This target can be achieved by developing mathematical models for the water hydrodynamic and quality distribution for the marsh by using River Modeming Analysis of the Surface Water Modeming System Package.

2. Methodology
The methodology of this research includes the collection of the available data like bed elevations, area elevation curves, storage elevation curves, evapotranspiration and the discharge of the feeder. Field investigation was carried out for specifying the feeder locations and updating the digital elevation model (DEM). The discharges of the feeders were measured and calculated according to the midsection method of the U.S. Geological Survey, USGS, [10]. A satellite image was used to set the layout of natural and artificial features in the marsh. The hydrodynamic and water quality models were constructed by using RMA2 and RMA4 software as a part of the SMS package. The models were developed by Norton, King and Orlob for water resource engineering in 1973 for the Walla district corps of engineers. This software is based on finite element method.

The hydrodynamics and water quality models were constructed by using RAM2 and RMA4 software as a part of the SMS package. The models were developed by Norton, King and Orlob of Water Resources Engineering in 1973 for the Walla District Corp of Engineers. This software is based on finite element method. The calibration and verification processes of the mathematical models were performed, before running, by comparing the field measurements with the results obtained from the software runs under the same conditions. The roughness coefficient and the Peclet number that is used in the next model runs are selected depending on the minimum error between the measured and acquired values.

Hydrological routing based on six suggested cases then was applied to specify the boundary conditions used in the mathematical models.

The obtained results of the two models suggested were analysed to obtain the best location among the suggested locations of the outlet of the marsh according to the distribution of TDS concentration and the velocity pattern.

3. Description of the Area of the Study
The west part of Al Hammar Marsh is located between E=635530 to E705470 and N=3398970 to N3426800, bounded by Euphrates River from the north boundary, Ar-Rumaila Oil Fields as the east boundary, and the main canal of Al Basrah Water Supply Project and the MOD as the south boundary, and Suq AshShuyukh as the west boundary, Figure 1. The west part of Al Hammar Marsh was covering a third of AnNassiriyah Governorate with an area about 1150 km² [11]. There are many natural and artificial features in the marsh such as islands, waterways, deep pools, security dikes and railway, these features were considered in the hydrodynamics and water quality models.
4. Available Data
This section presents the available topographical data, the area-elevation and the storage-elevation curves, evapotranspiration within the marsh, which are presented in [2]. Moreover, this section presents the discharges of Al Hammar and their water qualities that was provided by CRIM and the precipitation within the study area that was provided by the General Iraqi Meteorological Authority and Seismology.

4.1. The topography of the Marsh
The topography of Al Hammar Marsh, figure 2, was developed based on the available DEM, which was obtained from Shuttle Radar Topographical Mission Data of 90 meters definition.

4.2. Area and Storage Elevation Curves
Depending on the DEM of the marsh, the area and storage elevation curves for the west part of Al Hammar Marsh were obtained by [2], as shown in figures 3 and 4.
4.3. Discharge of Feeders
A complete set of monthly discharge measurements for the main feeders of the marsh was carried out by CRIMW as presented in table 1.

| FEEDER                          | MONTH                                      |
|---------------------------------|--------------------------------------------|
| AL KURMASHIA                    | Jan. 1.48 Feb. 1.84 Mar. 0.91 Apr. 1.60 May 1.42 June 1.35 July 2.81 Aug. 2.15 Sept. 2.23 Oct. 2.48 Nov. 1.13 Dec. 1.87 |
| UM NAKHLA                       | Jan. 2.63 Feb. 3.14 Mar. 1.50 Apr. 2.20 May 2.20 June 2.33 July 5.23 Aug. 3.98 Sept. 3.75 Oct. 3.83 Nov. 1.58 Dec. 3.00 |
| RIGHT OF EUPHRATES RIVER        | Jan. 18.48 Feb. 28.52 Mar. 14.89 Apr. 18.18 May 19.00 June 18.03 July 25.18 Aug. 34.08 Sept. 27.59 Oct. 27.13 Nov. 14.18 Dec. 20.34 |
| AL KHAMISSIA                    | Jan. 18.50 Feb. 27.35 Mar. 22.94 Apr. 34.73 May 27.65 June 22.75 July 21.45 Aug. 29.03 Sept. 32.06 Oct. 30.78 Nov. 17.30 Dec. 19.75 |

4.4. Evapo-transpiration
Evapo-transpiration within Al Hammar Marsh region is presented in figure 5. Al Hammar Marsh lies within a region of high evapo-transpiration with an annual value of 2909mm and a monthly average of 242.4mm. It is 52mm during January and increases to 470mm during June, which is 9.4 times that of January.
5. Field Work
An extensive field investigation was carried out to accurately specify the feeders of the west part of Al Hammar Marsh. It was found that there are fourteen feeders. Only Al Khamissiya Canals feeds the marsh with the brackish water of the MOD, all others feed the marsh with the water of Euphrates River. Table 2 presents a list of these feeders. The flow of eight of the feeders is supplied Al Hammar Marsh through Um Elwada Opening, E 646189 and N3409352. This opening was made in the dyke at the North West boundary of the marsh. The discharges of the feeders were measured by using a universal current meter model 6500, made by Rickly Hydrological Company, with a digital revolution counter that was used during the field investigations within the west part of Al Hammar marsh, it was found that the DEM requires some modification and updating. This includes the culverts of the railway and the security dyke, the dyke surrounding the residential area of AsSahalatt, and the dyke at the north-west boundary of the marsh that was constructed during 2011. The elevation of the railway is about 5 m.a.m.s.l. and that for security dyke is about 4 m.a.m.s.l. The water levels within the marsh will not exceed an elevation of about 3 m.a.m.s.l. Accordingly, the elevations of the railway and the security dyke were not measured. The location of the culverts through the railway and the security dyke and six small permanent islands within the marsh were specified.

| Feeder       | Location of outlet |
|--------------|--------------------|
| Al Nawashi   | East 641469        |
|             | North 3415670      |
| Al Gassid    | 641973             |
| Al Zaeelia   | 642261             |
| Khatlaan     | 642806             |
| Um           | 643418             |
| Altobool     | 644222             |
| Al Ramlia    | 646249             |
| Mahood       | 647101             |
| Al Had       | 649135             |
| Al kurmashia | 652657             |
| Um Nakha     | 663413             |
| Al Hamedy    | 677319             |
| Al Tar       | 683909             |
| Al Emlaq     | 637326             |
| Khamissiya   |                    |

6. Details of the Mathematical Models
The RMA2 and RMA4 models can be applied to investigate the profiles of the flow velocity, water depths, and the concentration of the total dissolved solids within the marsh. The flow and concentration of the dissolved solids of the feeders are considered as the conditions of the upstream boundary. Also, the water level of the marsh at the outlet is assumed to be the downstream boundary conditions. The features of the topography of the marsh are given by a digital elevation model Donnell, 2009.

6.1. Governing Equations
The governing equations hydrodynamic of the flow are the momentum and continuity equation. The momentum equations in both x and y directions are:

\[
\begin{align*}
    h \frac{\partial u}{\partial t} + hu \frac{\partial u}{\partial x} + hv \frac{\partial u}{\partial y} - h \frac{E_{xx} \frac{\partial^2 u}{\partial x^2} + E_{xy} \frac{\partial^2 u}{\partial x \partial y}}{\rho} + gh \left( \frac{\partial a}{\partial x} + \frac{\partial h}{\partial x} \right) \\
    + \frac{gun^2}{(1.486h^{1/6})} \left( u^2 + v^2 \right)^{1/2} - 2hv \omega v \sin \phi = 0
\end{align*}
\]

And

\[
\begin{align*}
    h \frac{\partial v}{\partial t} + hu \frac{\partial v}{\partial x} + hv \frac{\partial v}{\partial y} - h \frac{E_{yx} \frac{\partial^2 v}{\partial x^2} + E_{yy} \frac{\partial^2 v}{\partial y^2}}{\rho} + gh \left( \frac{\partial a}{\partial y} + \frac{\partial h}{\partial y} \right) \\
    + \frac{gun^2}{(1.486h^{1/6})} \left( u^2 + v^2 \right)^{1/2} - 2hv \omega v \sin \phi = 0
\end{align*}
\]

The continuity equation in unsteady flow problems may be written as:

\[
\frac{\partial h}{\partial t} + h \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) + u \frac{\partial h}{\partial x} + v \frac{\partial h}{\partial y} = 0
\]

The depth-averaged transport and mixing process is governed by the following equation:

\[
h \left[ \frac{\partial c}{\partial t} + u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} - \frac{\partial}{\partial x} \left( D_x \frac{\partial c}{\partial x} - \frac{\partial}{\partial y} \right) - \frac{\partial}{\partial y} \left( D_y \frac{\partial c}{\partial y} \right) + \frac{R(c)}{h} \right] = 0
\]

Where the \( z \) is elevation of Bottom, \( c \) is the concentration of pollutant for a given constituent, \( D_x \) and \( D_y \) are the turbulent mixing, dispersion, coefficients, \( E_{xx} \) is eddy viscosity coefficient on x axis surface, \( E_{yx} \) and \( E_{yy} \) is shear direction on each surface, \( \sigma_y \) is eddy viscosity coefficient on y axis surface, \( g \) is acceleration due to gravity, \( h \) is water depth, \( n \) is Manning's roughness, \( R(c) \) is rainfall/evaporation rate, \( t \) is time, \( u \) and \( v \) are velocities in Cartesian coordinates, \( \rho \) is the density of fluid, \( \omega \) is rate of earth angular rotation, and \( \Phi \) is local latitude. The depth-averaged transport equation is solved by the finite element method using Galerkin weighted residuals. As with the hydrodynamic model RMA2, the transport model RMA4 handles one-dimensional segments or two-dimensional quadrilaterals or triangles. Curved element edges are also supported. Spatial integration of the equations is performed by Gaussian techniques and the temporal variations are handled by nonlinear finite differences consistent with the method described for RMA2.

6.2 RMA2 Model
RMA2 is a two-dimensional depth-averaged finite element hydrodynamic numerical model that can compute water surface elevation and horizontal velocity components in a free-surface field. This model was developed by Norton, King and Orlob for water resource engineering in 1973 for the Walla district corps of engineers. Graphic pre and post-processing routines were updated by Brigham Young University through a package called the Surface water Modelling System, SMS, RMA2 is also included as a part of the SMS package [12]. Hydrodynamic equations are solved by the finite element method using the Galerkin Method of weighted residuals. The elements may be one-dimensional channel reaches, or two-dimensional quadrilaterals or triangles, and may have curved (parabolic) sides.

6.3 RMA4 Model
RMA4 is a finite element water quality transport numerical model when the depth concentration distribution is supposed to be uniform. It calculates the concentrations of many elements/constituents. RMA4 was developed by Norton, King and Orlob, 1973, of Water Resources Engineers, for the Walla
District Corps of Engineers, and delivered in 1973. Subsequent enhancements have been made by King and Rachiele, of Resource Management Associates, RMA, and by the US ERDC. WES coasted and Hydraulics laboratory [13].

7. Selecting the Location of the Outlet
In order to reduce the accumulation of salts within the west part of Al Hammar Marsh, the marsh must have an outlet to flush out the accumulated salts. The outlet must be located at a point where the topography helps the flow toward the outlet, near the MOD or the nearby drains, at the downstream end of the marsh, and far from the oil field at the region. Accordingly, five locations for the outlet of the marsh were suggested as shown in figure 6. Table 5 presents the coordinates of the suggested locations.

![Figure 6. The suggested locations for the outlet.](image)

8. Input Data of the Mathematical Models
Based on the hydrologic analysis, six cases are considered. The first three cases include the analysis flow within the marsh based on a minimum area of the marsh, of 250 km², with the average of the measured discharges, 30% higher than the measured discharges, and 30% less than the measured discharges. Depended on these cases, the downstream water level of 1 m.a.m.s.l. was adopted as a downstream boundary condition. In the three other cases, the maximum area of the marsh is obtained based on the maximum flow from Al Khamissiya Canal, of 40 m³/s, and with the average of the measured discharges, 30% higher than the measured discharges, and 30% less than the measured discharges. The downstream boundary condition for the second three cases were 1.15, 1.25, and 1.1 m.a.m.s.l. respectively taken from the area elevation curve.

9. Results
The results of the mathematical models showed that the studied variables such as water depth, velocity profiles, and TDS concentration in the marsh are affected by the location within the marsh, feeder discharges, and the concentration of the TDS of the feeders. In addition, the marsh characteristics are also significantly influenced by the outlet location, the topographic characteristics at the outlet upstream, and evapo-transpiration.
Figures 7 and 8 show the results of the mathematical model for case (1). It is stated that the water depth, the velocity profile, and the TDS concentration within the part that, which lies before the railway and the security dyke, were not affected by the outlet location. This can be because these barriers prevent the effect of changing the location of outlet on the areas upstream them. It is also observed that the North West part of the marsh presented low TDS, this can be explained by the fact that all the locations of the feeders, which supply the marsh with Euphrates Rivers’ water, are joined to this part. Further, there is a main path of the water flow lying close to the north of the marsh centreline and turns toward the outlet at the path end. It is well known that the increased evaporation reduces the outflow discharge and increases the concentration of the TDS. This is consistent with the model results as the TDS concentrations are increased in downstream part of the marsh.
Regarding case (2), where the outlet was located at E= 699300 and N= 3409460, high water levels are observed within the marsh. This seems to be a result of the relatively low water depths owing to the high ground levels at the upstream the outlet. It is important to mention that the low concentration of TDS in the outlet discharge does not necessarily apply to a low concentration of TDS. This is because the water flow of low concentration of TDS can find a direct way toward the outlet leaving other areas of the marsh with high TDS concentrations. The results of all six cases show that the 3rd location which located at E=699003 and N=3404760, gives the minimum deteriorated area among all other locations. From these results, it can be concluded that the 3rd location is the best outlet location under the current study conditions. Table 3 presents the percentage of the deteriorated area with respect to the total area of the marsh and the range of TDS concentration in these areas of the studied cases. It can be noticed that the outlet location in case (2) has resulted in minimum concentration of the TDS within the marsh. This was where the discharge of Al Khamissiya canal is at its minimum value (20.8 m³/s) and the discharge of the feeders at the measured value plus 30% (37.7).

**Figure 7.** Hydrodynamic model run results for condition of case 1
Figure 8. Variation of the concentration of TDS within the marsh.

Table 3. The results of mathematical models of 3rd location of outlet for the six cases.

| Case | Discharge, m$^3$/s | Most deteriorated area | range of TDS, mg/l |
|------|--------------------|------------------------|--------------------|
|      |                    | Al Khamissiya feeders  | %                  |
| 1    | 27.7               | 29.1                   | 20.5               |
| 2    | 20.8               | 37.7                   | 31.7               |
| 3    | 34.7               | 20.3                   | 6.5                |
| 4    | 40.0               | 29.1                   | 6.7                |
| 5    | 40.0               | 37.7                   | 22.3               |
| 6    | 40.0               | 20.3                   | 17.4               |

10. Conclusions

1. In all the cases that were analyzed by using the hydrodynamic and water quality models, the water depth, the velocity profiles, and the concentration of the TDS are affected by the location, discharge, and the concentration of the TDS of the feeders, location of the outlet and the topographic characteristics at its upstream, evapo-transpiration.

2. In all models runs, the concentrations of the TDS within the North West part of the marsh is relatively of less TDS because all of the locations of the feeders supplying the marsh with Euphrates Rivers are located within this part.

3. In all cases that were analyzed by using the hydrodynamic and water quality models, and depending on the overall distribution of concentrations of the TDS within the marsh, the third location of the outlet gives the minimum deterioration in the concentration of the TDS and in the velocity profiles within the marsh.

References

[1] Ryidh Abood Yasir, Khayyun Amtair Rahi and Zaidun Naji Abudi 2018 Water budget for Abu Zirig Marsh in Southern Iraq, Journal of Engineering and Sustainable Development Vol. 22, No. 10, 2018

[2] Center for the Restoration of Iraqi Marshes, CRIM, 2010, Possibility of using the water of the main outfall drain to restore Al Hammar Marsh after operating the pumping station in Al Nassiriya.

[3] Partow H 2001 Book, The Mesopotamian marshlands: demise of an ecosystem.

[4] Ministry of Irrigation 2004 Report on Iraqi Marshes (Unpublished, in Arabic).

[5] Sharp W E 1971 A topologically optimum water-sampling plan for rivers and streams. Water Resour Res 7(6): pp1641–1646

[6] Bellman R 1975 Dynamic programming. Princeton University Press, Princeton

[7] Harmancioglu N B, Icaga Y, Gul A 2004 The use of an optimization method in assessment of water quality sampling sites. Eur Water 5(6): pp 25–35
[8] Park C, Kim SH, Telci I T and Aral M M 2010 Designing optimal water quality monitoring network for river systems and application to a hypothetical river. In: Proceedings of the 2010 Winter Simulation Conference (WSC), 5-8 Dec. 2010

[9] Shamsuddin NHM, Bin Othman MS, Bin Selamat MH 2013 Identifying of potential crime area using Analytical Hierachy Process (AHP) and Geographical Information System (GIS). *Int J Innov Comput Appl* 2(1): pp 15–22

[10] USGS 1976 Techniques of water-resources investigations of the United States geological survey, Chapter A8, Discharge Measurements at Gauging Stations

[11] Center for the Restoration of Iraqi Marshes, CRIM, 2007, Study of improving the environmental present condition of Southern Marshes, *Hydrological and Water Quality Study*

[12] Donnell B P 2009 (b) User Guide to WES-RMA2 Version 4.5, Water Ways Experiment Station, Costal and Hydraulics Laboratory, California, Davis, U.S.A.

[13] Donnell B P 2009 (a) User Guide to WES-RMA4 Version 4.5, Water Ways Experiment Station, Costal and Hydraulics Laboratory, California, Davis, U.S.A.