Republic Of Iraq
Ministry of Higher Education
and Scientific Research
University of Technology
Building and Construction Dep.
Water and Dams Engineering Branch

Design of Al Khamissyia Canal by using HEC-RAS Software

Annual project submitted to the department of building of construction engineering of the University of Technology in partial fulfillment of requirements for the degree of B.Sc

In building and construction engineering

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2011 1432

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العليم الحكيم

صدق الله العلي العظيم

سورة البقرة (٣٢)

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LIST OF ABBREVIATIONS

CRIM	Center for the Restoration of Iraqi Marsh lands.
FAO	Food and Agriculture Organization.
MOD	Main Outfall Drain.
MOE	Ministry of Environment
MOWR	Ministry of Water Resources.
UNEP	United Nation Environmental Program.
WHO	7World Health Organization.

CHAPTER ONE
INTRODUCTION

1.1 General

Al Hammar Marsh is considered as one of the largest Marshlands in Iraq. The marsh running below Euphrates River before it joins Tigris River, at Al Qurna City, from Al Nassiriyah City in Thi Qar Governorate to Al Chibaeich north of Al Basrah Governorate. Al Hammar Marsh is located between latitude 46° to 47°, and longitude 30° to 30.5°, bounded by Euphrates River as the north boundary, Shatt Al Arab River as the east boundary, and Al Basrah Water Supply Project main supply channel and the Main Outfall Drain as the south boundary, and Suq AshShuyukh as the west boundary.

During the last two dry years, there was a great shortage in the water required maintain Al Hammar Marsh. The area of the marsh was reduced greatly threatening the ecological system and economics of the marsh residents.

A suggestion was made by CRIM and other related ministries to make use of the MOD water to feed the marsh as ***a temporary solution*** that will prevent the marsh to dry again. CRIM studied the impact of this temporary solution on the water quality within the marsh and on the ecological system. CRIM carried out a hydrological routing analysis based on the objective of maintaining Al Hammar Marsh area and minimizing the evapo-transpiration, ETO, losses.

A suggestion was made to minimize the marsh area to a value that keeps contiguous lake during the period of high ET_O and to be increased up during the period of low ET_O. Accordingly, based on the incoming and outgoing discharges, the variation of inflow and outflows discharges, water level, marsh area, water volume, and the water quality within the marsh were specified. The decision which marsh operation is the optimal is based on minimizing the water quality deterioration within Al Hammar Marsh.

Based on the hydrological routing analysis, a mathematical hydraulic model was implemented to specify the submerged area within the marsh. The discharges that could be inflow into the marsh from the MOD and conserve the ecological system of Al Hammar Marsh within the acceptable international standards were specified according to results of the hydrological routing and the hydraulic models.

To divert these discharges from the MOD to the marsh it is necessary to construct an open canal with a control structure at the upstream of this canal to control these discharges.

CRIM studied several possible locations to divert the MOD water to Al Hammar Marsh. The conclusion that was made by CRIM is to divert an average of about 130 m^3/s to Al Hammar Marsh from the MOD by constructing a linking canal. The canal intake is located downstream of the pump station at 136 +430 *km* of the MOD, E= 633137 N= 3407199, and ends at a point within Al Hammar Marsh located by E=637273 and N= 3411982. This canal is called Al Khamissiya Canal.

1.2 Aim of the project

This project aims to prepare designs of Al Khamissiya Canal and hydraulic structure to control the inflow discharges from the MOD to Al Hammar Marsh.

1.3 Methodology of work

The methodology of carrying out this project can be summarized as follows:

1- Reviewing the related literatures,
2- Collecting the topographical, hydrological and water quality data,
3- Implementing a steady one dimensional hydraulic model by using the HEC- RAS software to simulate the flow in the MOD.
4- Using the HEC- RAS software to design the proposed canal ,
5- Using the HEC- RAS software to design the proposed control structure by using a steady one dimensional hydraulic model to simulate the flow in Al Khamissiya Canal.
6- Discussing the results and giving the necessary recommendations.

CHAPTER TWO
AREA OF STUDY

2.1 Al-Hammar Marsh

Al Hammar Marsh is considered as one of the largest Marshlands in Iraq. The marsh running below Euphrates River before it joins Tigris-River, at Al Qurna City, from Al Nassiriyah City in Thi Qar Governorate to Al Chibaeich north of Al Basrah Governorate. Al Hammar Marsh is located between latitude 46° to 47°, and longitude 30° to 30.5°, bounded by Euphrates River as the north boundary, Shatt Al Arab River as the east boundary, and Al Basrah Water Supply Project main supply channel and the Main Outfall Drain as the south boundary, and Suq AshShuyukh as the west boundary. **Figure 1** shows the general layout of Al Hammar Marsh.

Some parts of Al Hammar Marsh was isolated by constructed dykes and drained to facilitate the development and exploitation of oil resources by the South Petroleum Company. An unpaved road was constructed to connect the north part of Al Hammar Marsh with the south part at ArRumaila Oil Fields, separating the marsh into two parts, the east and west parts. This road has 334 culverts and three bridges with total length of 4350 m, CRIM 2008.

Before construction of great dams and developing new irrigation projects in Turkey, Syria, and Iraq and the massive drainage and drying processes of marshes, during nineties of the last century, "Al Hammar Marsh was covering a third of Thi Qar Governorate with an area ranged between 2800km^2 of contiguous permanent marsh and lake, extending to a total area of over 4500km^2 during periods of seasonal and temporary inundation, it is approximately 120*km* long and 25*km* at its widest point.

The maximum depth at low water levels is 1.8*m* and about three meters at high water levels. During the summer, large parts of the littoral zone dry out, and banks and islands emerge in many places", UNEP 2001. Several branches from Euphrates River were feeding Al Hammar Marsh. Some of these branches are controlled by head regulators of different capacities varying between 50-500 m^3/s, with a total capacity of 1300m^3/s. Al Hammar Marsh is also fed directly from an opening through the right embankments of Euphrates River with a capacity of 500m^3/s. During flood seasons, Tigris River flow through Al Qurna Marshes then to Al Hammar Marsh though culverts and escapes that were constructed for this purpose, sometime the water of Al Qurna Marshes reaches high levels and flood toward Al Hammar Marsh over the road parallel to Euphrates River conveying. The main outlets of Al Hammar Marsh are AshShafi, Al Ghameej and Garmat Ali Rivers. These rivers discharge its flow to Shatt Al Arab River, CRIM, 2008.

During nineties of the last century 94% of the Al Hammar Marsh was dried. Some of the dried lands were used for agriculture purposes. Al Malha, AshShafi, Um Nakhla, and the Right Side Euphrates irrigation projects were constructed on these dried lands. CRIM, 2007.

Currently, the main feeders of Al Hammar Marsh are the main channels of the irrigation projects of Um Nakhla, Al Kurmashia, Al Malha, and AshShafi Irrigation Projects. Dwellers have breached the embankments and levees of Al Hammar Marsh near Al Chibaeich City allowing water to feed Al Hammar Marsh directly from Euphrates River. Al Hammar Marsh drains through Garmat Ali River into the Shatt Al Arab near Al Basrah. Garmat Ali River is formed by when AshShafi and Al Ghameej are jointed.

With the efforts of the Center for the Restoration of Iraqi Marsh lands, CRIM, and of Ministry of Water Resources of Iraq, MoWR, at some time, 900km^2 of Al Hammar Marsh area was restored, but that restoration was affected by last dry years.

CRIM is planning to construct a hydraulic structure, **Figure 1,** which will control the outflow of the west part of Al Hammar Marsh and is designed to discharge $2300 m^3/sec$. This control structure has twenty seven pipes with diameter of $1.2m$ controlled by gate valves, and a weir of $2100m$ in length. The weir crest is at elevation of $2 m.a.m.s.l.$

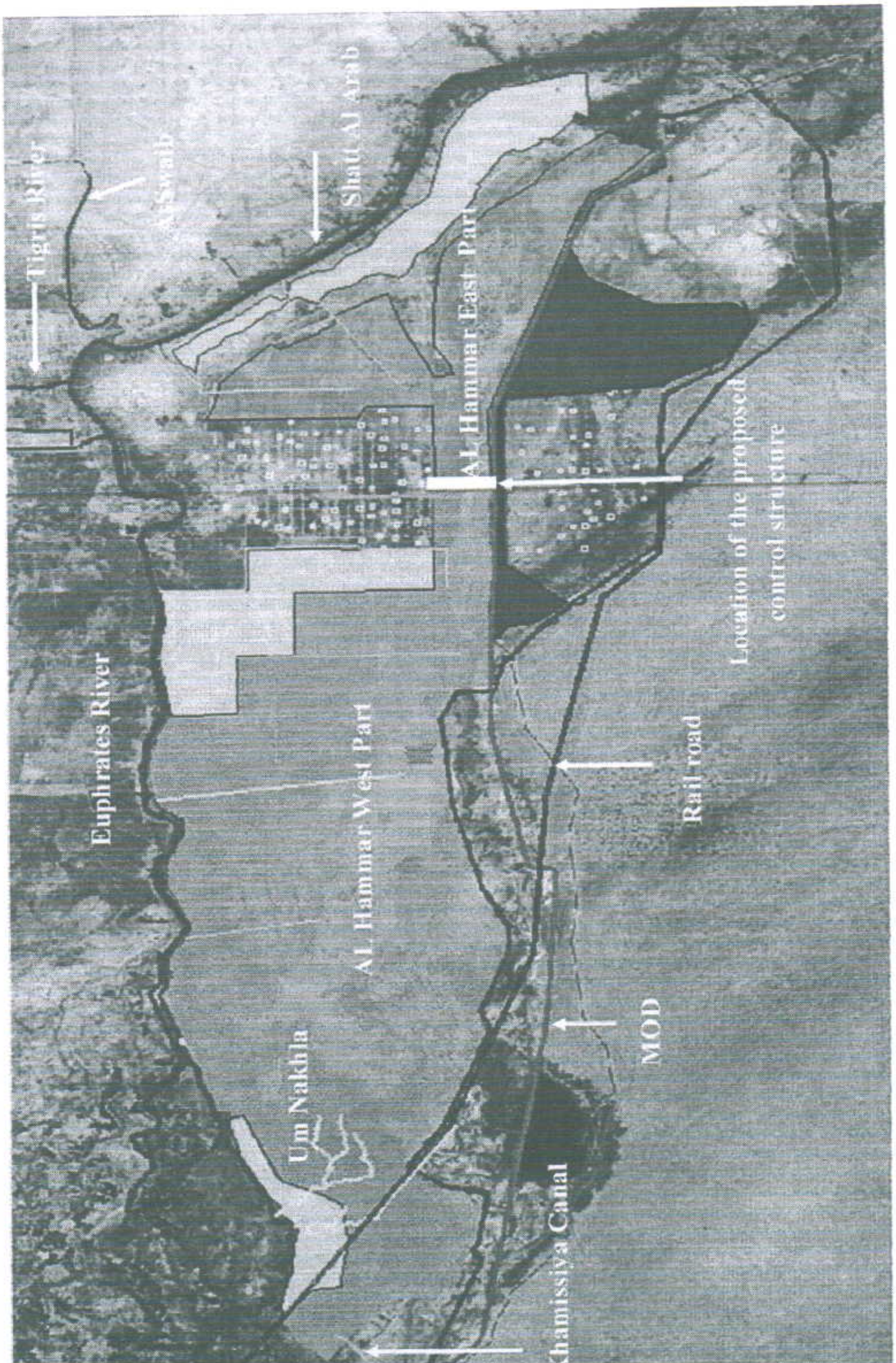


Figure 1. General layout of Al Hammar Marsh, with the proposed control structures.

The topography of Al Hammar Marsh was developed based on the available digital elevation model, DEM, obtained from Shuttle Radar Topographical Mission Data SRTM, of 90 meters definition in the investigated area and the bathymetric surveys provided by CRIM. The DEM of Al Hammar Marsh is shown in **Figure 2**.

CRIM intends to construct a control structure that will separate Al Hammar Marsh into two parts, the east and west parts. The control structure will control the outflow from the west part toward the east part. This control structure has twenty seven pipes with diameter of 1.2*m* controlled by gate valves, and a weir of 2100*m* in length. The weir crest is at elevation of 2*m.a.m.s.l.*

At an elevation of 1.25 *m* the marsh area is that kept as a contiguous lake with an area of 250 km^2. At the elevation of 2m, which is the weir crest elevation the marsh area is 780 km^2.

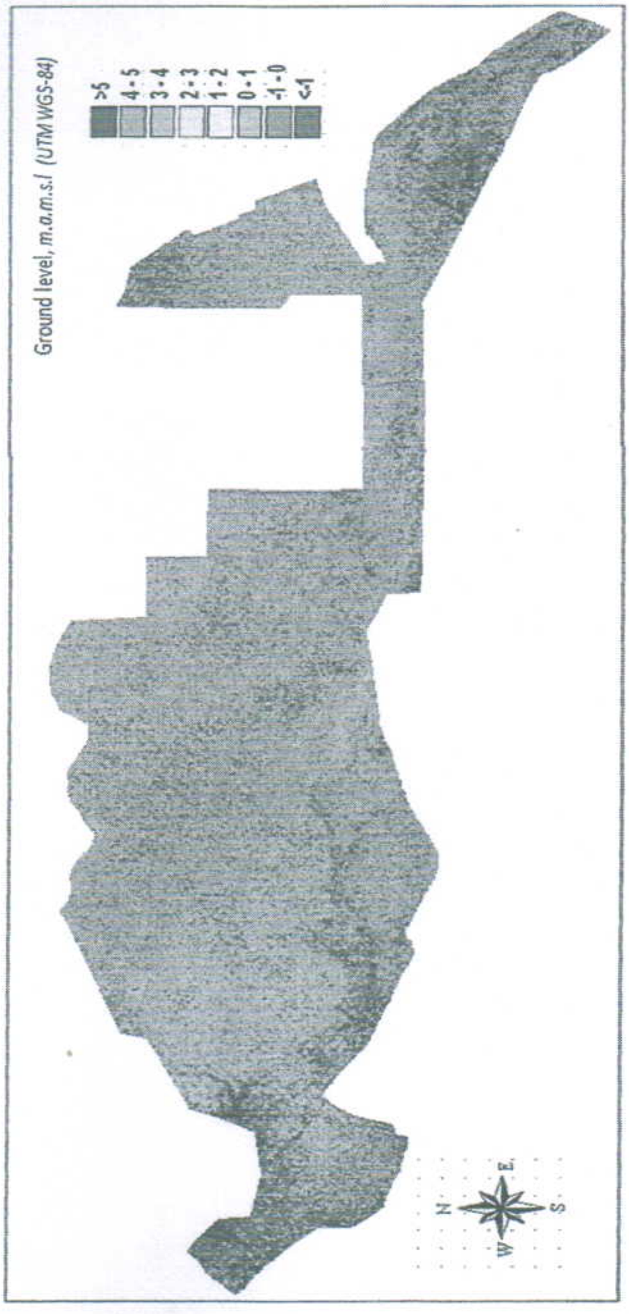
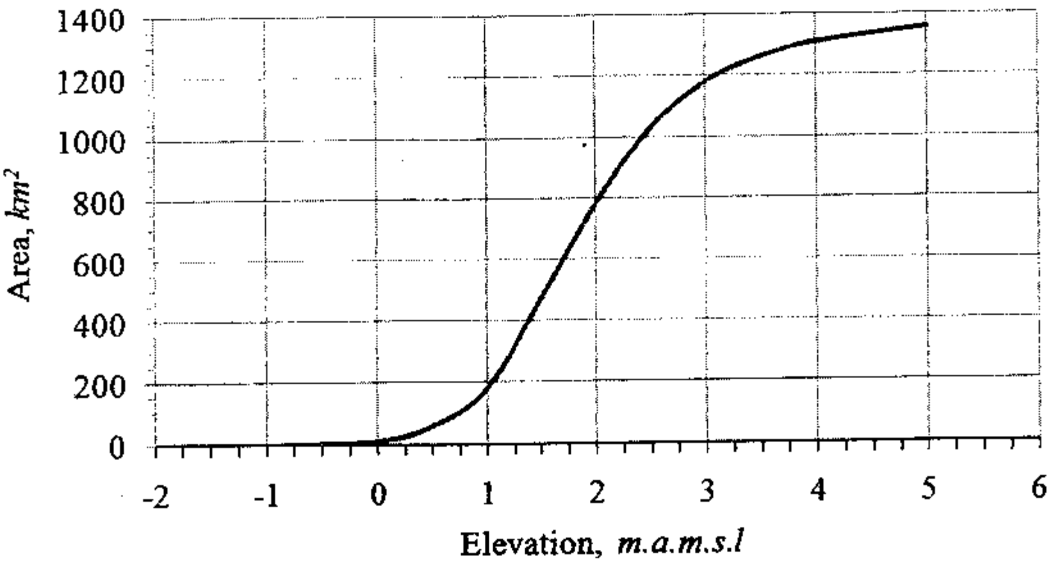
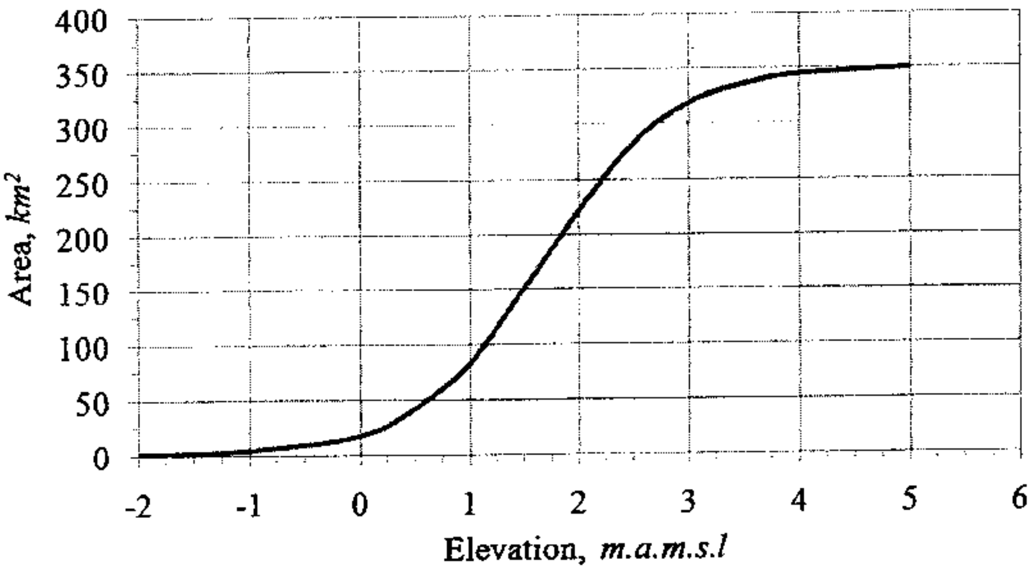


Figure 2. The developed DEM of Al Hammar Marsh.

Figures 3 and 4 show the Area-storage relationship of the two parts of the marsh that were derived from the area-elevation and storage-elevation relationships.

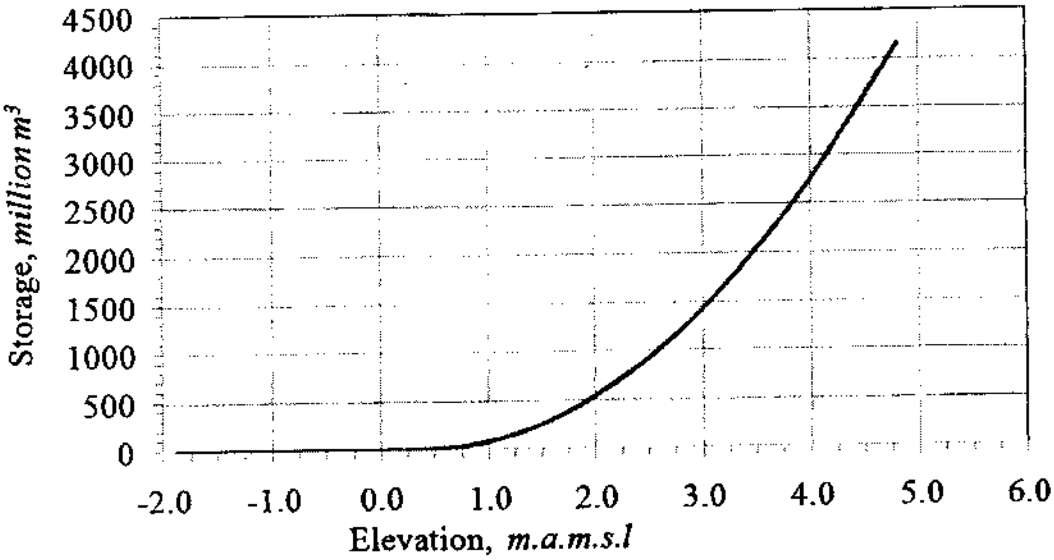


a- West part of Al Hammar Marsh.

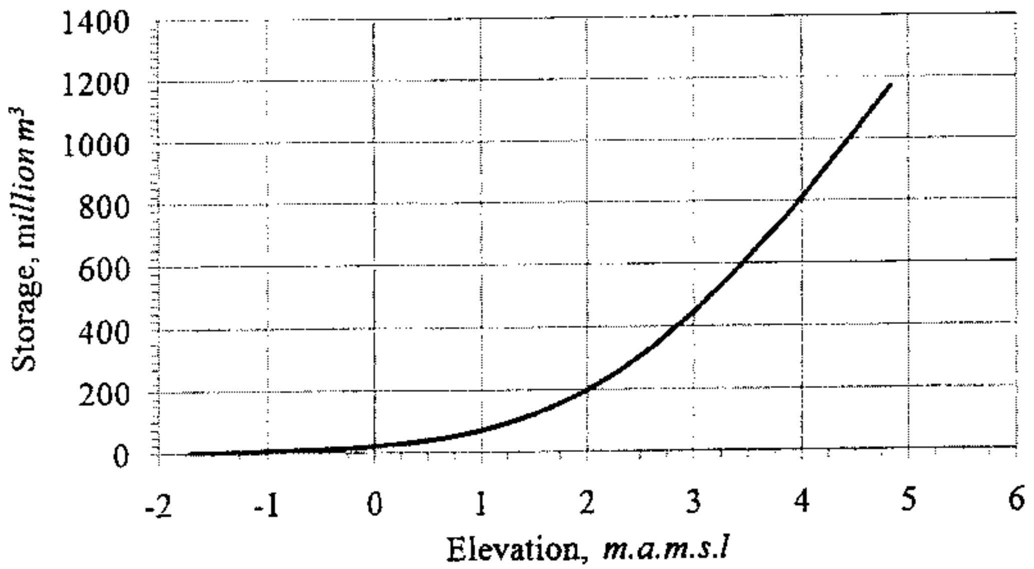


b- East part of Al Hammar Marsh.

Figure 3. Area-elevation curves of Al Hammar Marsh.



a- West part of Al Hammar Marsh



b- East part of Al Hammar Marsh.

Figure 4. Storage-elevation curves of Al Hammar Marsh.

The inflow discharges of the marsh feeders were measured by CRIM during 2008, **Table 1**, CRIM, 2008.

Table 1. Discharge measurements, in m^3/s, during 2008, CRIM, 2008.

Feeders	Spring	Summer	Autumn	winter
Al Malha Irrigation Project Main canals	28.9	23.4	24	21
Um Nakhla Irrigation Project Main canals	9.2	2.8	15.6	9.2
Al Kurmashia Irrigation Project Main canals	3.7	2.2	5.2	3.7
AshShafi Irrigation Project Main canals	20.8	6.1	16.7	14.5
Al Mus'hab River	31.2	13.5	90.5	45.1
AsSalal River	14.5	15	14	14.5

TDS measurements on the marsh feeders were carried out by CRIM during 2007 and 2008, **Table 2**, CRIM, 2008.

Table 2. TDS measurements in *ppm* during 2007-2008, CRIM, 2008.

Month	Um Nakhla	Al Kurmashia	Al Malha	AshShafi	Al Ghameej
Oct.	6070	6240	6419	----	6300
Nov.	5800	5980	6405	5790	6000
Dec.	5800	5980	6405	5790	6000
Jan.	5800	5980	6405	5790	6000
Feb.	2218	2012	3600	2470	2650
Mar.	2218	2012	3600	2470	2650
Apr.	2218	2012	3600	2470	2650
May	6340	6500	6428	6338	6600
Jun.	6340	6500	6428	6338	6600
Jul.	6340	6500	6428	6338	6600
Aug.	6070	6240	6419	6064	6300
Sep.	6070	6240	6419	6064	6300

CRIM is carrying out discharge and water quality measurement since October 2009. **Table 3** shows the average discharges into Al Hammar Marsh, measured during 2009-2010, CRIM, 2010.

Table 3. Discharge measurements, in m^3/s, during 2009-2010.

Month	Al Kurmashia Canal	Um Nakhla	Al Malha
Jan.	0.9	3.7	NA
Feb.	0.6	1.0	NA
Mar.	0.4	0.9	NA
Apr.	0.7	1.9	NA
May	0.6	2.2	NA
Jun.	2.5	0.7	15.1
Jul.	2.7	13.9	11.9
Aug.	0.7	12.2	NA
Sep.	1.3	10.4	NA

Water quality measurements, at locations related to this study, were carried out by CRIM in the stations which are listed in **Table 4,** and are shown in **Figure 5**.

Table 4. Water quality measurements stations.

Station	Location	
	East	North
Al Kurmashia Canal	648816	3415544
Um Nakhla	650609	3416718
MOD Al Fadhliya Bridge	626911	3426244
Garmat Beni Si'ed	650550	3417514
Al-Shafi	NA	NA
Al Mus'hab	NA	NA
AsSlal	NA	NA

TDS measurements carried out by CRIM during 2009-2010 are presented in **Table 5**.

Table 5. TDS measurements, in *ppm*, during 2009-2010.

Months	Um-Nakhla	Kurmashia	Garmat Beni Si'ed	AshShafi	Al Mus'hab	AsSlal
Oct.	3360	3420	3260	885	5970	5960
Nov.	3830	3860	3840	1000	7350	6900
Dec.	2155	2160	2170	1010	6070	5850

Measured TDS values of AshShafi River show a strange behavior, they are much less than it expected to be. Moreover, TDS values that were measured during 2009, presented in **Table 5,** are much less than that measured during 2007 and 2008 that are listed in **Table 2**.

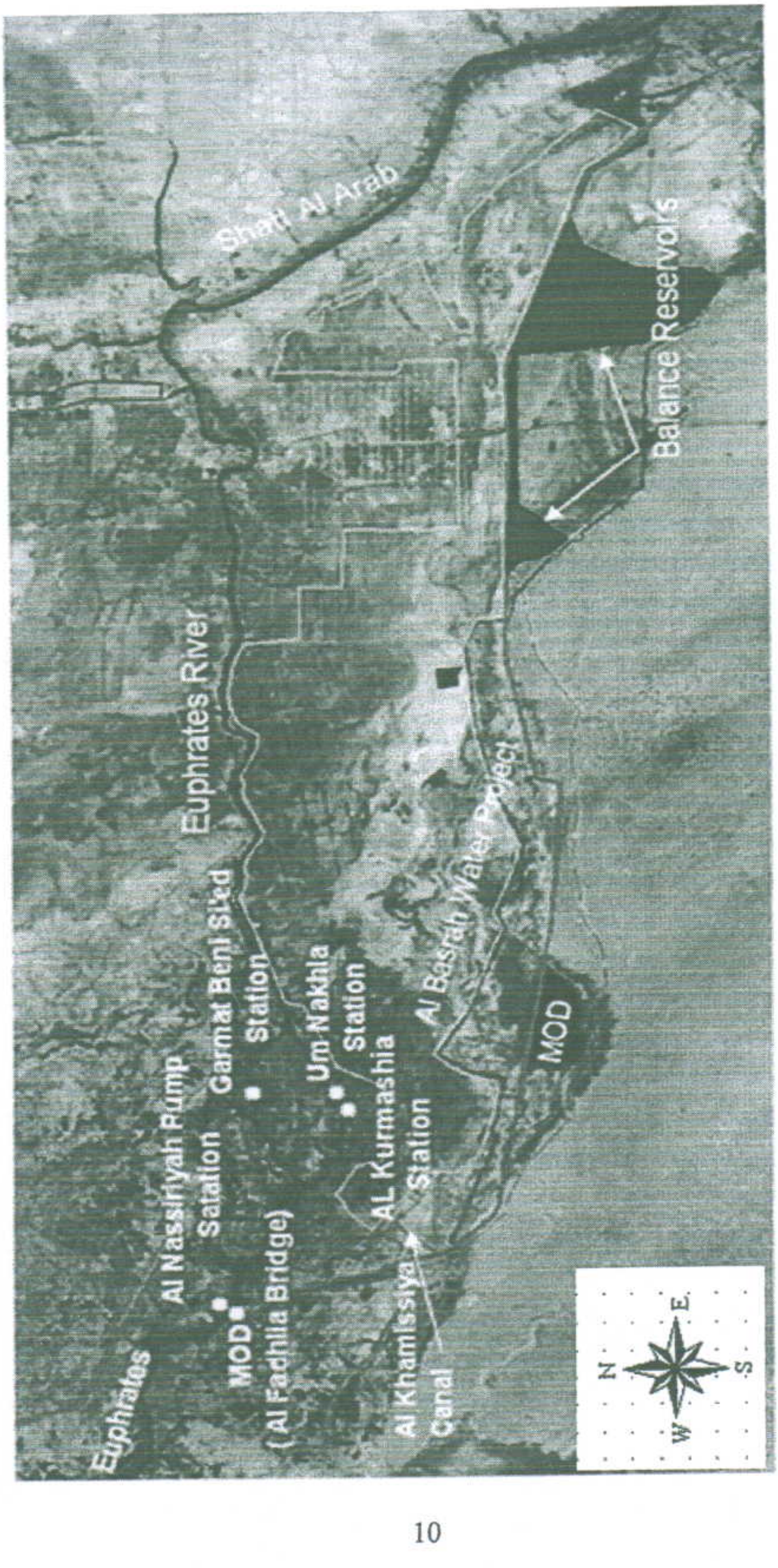


Figure 5. Water quality measurement stations.

Evapo-transpiration, ET_O, within Al Hammar Marsh region was listed in CRIM, 2008 study and is presented in **Figure 6.** Al Hammar Marsh lies within a region of high ET_O with an annual value of 2909 *mm*. The average monthly ET_O is 242.4 *mm;* it is 52 *mm* during January, increased to 470 *mm* during June, which is 9.4 times that of January.

The annual precipitation within the marsh is approximately 150*mm.* The effective rainfall is considered small compared with the evaporation.

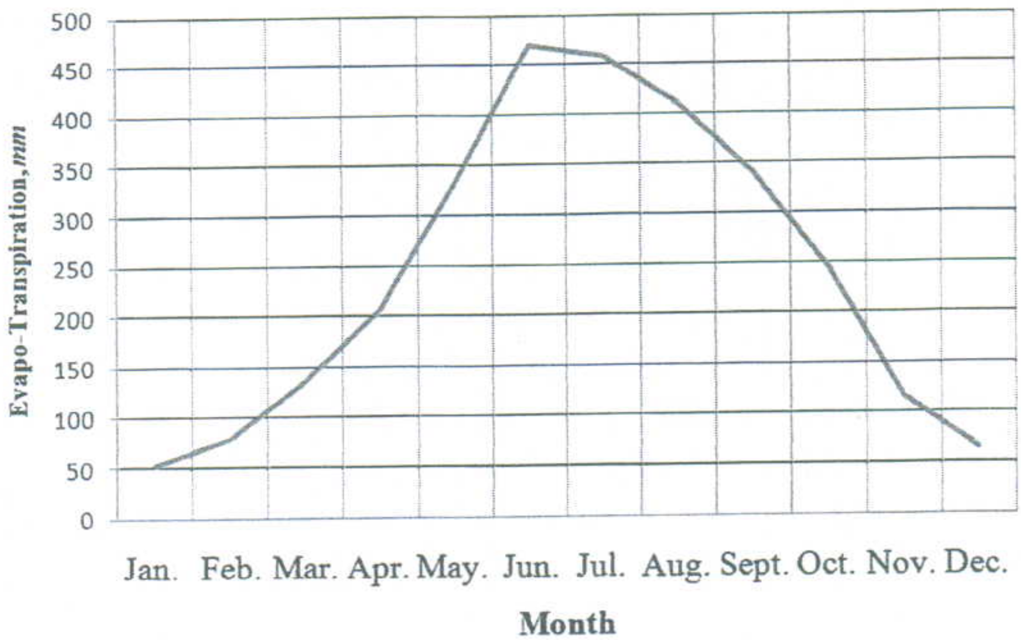


Figure 6. Evapo-transpiration

2.2 The Main Outfall Drain

The basic idea of the Main Outfall Drain, MOD, **Figure 7**, which was suggested in beginning of the last century, is to construct a main channel to collect highly saline drained water of the irrigation projects within central and southern parts of Iraq and discharge it down to the Arabian Gulf.

In mid of the last century the MOD was designed to flow between the Tigris and Euphrates Rivers, then it crosses the Euphrates riverbed, via large pump station east of Al Nassiriyah City, toward the Arabian Gulf. The MOD serves more than six million Donums of agricultural lands.

Construction of some parts of the MOD started in the 1950s and more were completed in the 1960s, but the entire project was not completed until December 1992, when the final section, linking the seaward end to that built at Al Dalmaj Lake northwest of Al Nassiriyah, was constructed. The MOD crosses the Euphrates River just east of Al Nassiriyah, beneath the riverbed in large pipes limiting its discharge to 140m^3/s which was then replaced by a huge pumping station of 220m^3/s in 2009.

The total length of the MOD is 565*km*, was divided into three sectors based on the construction stage as follow, MoWR, 2005:

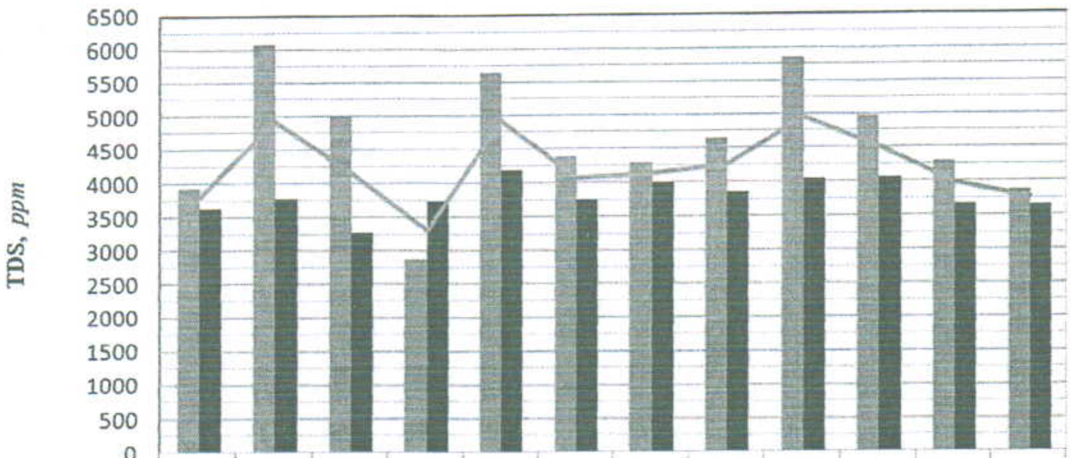
The Northern sector: the total length of this part is 206*km*, starts from Al Es'haki Main Drain north of Baghdad down to Al Dalmaj Lake. The total area served by this sector is 2320000*donums*. The discharge of this sector at Al Dalmaj Lake is 88m^3/s. The bed and top widths of this sector of the MOD at Al Es'haki Main are 7.8*m*, and 46*m*, respectively, and at Al Dalmaj Lake are 21.2*m*, and 57*m*.

The Central Sector: this sector starts north of Al Delmaj Lake and ends at the point where the MOD crosses the Euphrates with a length of 187*km*. this sector consist of a navigation channel of a bed width of 50-34 *m* and a top width of 98*m*. The maximum capacity of this sector is 220m^3/s. The total area served by this sector is 4000000*donums*. This sector is connected to Al Dalmaj Lake insure the required water levels for navigation during the whole year.

The Southern Sector: this sector starts at the point where the MOD crosses the Euphrates River down to Shatt Al Basrah River with a length of 172*km*. This section has two reservoirs to storage the MOD discharge when Shatt Al Basrah regulator is closed during tide and releases it when it is opened during ebb. The bed width of this sector is 50*m* and a top width of 110*m* and its capacity at Shatt Al Basrah is 200m^3/s.

The pumping station used to discharge the MOD water through the culvert beneath the riverbed of the Euphrates River consist of twelve pumps, eight of them are of a capacity of 25m^3/s and the others are of a variable capacity varies between 12 to 25m^3/s. The culvert is of 440 *m* in length with three openings of 4 by 5*m* cross section each. **Figure 9** shows a schematic diagram of main structures locations on the MOD downstream Al Nassiriyah Pump Station.

TDS of the MOD measured by UNEP, at Al Nassiriyah pumping station, which is the nearest measuring station to Al Khamissiya Canal, are presented in **Figure 8**, UNEP 2009.



	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
2008	3920	6065	5005	2885	5645	4387	4289	4640	5847	4965	4285	3870
2009	3640	3770	3275	3735	4188	3748	3990	3865	4053	4060	3670	3655
Average	3780	4918	4140	3310	4917	4068	4140	4253	4950	4513	3978	3763

Figure 8. TDS variation at Al Nassiriyah Pump Station, UNEP, 2009.

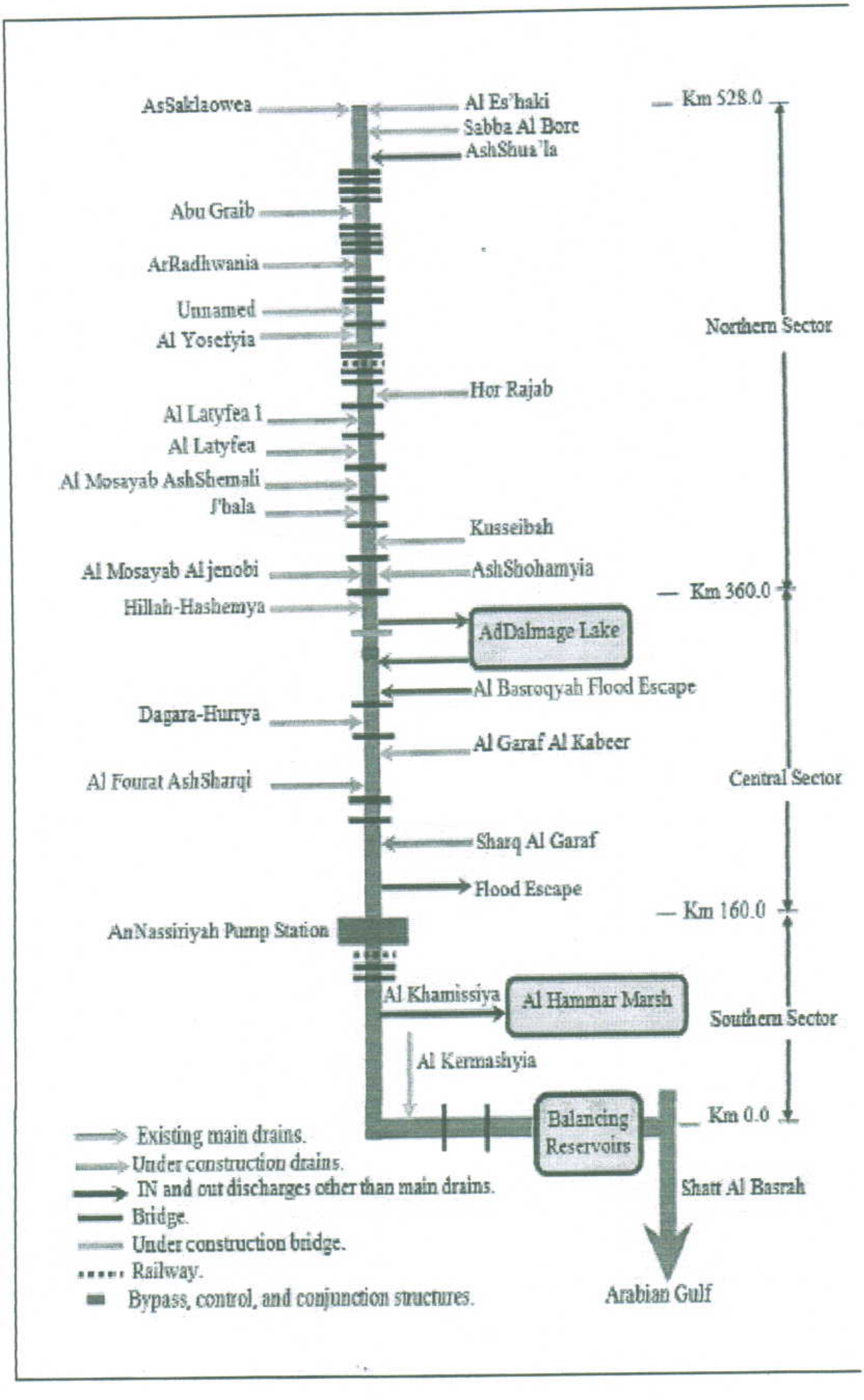


Figure 7. A schematic diagram of the MOD.

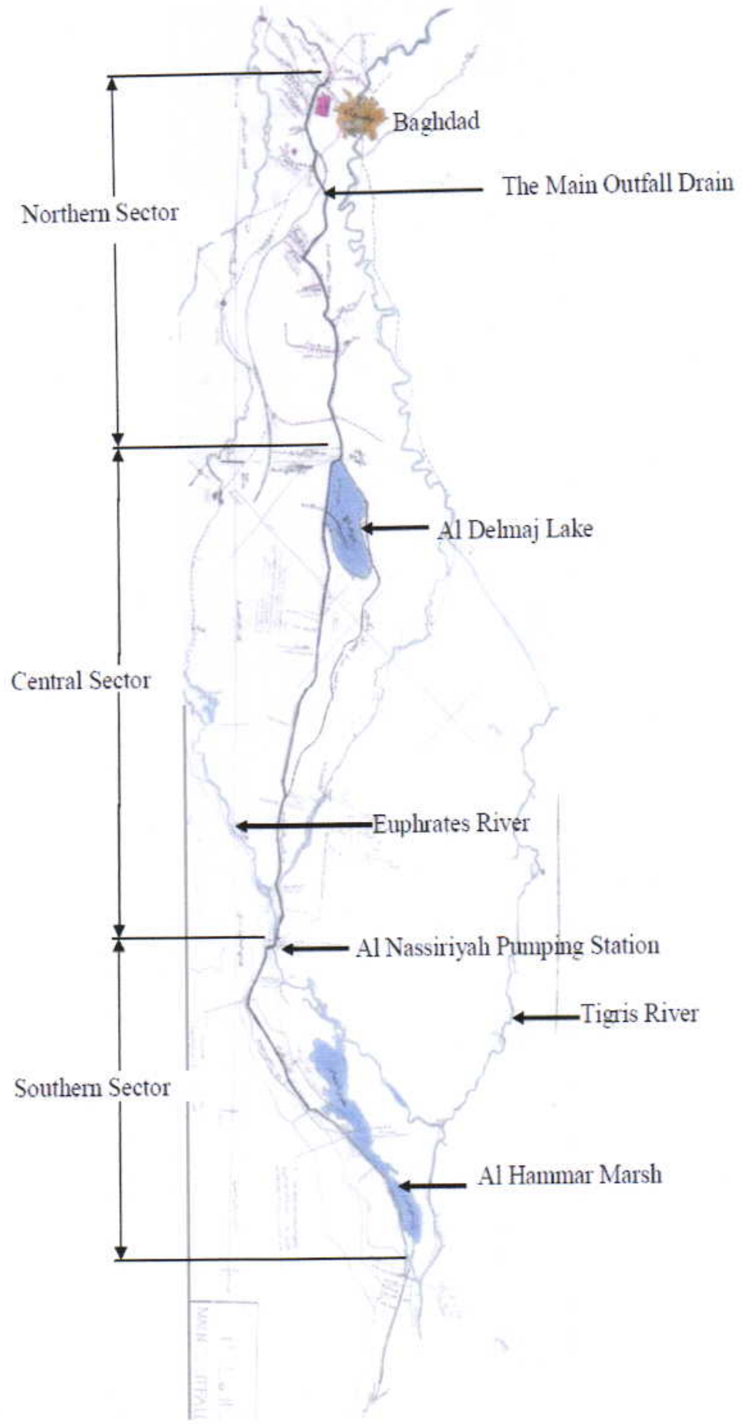


Figure 9. General layout of the MOD, after the directorate of the MOD.

2.3 Al-Khamissiya Canal

Due the water shortage required to feed Al Hammar Marsh during the last two dry years, the area of the marsh was reduced greatly threatening the ecological system and economics of the marsh residents. A suggestion made by the CRIM of MoWR and other related ministries to make use of the MOD water to feed the marsh as ***a temporary solution*** that will prevent the marsh to dry again. This suggestion was made based AdDalmage Lake is a successful example of using the water of the MOD. It is used now for rising fish and it provides a suitable environment for many aquatic plant and bird species. CRIM studied several possible locations to divert the MOD water to Al Hammar Marsh. The conclusion that was made by CRIM is to divert an average of about 130 m^3/s to Al Hammar Marsh from the MOD by constructing a linking canal. The canal intake is located downstream of the pump station at 136 +430 *km* of the MOD, E= 633137 N= 3407199, and ends at a point within Al Hammar Marsh located by E=637273 and N= 3411982. This canal is called Al Khamissiya Canal. **Figure 10** shows the general view of Al Khamissiya Canal layout,CRIM, 2009.

CRIM proposed to construct a bridge at station 620 + 00*km* along Al Khamissiya Canal, CRIM, 2010, of 24 piers, 0.3×0.3m distributed along a span of 100m.

The surveyed ground level profile is shown in **Figure 11,** CRIM, 2009.

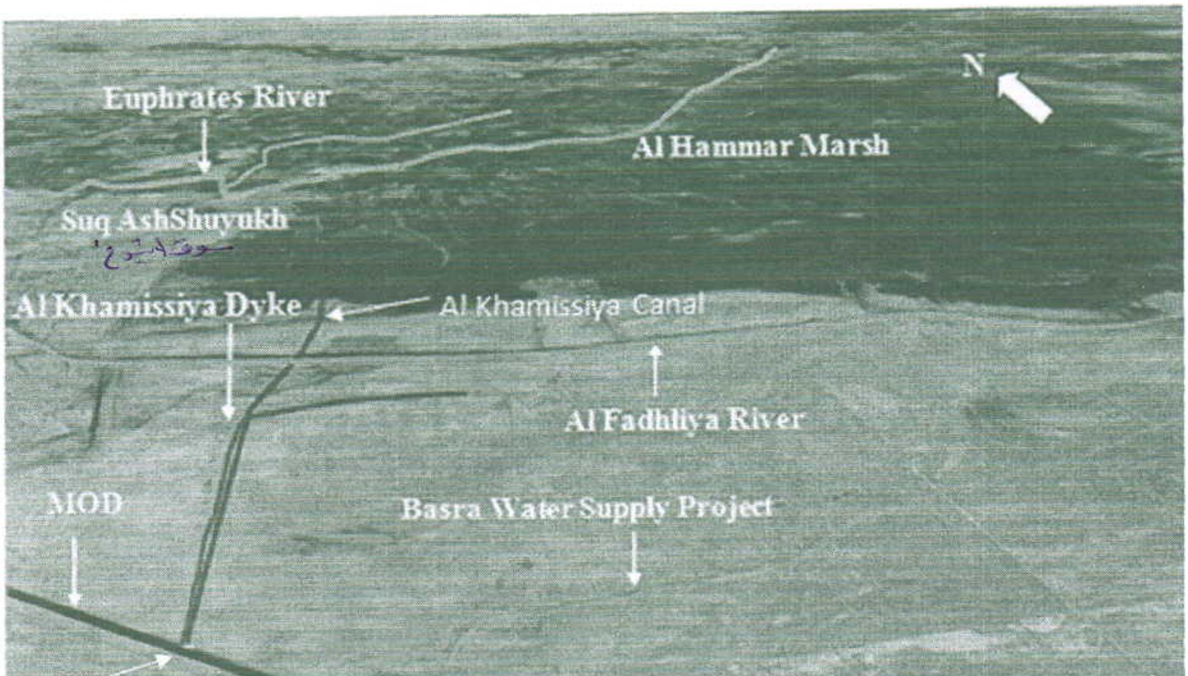


Figure 10. General layout view of Al Khamissiya Canal.

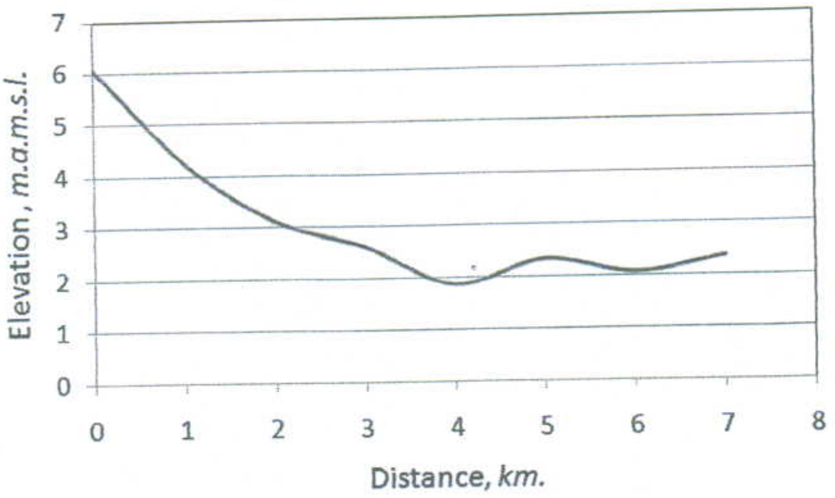


Figure 11. Al Khamissiya canal surveyed ground level profile, provided by CRIM.

2.4 Discharges that could be supplied to al hammar marsh

Table 6 and **7** summarize the results of the hydrological routing of Al Hammar Marsh that was carried out by CRIM 2010. In **Table 6** the monthly discharges required to feed Al Hammar Marsh corresponding to each of the assumed constant outflow are presented. While, **Table 7** shows the monthly outflow corresponding to each assumed constant inflow required to feed Al Hammar Marsh. It must be noted that the discharges required to feed Al Hammar Marsh are the sum of the feeder's discharges and the MOD water. If there is sufficient water at the feeders to supply the west part of Al Hammar, then MOD water can be used only to complete the total inflow requirement. Obviously, this improves the water quality of the required inflow, since the water quality of the feeders is betters than that of the MOD.

Table 6. The constant outflow and inflow discharges of Al Hammar Marsh according to the first scenario.

Months	**Constant outflow from Al Hammar Marsh, m³/s**								
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
	Inflow to Al Hammar Marsh, m³/s								
Oct	90	95	100	105	110	115	120	125	130
Nov.	49	54	59	64	69	74	79	84	89
Dec.	23	28	33	38	43	48	53	58	63
Jan.	2	7	12	17	22	27	32	37	42
Feb.	0	5	10	15	20	25	30	35	40
Mar.	6	11	16	21	26	31	36	41	46
Apr.	5	10	15	20	25	30	35	40	45
May	20	25	30	35	40	45	50	55	60
Jun.	47	52	57	62	67	72	77	82	87
Jul.	56	61	66	71	76	81	86	91	96
Aug.	65	70	75	80	85	90	95	100	105
Sep.	77	82	87	92	97	102	107	112	117

Table 7. The outflow and constant inflow discharges of Al Hammar Marsh according to the second scenario.

Months	Constant Inflow to Al Hammar Marsh, m^3/s								
	90	**95**	**100**	**105**	**110**	**115**	**120**	**125**	**130**
	Outflow from Al Hammar Marsh, m^3/s								
Oct	0	5	10	15	20	25	30	35	40
Nov.	41	46	51	56	61	66	71	76	81
Dec.	67	72	77	82	87	92	97	102	107
Jan.	85	90	95	100	105	110	115	120	125
Feb.	91	96	101	106	111	116	121	126	131
Mar.	84	89	94	99	104	109	114	119	124
Apr.	85	90	95	100	105	110	115	120	125
May	70	75	80	85	90	95	100	105	110
Jun.	43	48	53	58	63	68	73	78	83
Jul.	34	39	44	49	54	59	64	69	74
Aug.	25	30	35	40	45	50	55	60	65
Sep.	13	18	23	28	33	38	43	48	53

CHAPTER THREE
HYDRAULIC MODELS

3.1 General description of the Hec-Ras software

This software allows the user to perform one-dimensional steady and unsteady flow hydraulics. It is an integrated system of software, designed for interactive use in multi-tasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities graphics and reporting facilities.

Theoretical Basis for One-Dimensional Flow Calculations

Topics discussed below include equations for basic profile calculation, in steady and unsteady flow.

Steady flow

Water surface profiles are computed from one cross-section to the next by solving the energy equation. The energy equation is:

$$y_1 + \frac{\alpha_1 v_1^2}{2g} + z_1 = y_2 + \frac{\alpha_2 v_2^2}{2g} + z_2 + h_e \quad \text{.......(1)}$$

where:

y_1, y_2 : depth of water at cross-section, m.

z_1, z_2: elevation of the main channel inverts, m.

v_1, v_2: Averaged velocity at the section, m/sec.

g: gravitational acceleration, m^2/sec.

h_e: head loss ,m.

The head loss in a reach of length L may be calculated as:

$$h_e = L * \bar{S_f} + C\left[\frac{\alpha_1 v_1^2}{2g} + \frac{\alpha_2 v_2^2}{2g}\right] \quad \text{.......(2)}$$

Where:

$\bar{S_f}$: Representative friction slope between the two sections.

C: Expansion or contraction loss coefficient

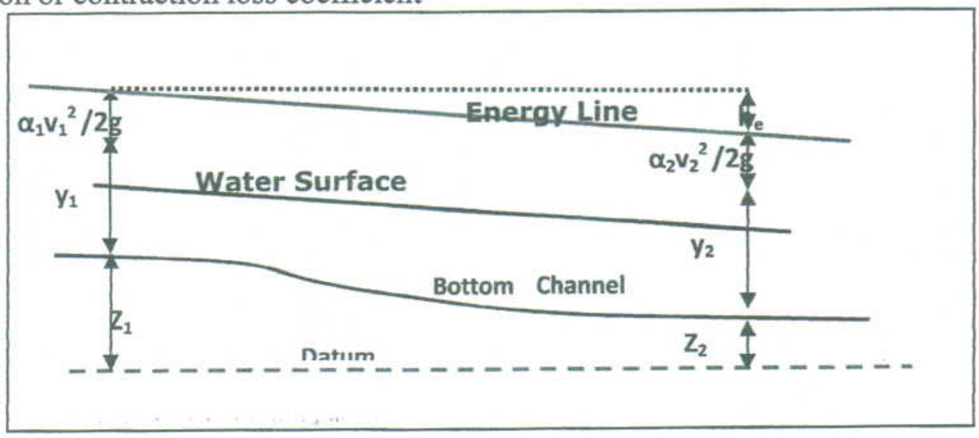


Figure 12. Longitudinal Section of Channel Reach

Basic Data Requirements

The main objective of the HEC-RAS software is quite simple- to compute water surface elevation at all locations of interest for either a given set of flow data(steady flow simulation) , or by routing hydrographs through the system (unsteady flow simulation). The data needed to perform these computations are divided into the following categories:

A- Geometric data
B- Steady flow data
C- Unsteady flow data.

Geometric data

Geometric data consists of establishing the connectivity of the river system (River system scheme): cross sections: reach lengths: energy loss coeff and Stream junction information's. Hydraulic structure data (bridge, culverts, spillway, weir etc…..). which area also considered geometric data.

Steady Flow Data

Steady Flow Data are required in order to perform a steady water surface profile calculation. This data consists of flow regime, boundary conditions and peak discharge information.

Flow regime

The flow regime is specified on the study flow analysis window of the user interface.

Boundary conditions

Boundary conditions are necessary to establish the staring water surface at the ends of the river system upstream (U/S) and down-stream (D/S). In a sub critical flow regime, Boundary conditions are only necessary at the D/S ends of the river system. If a super critical flow regime is going to be calculated, boundary conditions are only required at U/S ends of the river system. In the mixed flow regime both U/S and D/S Boundary conditions must be entered at all ends. Four types of Boundary conditions may be used as follows:

1- Known water surface elevation (constant elevation)
2- critical depth(y_n)
3- normal depth(y_c)
4- rating curve (relation between Q and y)

a- Rating curve.
b- Normal depth.
c- Stage hydrograph.
d- Flow hydrograph.
e- Stage and flow hydrograph.

Initial Conditions

The user is required to establish the initial conditions (flow and/or stage) at all nodes in the system at the beginning of the simulation.

3.2 MOD hydraulic model

To insure a discharge of 130 m^3/sec through Al Khamissiya, it is required to construct a control structure at the MOD just after the intake of Al Khamissiya Canal to raise the water surface elevation in MOD, during the low flow. This structure should be of a design discharge of 220m^3/sec, which is the design discharge of the MOD at this location. Taken into account that the water surface elevation just downstream of the MOD pumping station must not exceeds 4.5*m.a.m.s.l.* Soyuzgiprovodkhoz, 1984. The water surface elevation along the MOD reach, between the downstream of the pumping station and upstream the control structure must not exceed the minimum elevation of the MOD banks of *6m.a.m.s.l*, CRIM, 2010.

According to the above requirements, a steady one dimensional hydraulic model was implemented by using HEC-RAS software to simulate the flow and study the back water curve in the MOD upstream this structure.

3.2.1 MOD hydraulic model input data

Steady one dimensional flow hydraulic model, by using HEC-RAS software, was used to simulate the flow in the MOD reach. The simulated MOD reach started at the pumping station at station at 160 +500*km* and extends beyond the proposed location of Al Khamissiya Canal intake at station 139+500*km* to station 137 +200*km*.

Geometric data that comprise twenty one cross sections were used in the model, presented in **Annex A**. **Figure 13** shows the geometric input data menu of the HEC-RAS software.

The Manning's roughness coefficient of 0.03 was adopted for the all cross sections along the reach.

A range of discharge from 40 to 220 m^3/sec was adopted to study the MOD capacity, **Figure 14**.

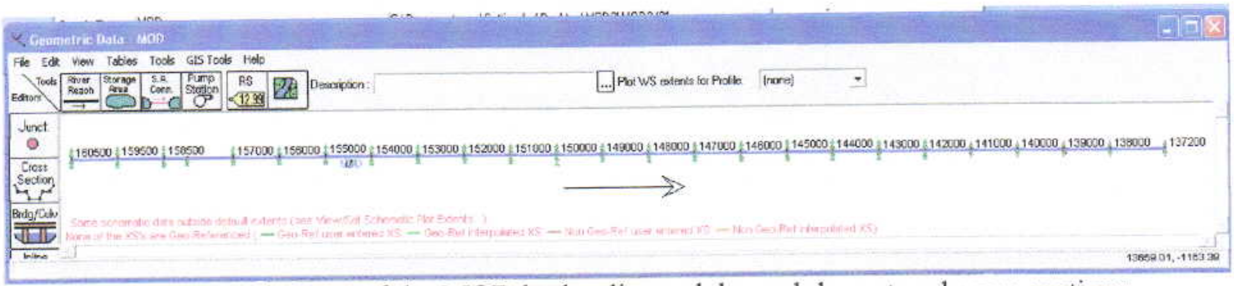


Figure 13. Geometric Data of the MOD hydraulic model, reach layout and cross sections.

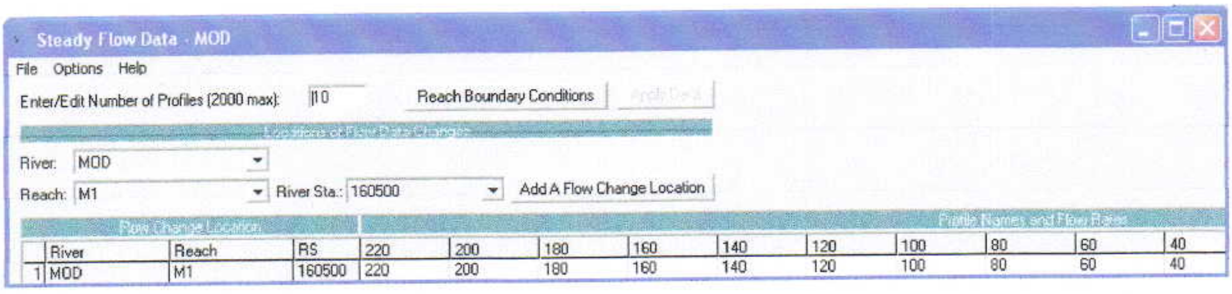


Figure 14. MOD steady flow data.

The maximum permissible water surface elevations at the proposed location of Al Khamissiya Canal intake at station 139+500*km*, that preserve the water surface elevation at the downstream of the pumping station, station 160 +500km, not exceeds 4.5m.a.m.s.l with each discharge of the adopted discharge range were considered as downstream boundary condition, **Figure 15**.

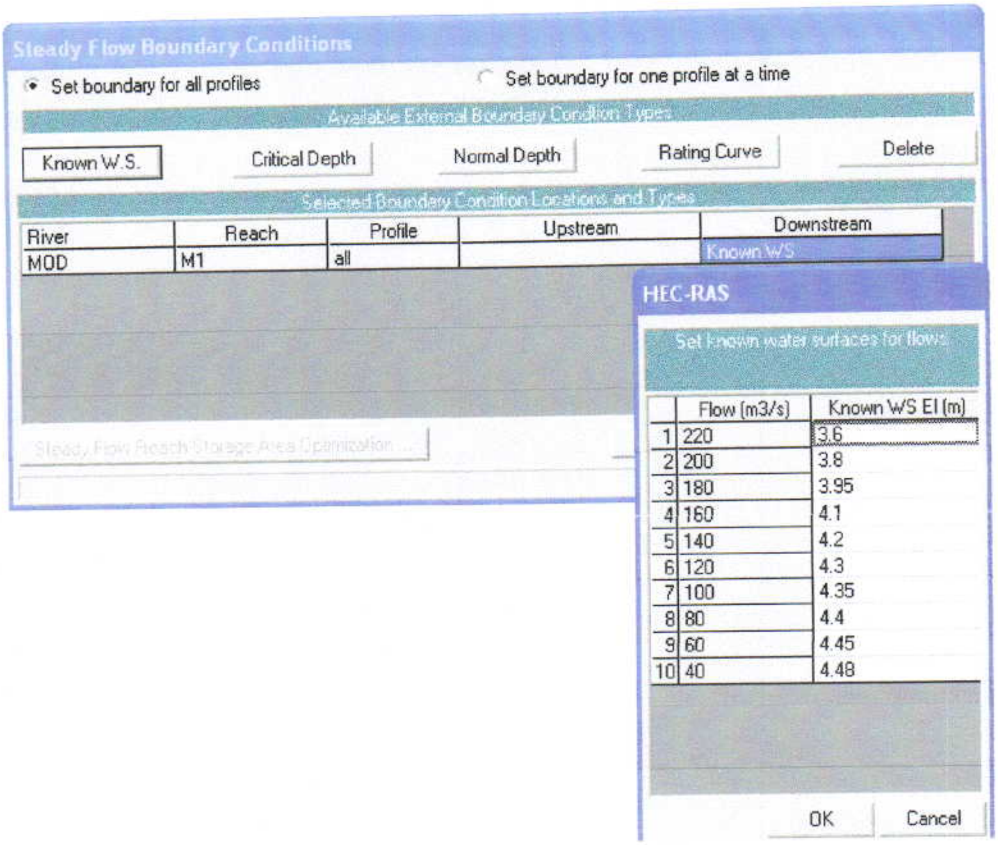


Figure 15. MOD downstream boundary condition.

3.3 AL KAMMISSIYA CANAL PRELMINARY DESIGN

The design is based on a constant discharge of $130m^3/sec$. Several trials were made to select the most proper cross section of Al Khamissiya Canal for both discharges. The HEC-RAS software was used to simulate the flow in Al Khamissiya.

Design Data of Al Khamissiya Canal

Al Khamissiya canal cross section designed is based on the following data:

- Design discharge: 130 m^3/sec.
- The Manning roughness coefficient is 0.03, Pencol, 1983.
- The surveyed ground level profile, as shown in **Figure 11**.
- Geometric data of a proposed bridge at station 620 + 00*km* along Al Khamissiya Canal,
- Canal longitudinal slope: 1 to 7*cm/km*, according to the ground surface profile, CRIM, 2010 and Pencol, 1983.
- The maximum left and right banks level of the MOD is 6 *m.a.m.s.l*, Soyuzgiprovodkhoz, 1984.
- The downstream boundary condition is a constant stage of 3.0 and 2 *m.a.m.s.l* which is the maximum and minimum water surface elevation at the canal outlet within the marsh during the wet and dry water year, respectively, CRIM, 2009.

- The downstream boundary condition is a constant stage of 3.0 and 2 *m.a.m.s.l* which is the maximum and minimum water surface elevation at the canal outlet within the marsh during the wet and dry water year, respectively, CRIM, 2009.
- The maximum permissible water surface elevation at the intake of Al Khamissiya Canal, at MOD station 139+500*km*, must be restricted to that of the case of the water surface elevation in the pumping station not greater than (4.5).
- Cross Sections Design; Due to the effect of the water surface elevation of Al Hammar Marsh, which represent the downstream boundary of Al Khamissiya Canal, makes the flow within Al Khamissiya Canal to be a non-uniform flow. A trial and error solution is adopted, starting by a cross section designed by using a steady uniform flow procedure that presented in the HEC-RAS software, **Figure 16**, then a steady one dimensional flow hydraulic model was implemented by using HEC-RAS software to simulate the flow in Al Khamissiya Canal and the cross section is modified until reaching an acceptable flow velocities and water surface elevation profile along the canal.

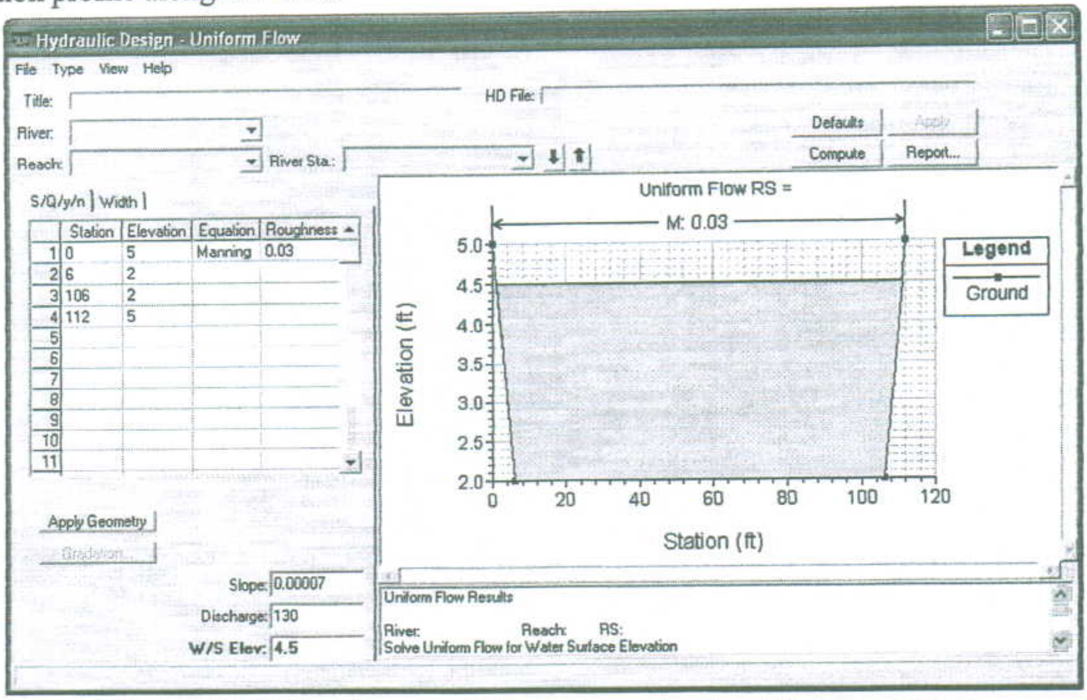


Figure 16. Trial and error solution using a steady uniform procedure.

3.4 Al Khamissiya canal hydraulic model

Steady one dimensional flow hydraulic model, by using HEC-RAS software, was used to simulate the flow in Al Khamissiya Canal taking in consideration the previously mentioned conditions and requirements of the marsh and MOD. Accordingly, the designed cross section by using the steady uniform flow procedure is modified until reaching an acceptable flow velocities and water surface elevation profile along the canal.

Eleven initial cross sections, designed by using the steady uniform flow procedure, **Figure 17**, and the geometric data of the proposed bridge were used to represent the canal geometry, **Figure 18**. The Manning roughness coefficient is 0.03, Pencol, 1983.

The steady flow data was the design discharge of the canal for the two proposed scenarios, 130 m^3/sec, which is discharged into this canal through the first station, station 0 +00 km, **Figure 19**.

The downstream boundary conditions is the known water surface elevation, constant stage, of 3 and 2 *m.a.m.s.l.* , **Figure20**, which represent the maximum and minimum water surface elevation at the canal outlet within the marsh during the wet and dry water year. These values of water surface elevation were considered in order to estimate the water surface elevation and flow velocity along the canal during the high and low flow conditions.

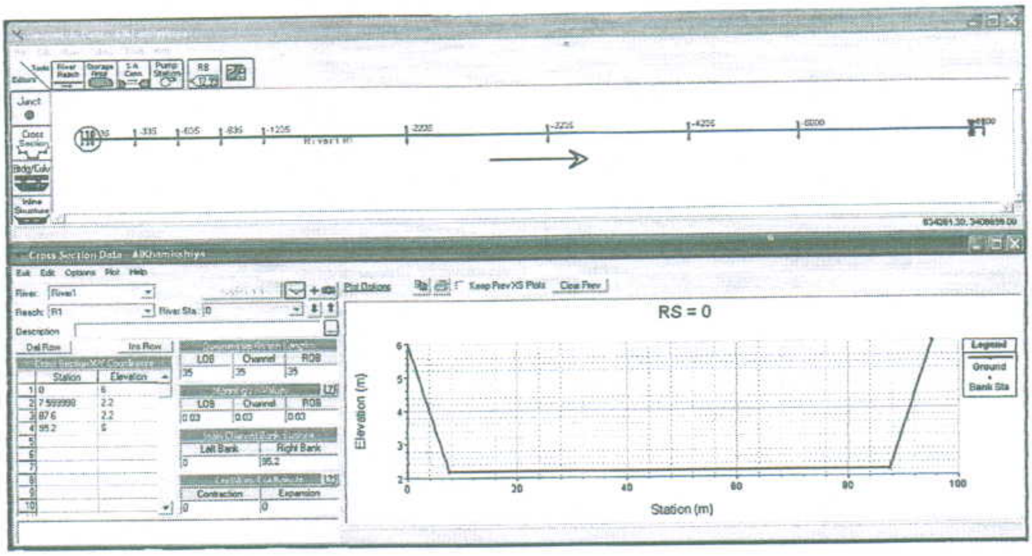
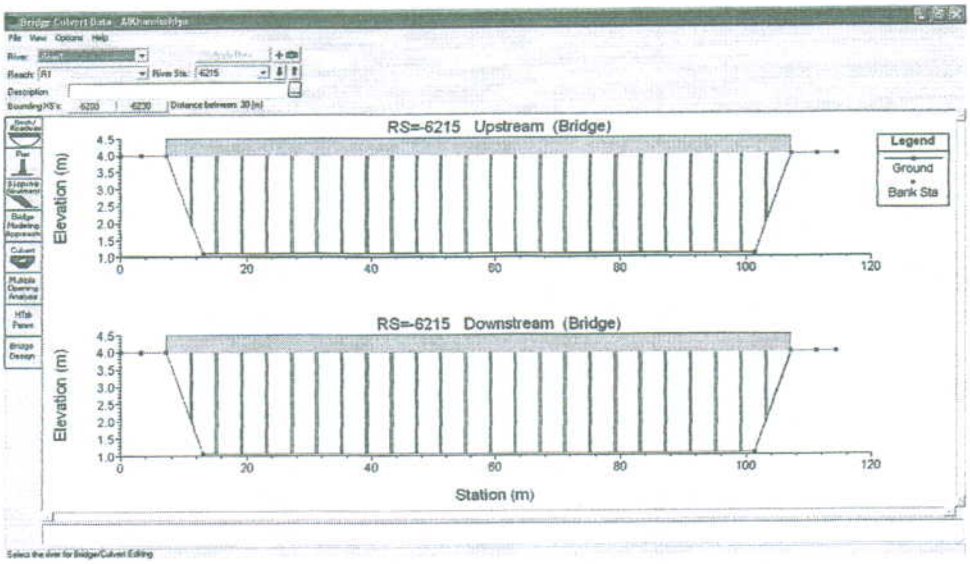


Figure 17. Geometric Data of Al Khamissiya Canal hydraulic model, reach layout and cross sections.



CHAPTER FOUR
RESULTS

4.1 MOD Hydraulic Model Runs Results

The maximum permissible water surface elevations were estimated by making use of the implemented hydraulic model. The hydraulic model run repeated many times with different water surface elevations until the water surface elevation at station 160 +500km not exceeds 4.5m.a.m.s.l for the adopted discharge range.

Profiles of water surface within the MOD reach from station 137 +200*km* to station 160 +500km with the adopted discharge range of the MOD pumping station is as shown in **Figure 21**.

The variation of water surface elevation within the MOD at station 139+500*km* with the discharge of the MOD pumping station is as shown in **Figure 22.**

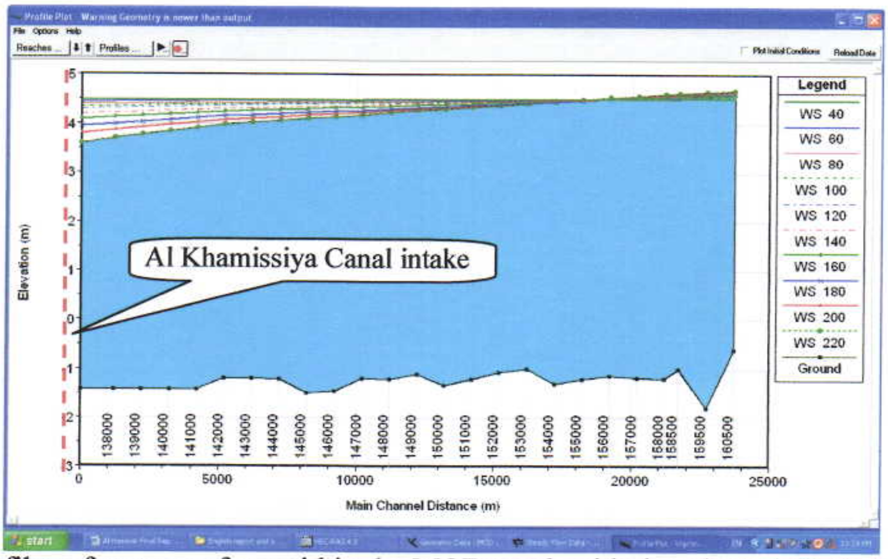


Figure 21. Profiles of water surface within the MOD reach with the adopted discharge range of the MOD pumping station.

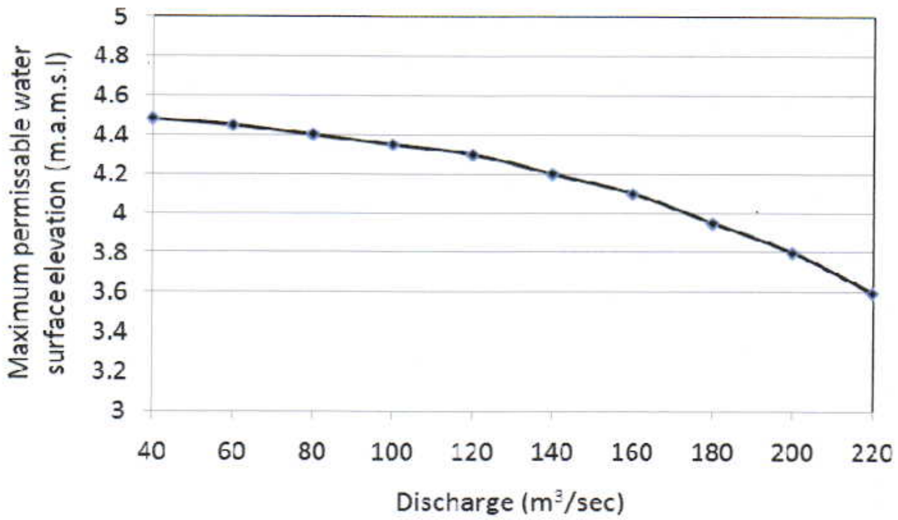


Figure 22. Maximum permissible water surface elevations at MOD station 139+500*km*, with the discharges of the MOD pumping station at station 160+500 km.

4.2 Design of Al Khamissiya Canal

Since the flow is a non-uniform flow, several model runs were made to select the most proper cross section of Al Khamissiya Canal for a discharge of 130 m^3/s by using the data that were presented in previous sections. The following sections presents the final results of the models showing the cross section, water level and velocity variation along the canal.

HEC-RAS model runs results with a discharge of 130 m^3/s and water surface elevation at the marsh is 3 and 2 m.a.m.s.l with a range of cross section bed width from 75 to 160*m* and a side slope of 2:1 showed that the required cross section of Al Khamissiya Canal for each maximum permissible water surface elevation at the MOD station 139+500*km*, **Figure 22**, was as listed in **Table 4**.

Table 4. . Required cross section of Al Khamissiya Canal, 130m^3/sec, for each maximum permissible water surface elevation at the MOD station 139+500km.

Discharge of MOD pumping station at station 160+500km m^3/sec	Maximum permissible water surface elevation at MOD station 139+500km *m.a.m.s.l*	Canal bed width m	Water surface elevation at the intake of Al Khamissiya Canal *m.a.m.s.l*
220	3.60	160	3.55
200	3.80	130	3.76
180	3.95	100	3.90
160	4.10	90	3.97
140	4.20	80	4.00
130	4.25	75	4.05

The high flow discharge of the MOD pumping station, 220 and 200m^3/sec, which correspond to Al Khamissiya Canal bed width 160 and 130*m* usually occurred during the wet years. At such years it is not required to feed the marsh from MOD. Therefore, the 100*m* canal bed width, corresponds to MOD pumping station discharge of 180m^3/sec, can be accepted. The canal cross sections required to convey 130m^3/sec with maximum upstream water surface elevation at the intake of the canal 3.90 *m.a.m.s.l.* and maximum downstream water surface elevation at the marsh 3*m.a.m.s.l.* are shown **Annex B**.

The water surface profiles along Al Khamissiya Canal for the adopted two water surface elevations at the marsh, 3 and 2 m.a.m.s.l. were shown in **Figure 23.** With these two water surface elevation the water surface elevations at the intake of the Canal at the MOD are 3.85 and 3.80 m.a.m.s.l, respectively. The top width of the canal at its intake at the MOD is of 112.8m. **Figure 24** shows the mean flow velocity variation along Al Khamissiya Canal, it shows that a velocity variation of an average of 0.65m/s occurs when the water surface elevation at the marsh is 3 m.a.m.s.l. It is clear that the flow within Al Khamissiya Canal is non-uniform when the water surface elevation at the marsh is 2 m.a.m.s.l. as shown in **Figure 24.** In this case a gradual declination in the water surface elevation takes place along the first four kilometers of the canal length with an average flow velocity of 0.66m/s. A sharp change in the water surface elevation take place in the last kilometer with a raped increase in the flow velocity occurred within the last kilometer up to 2.33m/s. A special treatment is required to prevent the canal within the last kilometer from erosion, such as using a riprap.

Figure 25 shows the profiles of the Ground, canal bed, bank, and water surface elevations along the canal.

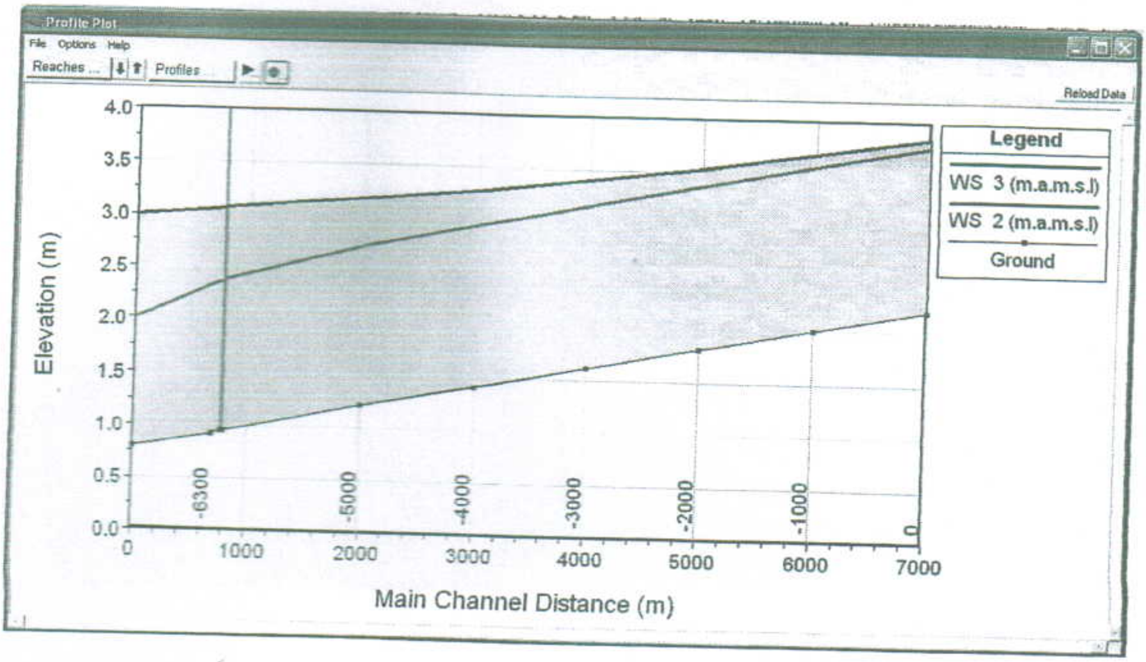


Figure 23. Water surface profile along Al Khamissiya Canal, $130m^3/s$.

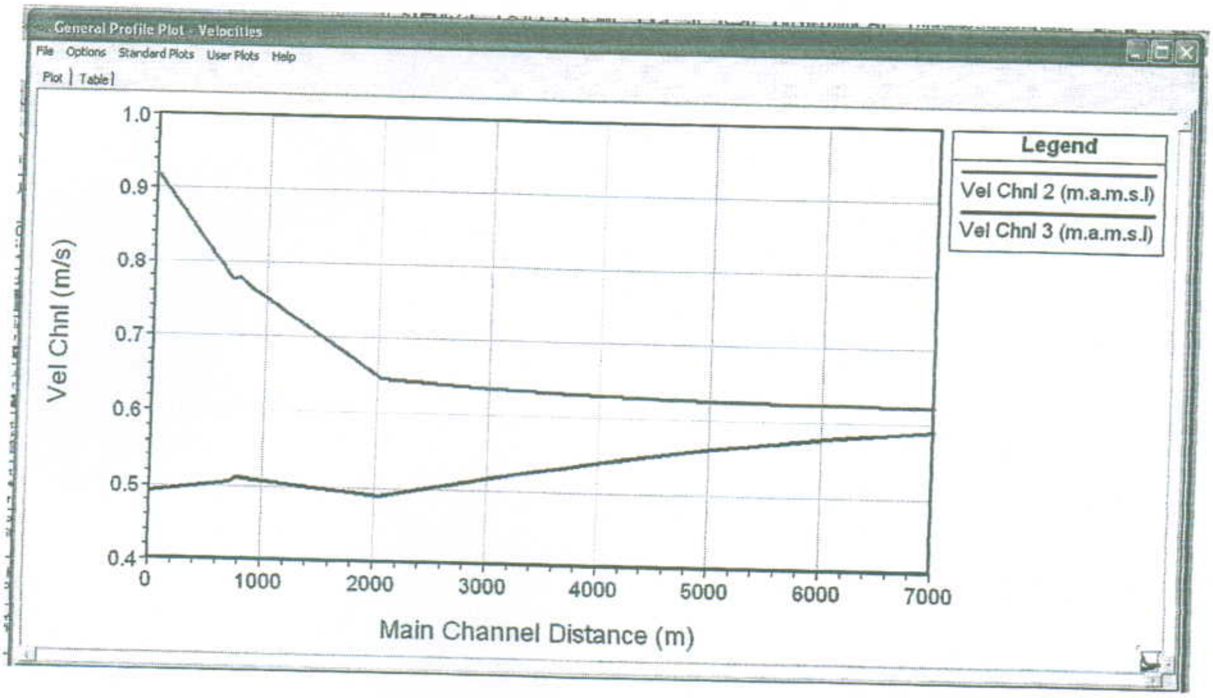


Figure 24. Velocity Variation along Al Khamissiya Canal, $130m^3/s$.

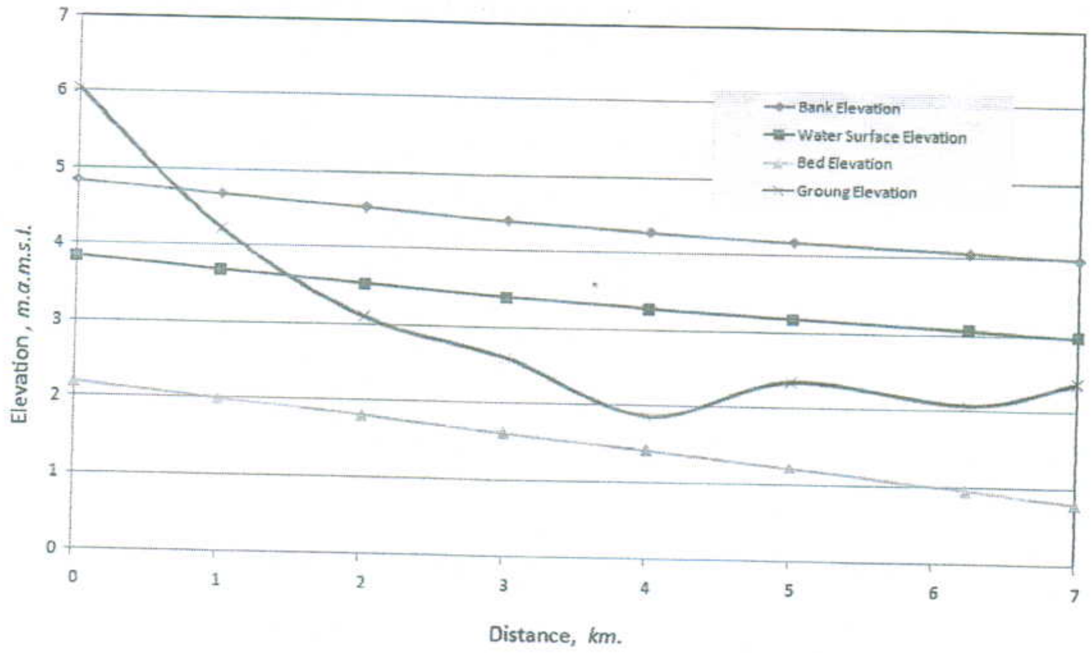


Figure 25. Ground, Bed, bank, and water surface elevation of Al Khamissiya Canal, $130m^3/s$.

4.3 Design of Al Khamissiya Canal Intake Control Structure

The proposed design of Al Khamissiya Canal and results of the implemented hydraulic models in the previous sections showed that the required maximum water surface elevation at the intake of Al Khamissiya Canal to insure discharge $130m^3/sec$ from the MOD water into the marsh are 3.90 and 3.52*m.a.m.s.l.* A water surface elevation of 3.90*m.a.m.s.l* was adopted.

It is required to construct a control structure at the intake of Al Khamissiya Canal to control the design discharge, 130 m^3/sec. Therefore, with leaving 1.00*m* as free board and adding 0.10*m* for the head loss through the Al Khamissiya Canal intake control structure, the crest elevation of the control structure must be not less than 5.00*m.a.m.s.l.*

According to the above requirements, the implemented steady one dimensional hydraulic model to design Al Khamissiya Canal was used, with the same geometric data, steady flow data and downstream boundary condition data, to design the required control structure.

The proposed geometric data of the required control structure were entered into the software by using the inline structure menu. These dimension and properties were proposed based on a model run and check process repeated many times until eventuate the requested destination of this control structure.

The proposed control structure of the $130m^3/sec$, after the repeated model run and check process, is a barrage of trapezoidal cross section with 80.00*m* bed width, 3.00*m* height, 2:1 side slope, 2.00 *m.a.m.s.*l bed elevation, 5.00 *m.a.m.s.l* crest elevation and 14 sluice gates with 3.00*m* width, 1.80*m* height and 2.2 *m.a.m.s.l* invert elevation, **Figure 26**

Accordingly, results of the implemented simulation model showed that the water surface elevation at the intake of the canal upstream and downstream the control structure was 3.90 and 3.91*m.a.m.s.l*, respectively, with water surface elevation at the marsh 3 m.a.m.s.l while , they were 3.89 and 3.90*m.a.m.s.l*, respectively, with water surface elevation at the marsh 2 *m.a.m.s.l*, **Figure 27**e canal cross sections along a distance of 200*m* downstream the control structure were modified to satisfy the transition to avoid the effect of flow turbulence, Pencol, 1983, these modified cross

sections are shown in **Annex D**. Accordingly, the flow velocity along the canal is as shown in **Figure 28.**

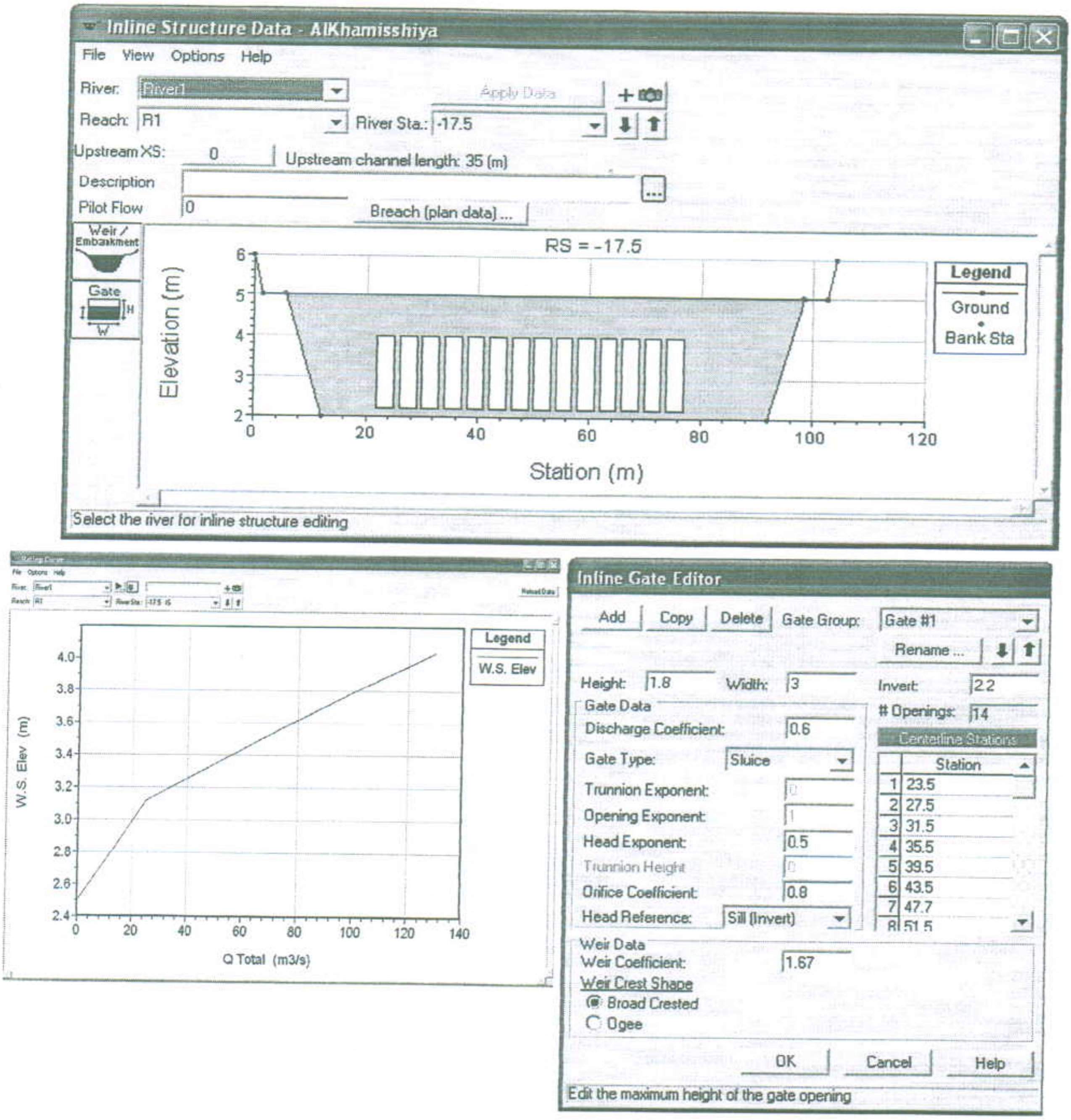


Figure 26. Dimension and properties of the designed control structure at the intake of Al Khamissiya Canal for 130m^3/sec.

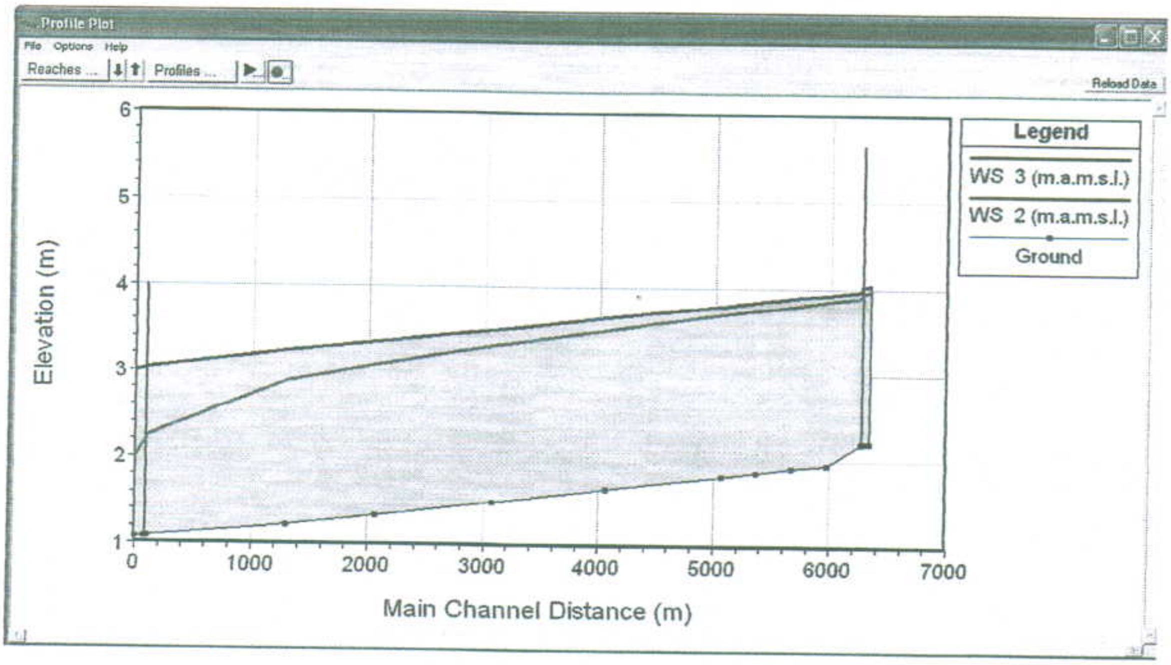


Figure 27. Water surface profile along Al Khamissiya Canal for 130m^3/*sec*.

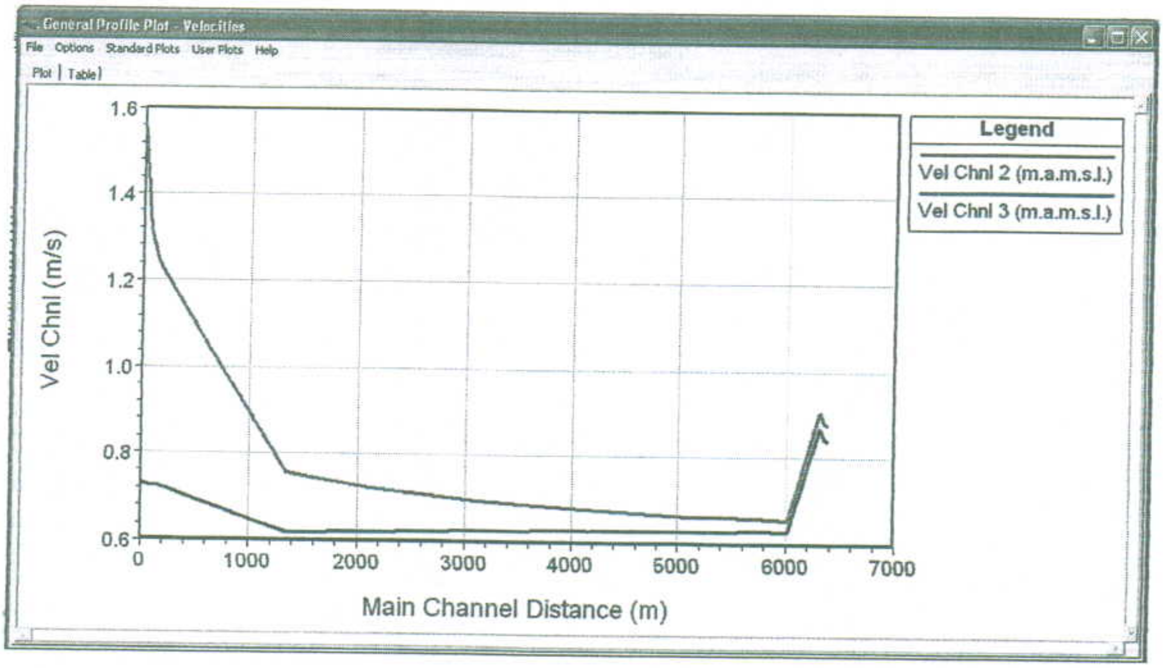


Figure 28. Flow velocity profile along Al Khamissiya Canal for 130m^3/*sec*.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Diverting the required discharge, 130m^3/sec, through the proposed canal from the MOD to the marsh required specifying the maximum and minimum water surface elevation at the upstream of this canal. This required studying the hydraulic flow in the MOD. Accordingly; a steady one dimensional hydraulic model was implemented by using HEC-RAS software to simulate the flow in the MOD.

The required geometric, flow, and boundary conditions data were input. The results of applying this model considering the required discharge from MOD to Al Hammar Marsh, 130m^3/sec and the water surface elevation at the MOD pumping station, at the upstream of the studied reach must be less than 4.5 m.a.m.s.l., showed that the maximum permissible water surface elevation at the upstream of the proposed canal is 3.9 m.a.m.s.l. with MOD discharge 180m^3/sec. while to discharge 220m^3/sec through the proposed MOD hydraulic control structure the water surface elevation at the upstream of this control structure must not exceed 3.6 m.a.m.s.l. The high flow discharge of the MOD pumping station, 220 and 200m^3/sec usually occurred during the wet years. At such years it is not required to feed the marsh from MOD. Therefore, the water surface elevation, 3.9 m.a.m.s.l., corresponds to MOD pumping station discharge of 180m^3/sec, can be accepted to discharge the 130m^3/sec into the marsh and the upstream water surface elevation at the control structure must not exceed of 3.6 m during the high flow. Therefore the proposed MOD control structure must be designed to discharge 220m^3/sec with upstream water surface elevation 3.6 m.a.m.s.l..

Preliminary dimensions for the proposed canal were estimated by using HEC–RAS softwere and the run and check process. The preliminary dimensions of the canal were; 100m bed width, 5m depth and 2:1 side slope.

A steady one dimensional hydraulic model was implemented to simulate the flow in the canal and then the suggested preliminary canal cross section dimensions were modified along the reach until achieving the design criteria of the MOD and marsh.

To control the inflow discharges from the MOD to the marsh, the required control structure was designed by using the implemented model.

Results of applying the implemented simulation model showed that the control structure is a barrage of trapezoidal cross section with 80.00*m* bed width, 3.00*m* height, 2:1 side slope, 2.00 *m.a.m.s.*l bed elevation, 5.00 *m.a.m.s.l* crest elevation and 14 sluice gates with 3.00*m* width, 1.80*m* height and 2.2 *m.a.m.s.l* invert elevation,

The water surface elevation at the intake of the canal upstream and downstream the control structure was 3.90 and 3.90*m.a.m.s.l*, respectively, with water surface elevation at the marsh 3 m.a.m.s.l while , they were 3.89 and 3.89*m.a.m.s.l*, respectively, with water surface elevation at the marsh 2 *m.a.m.s.l.*

Canal cross sections along a distance of 200*m* downstream the control structure were modified to satisfy the transition to avoid the effect of flow turbulence.

5.2 Recommendations

1. The water surface elevation, 3.9 m.a.m.s.l., corresponds to MOD pumping station discharge of $180m^3$/sec, can be accepted to discharge the $130m^3$/sec into the marsh and the upstream water surface elevation at the control structure must not exceed of 3.6 m during the high flow, 220 m^3/sec.
2. The proposed MOD control structure must be designed to discharge $220m^3$/sec with upstream water surface elevation 3.6 m.a.m.s.l..
3. The cross sections of the canal must be designed as shown in annex C.
4. The control structure is a barrage of trapezoidal cross section with 80.00*m* bed width, 3.00*m* height, 2:1 side slope, 2.00 *m.a.m.s.*l bed elevation, 5.00 *m.a.m.s.l* crest elevation and 14 sluice gates with 3.00*m* width, 1.80*m* height and 2.2 *m.a.m.s.l* invert elevation,
5. Canal cross sections along a distance of 200*m* downstream the control structure were modified to satisfy the transition to avoid the effect of flow turbulence.

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ANNEX A

CROSS SECTIONS OF THE MOD

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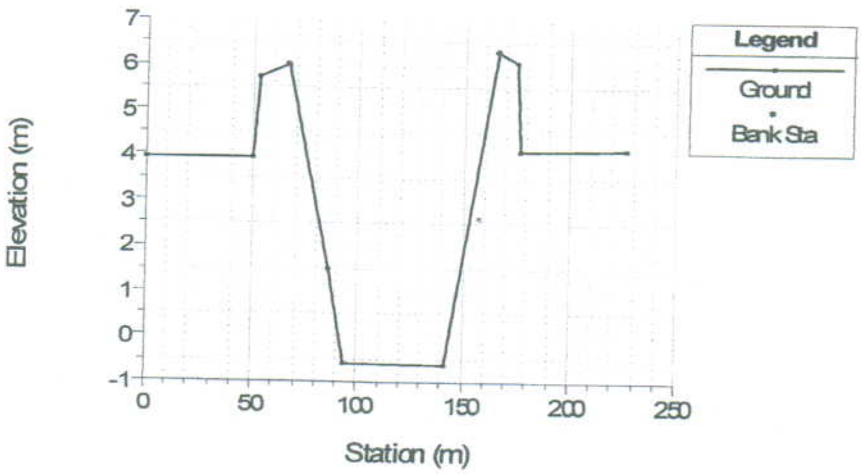

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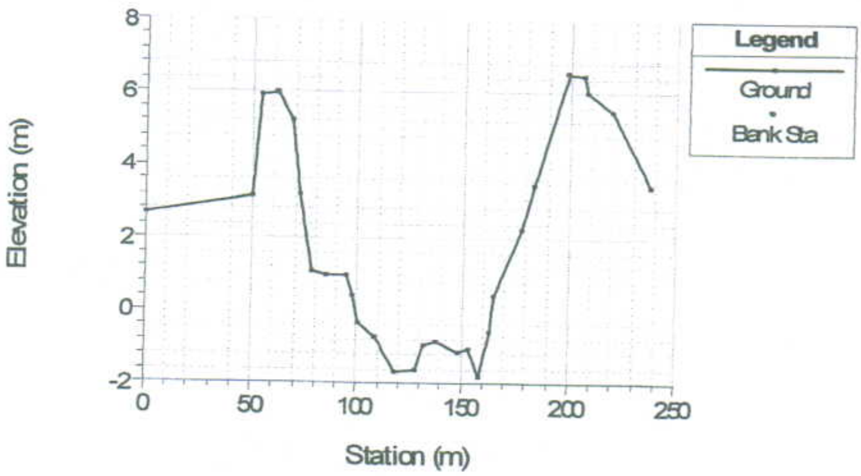

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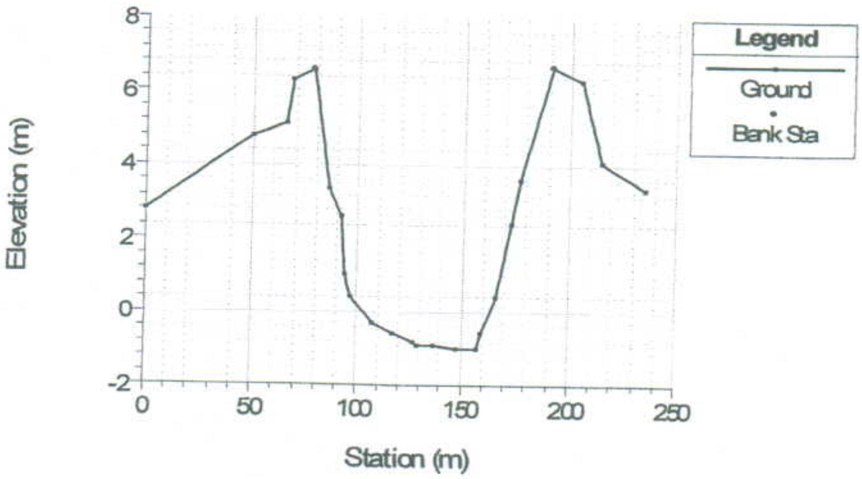

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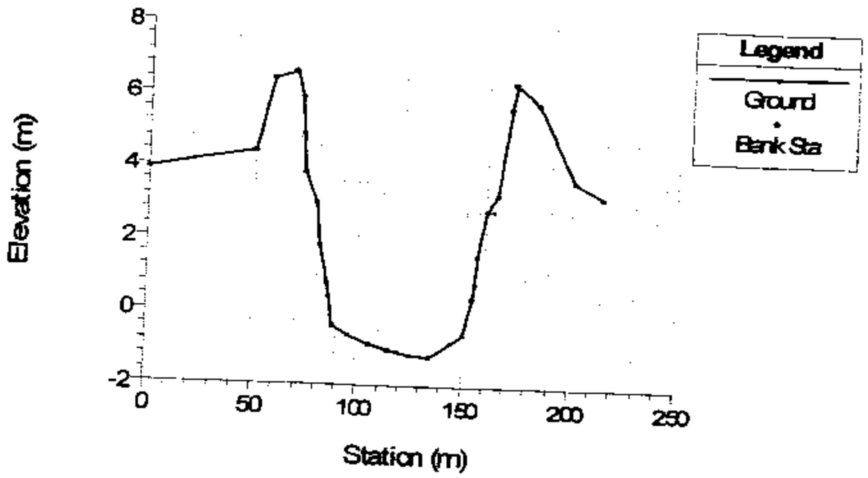

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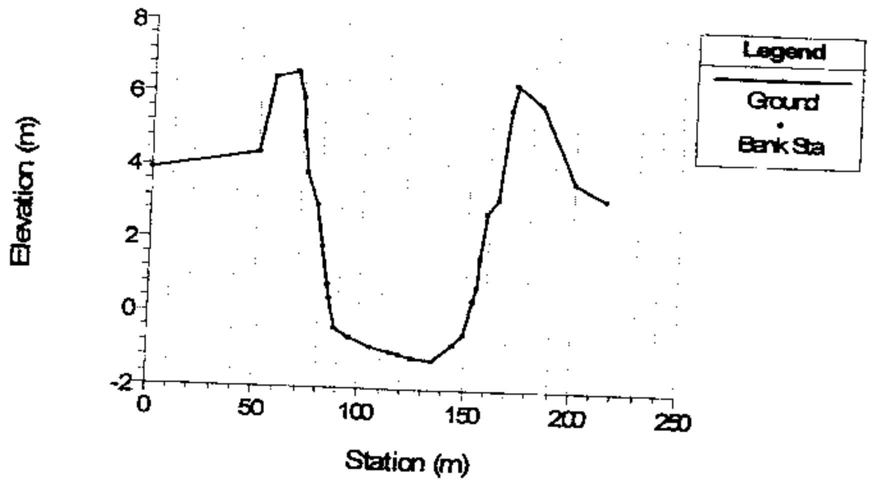

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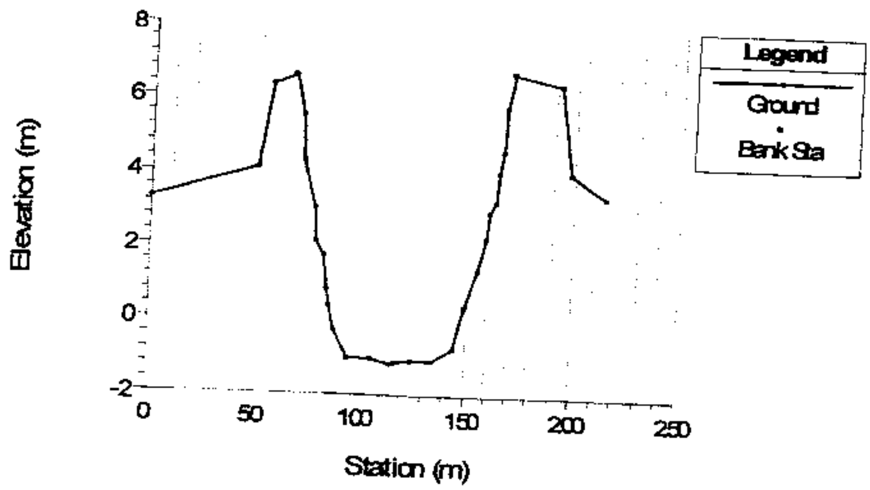
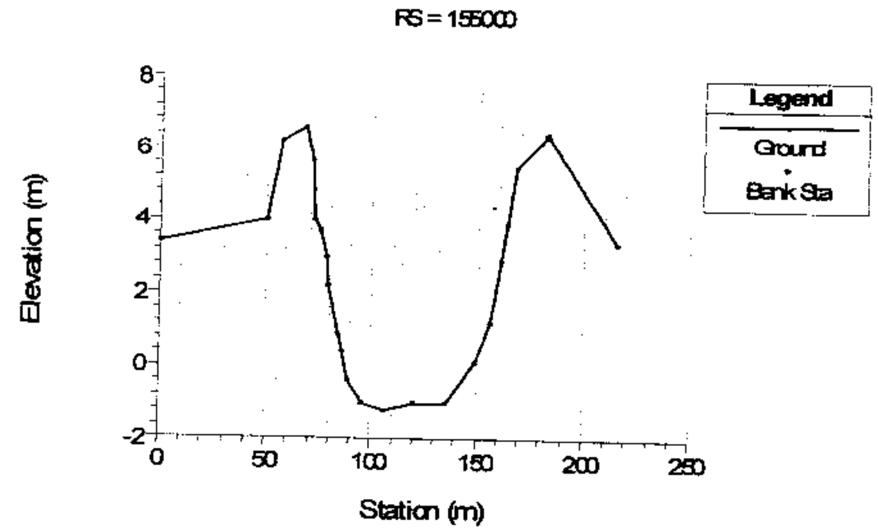
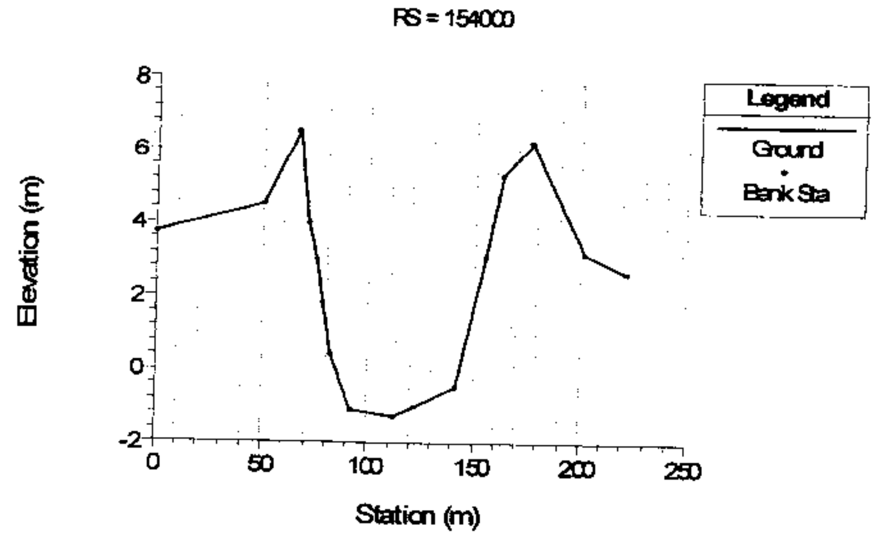
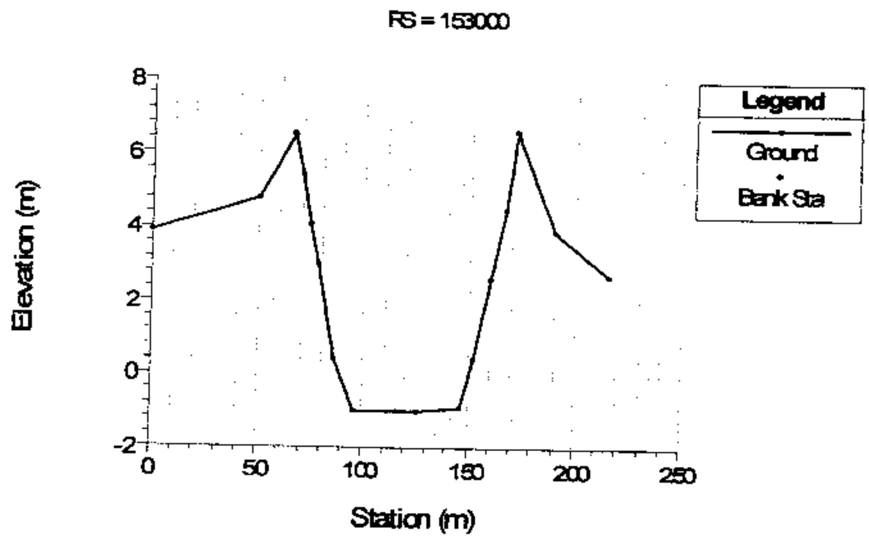
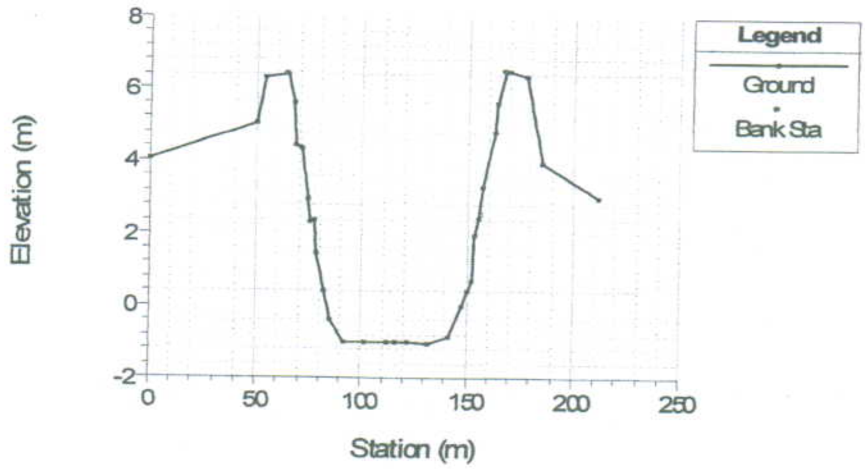



RS = 155000
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
8
6
4
2
0
-2
0
50
100
150
200
250

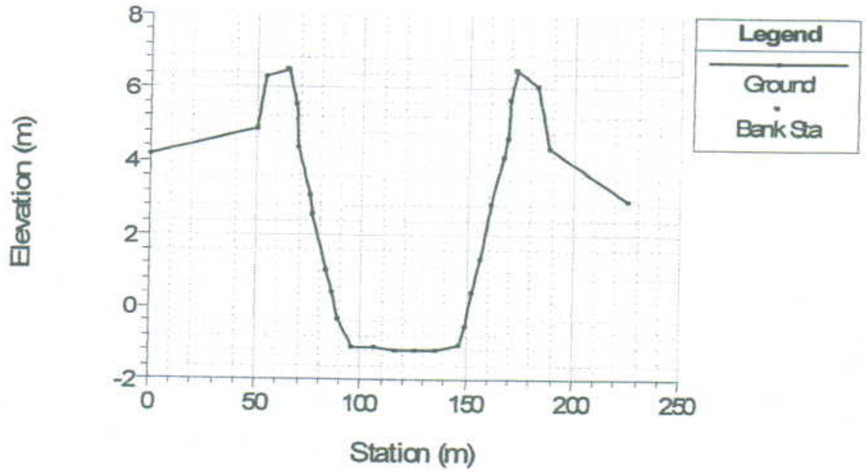

RS = 154000
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
8
6
4
2
0
-2
0
50
100
150
200
250


RS = 153000
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
8
6
4
2
0
-2
0
50
100
150
200
250

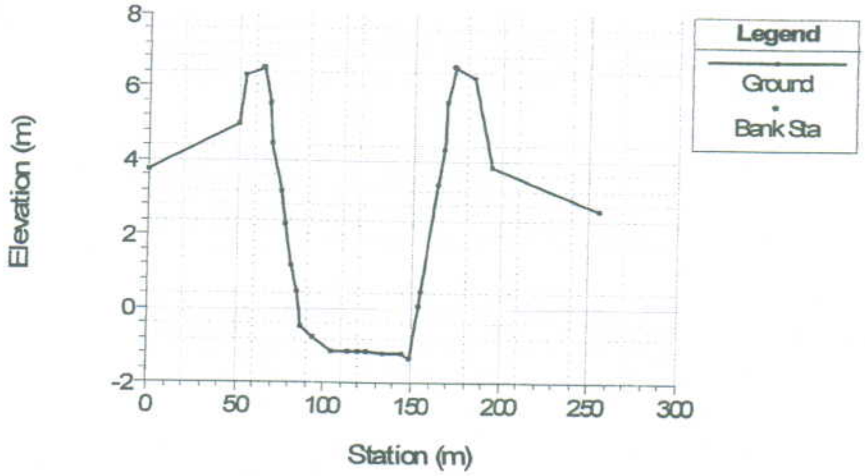
RS = 152000



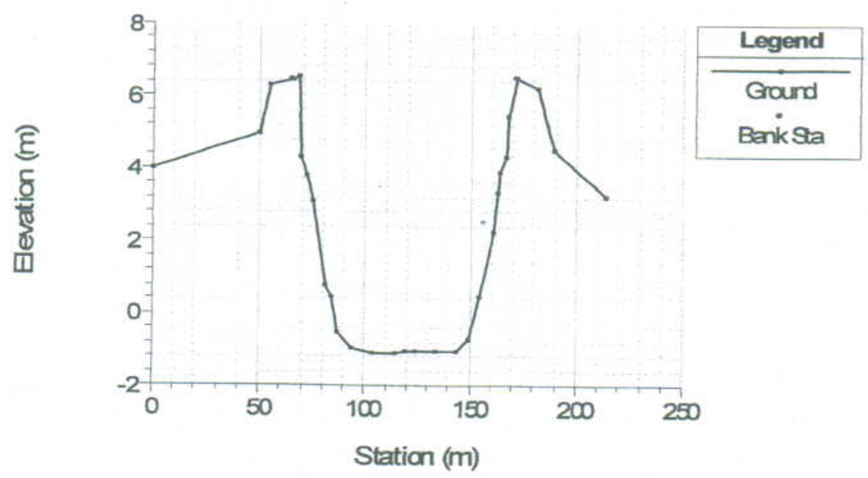
RS = 151000



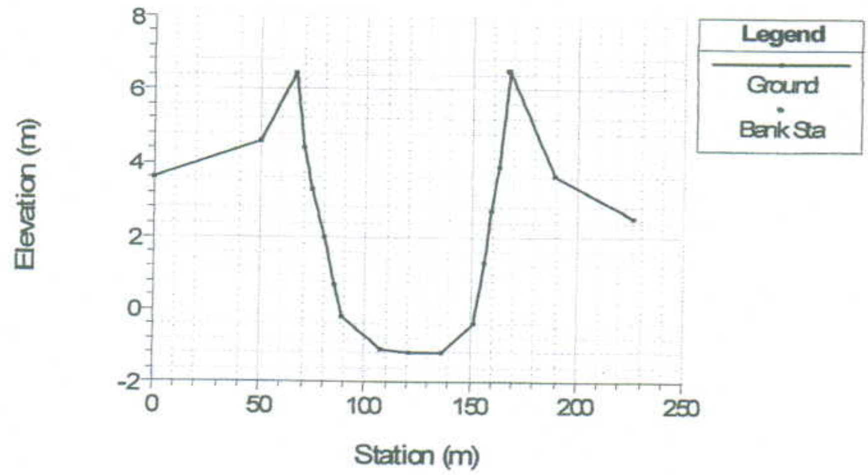
RS = 150000



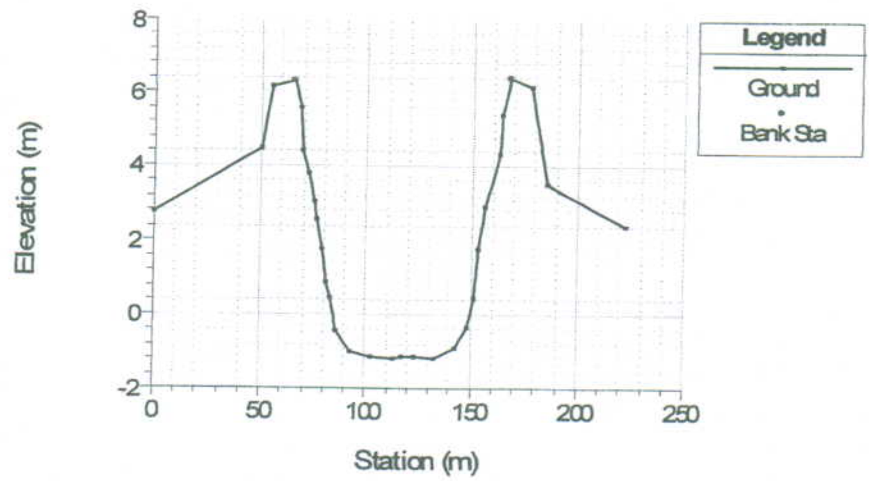
RS = 149000



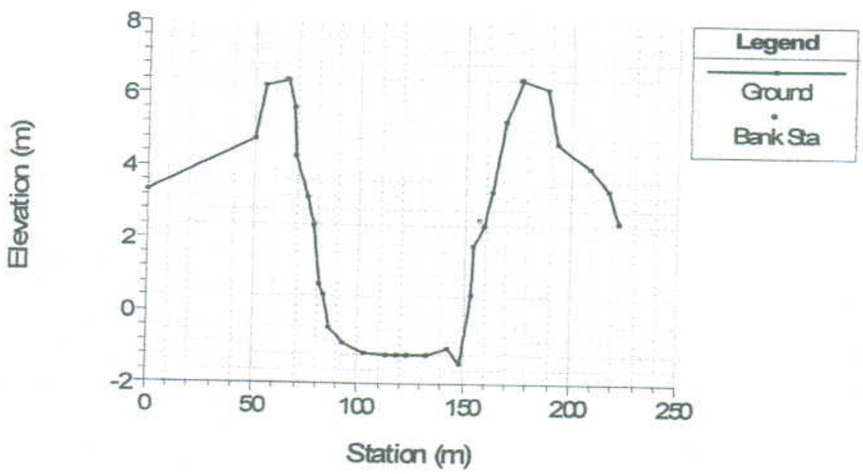
RS = 148000



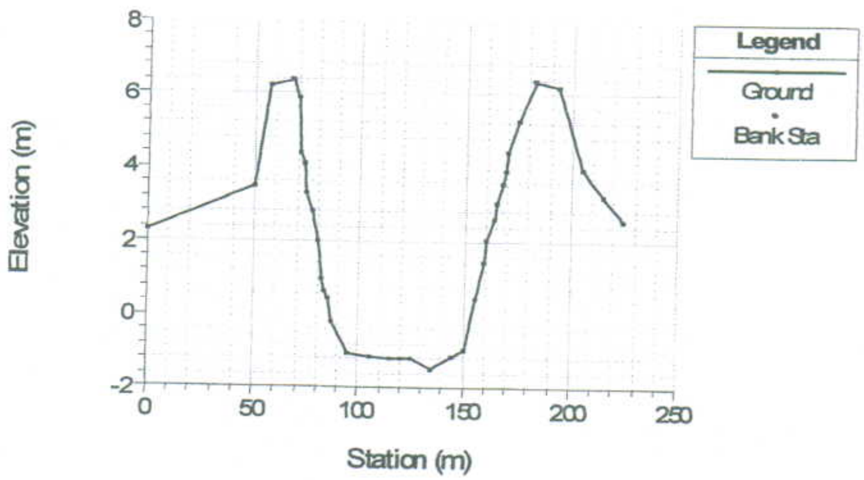
RS = 147000



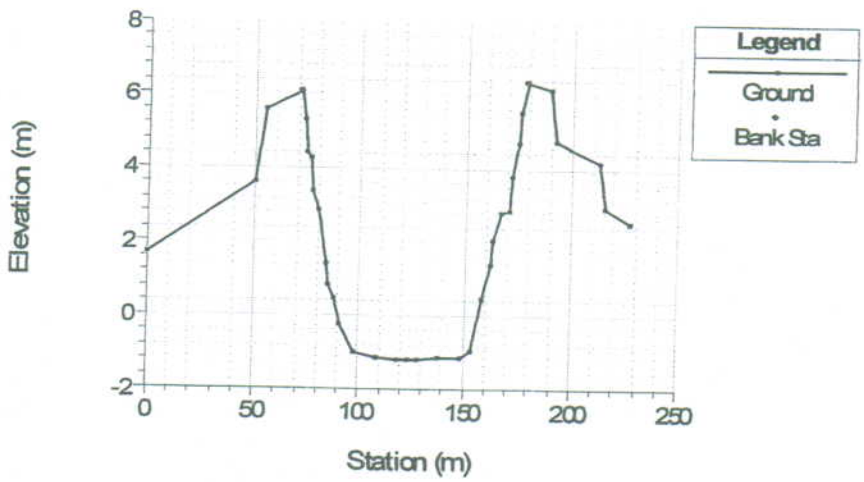
RS = 146000



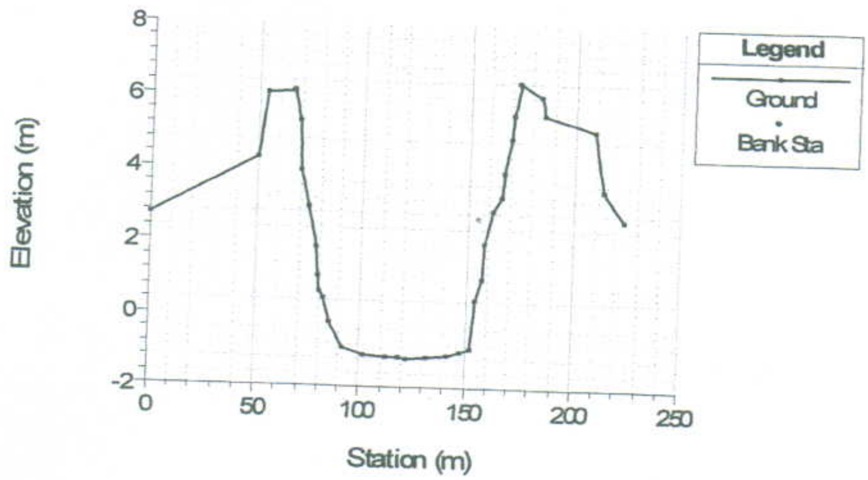
RS = 145000



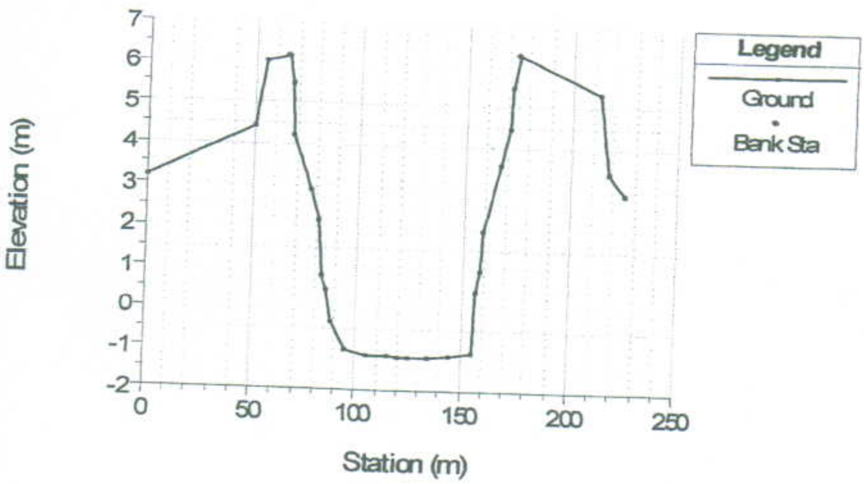
RS = 144000



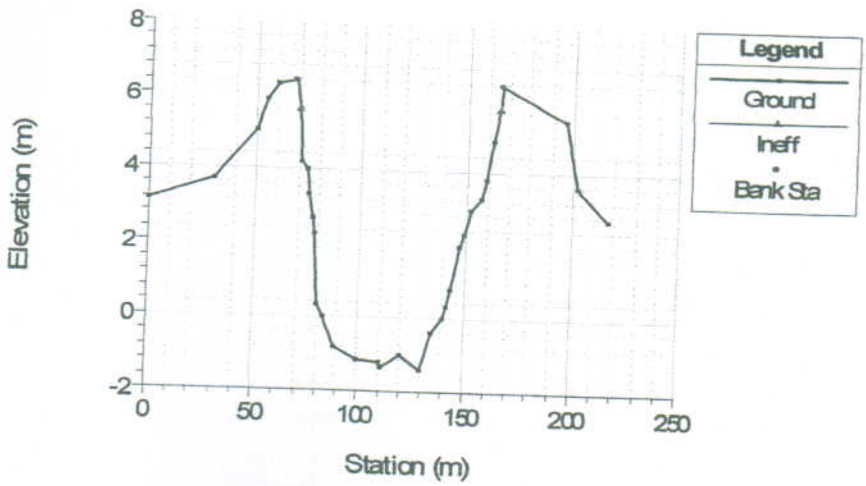
RS = 143000



RS = 142000

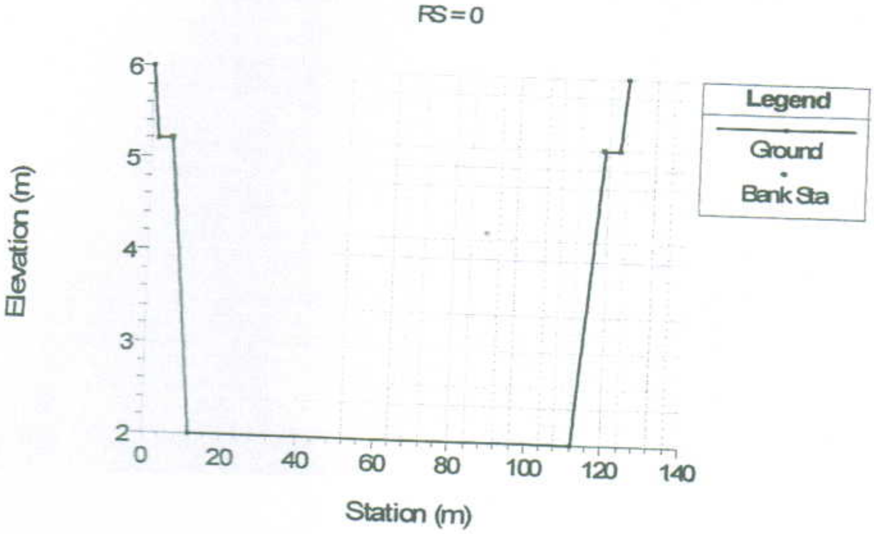


RS = 141000

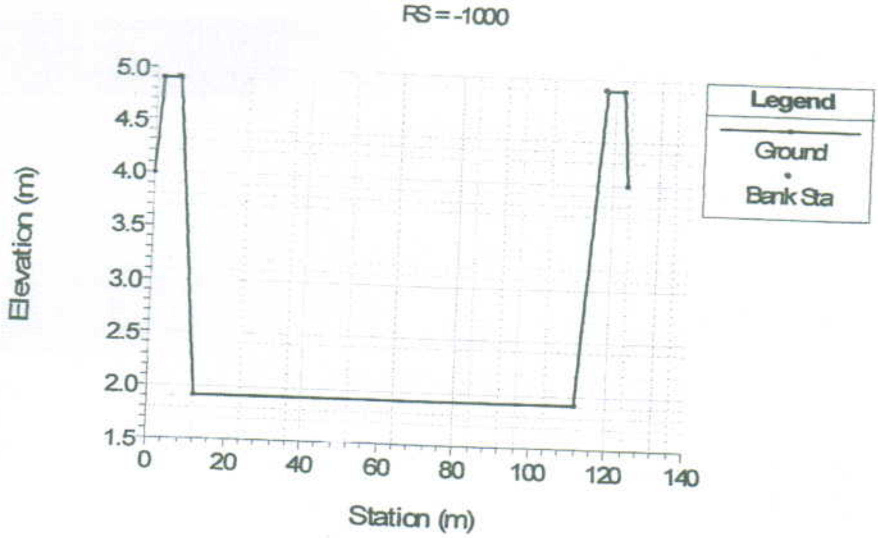


ANNEX B

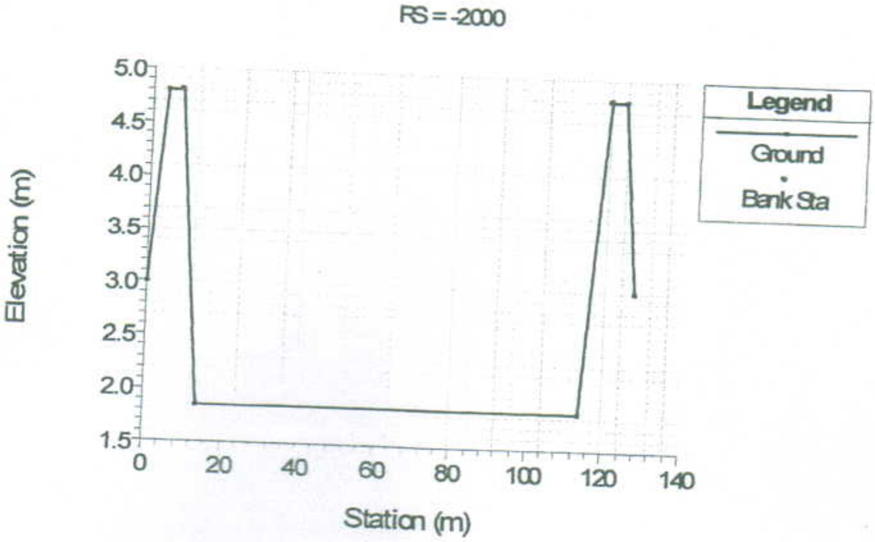
PROPOSED CROSS SECTIONS OF AL KHAMISSIYA CANAL



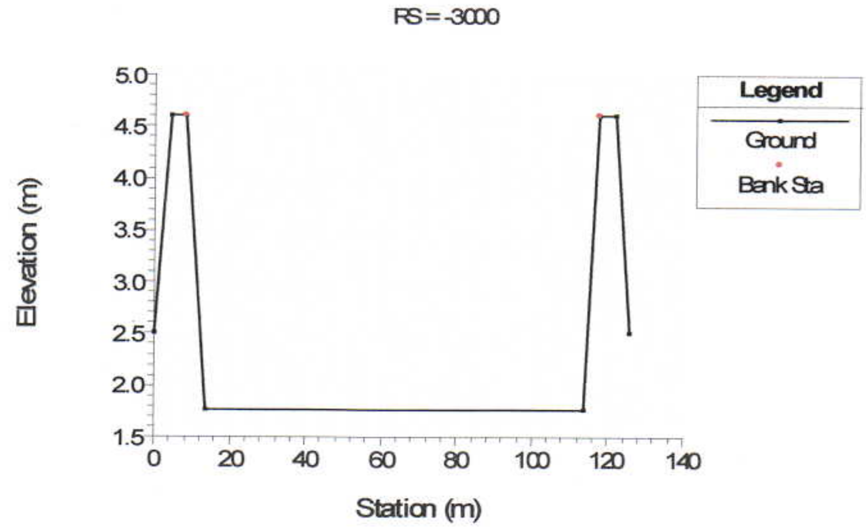
RS = 0
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

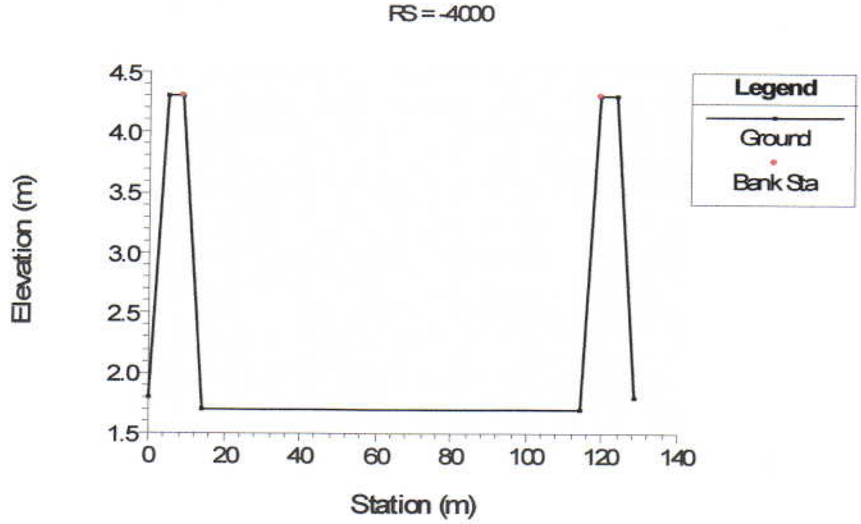


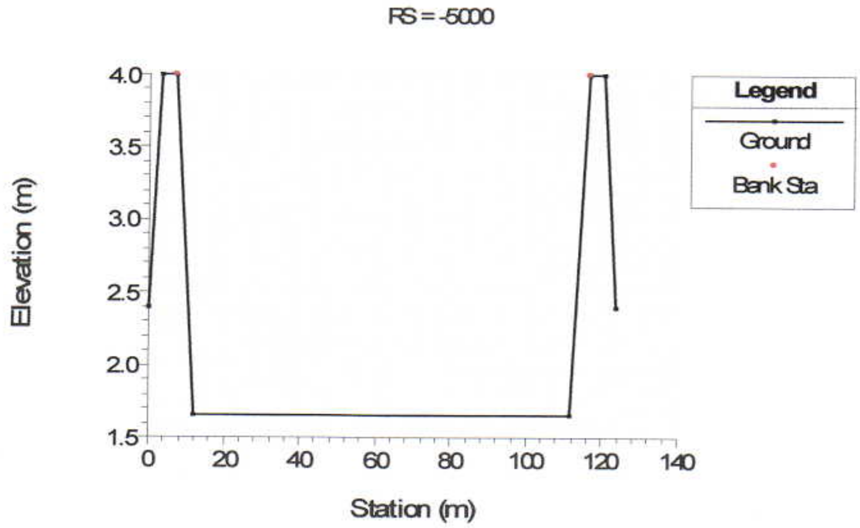
RS = -1000
Elevation (m)
Station (m)
Legend
Ground
Bank Sta



RS = -2000
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

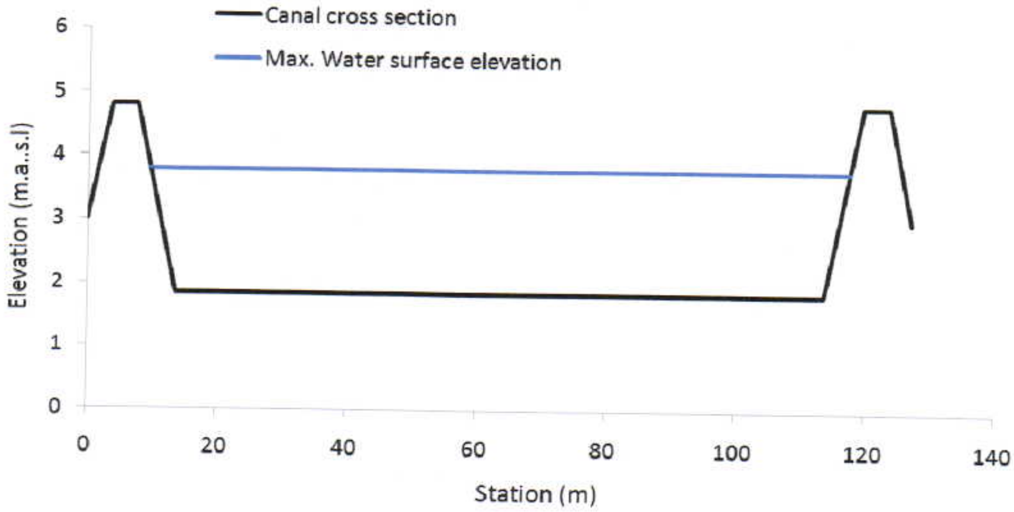

RS = -3000
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


RS = -4000
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

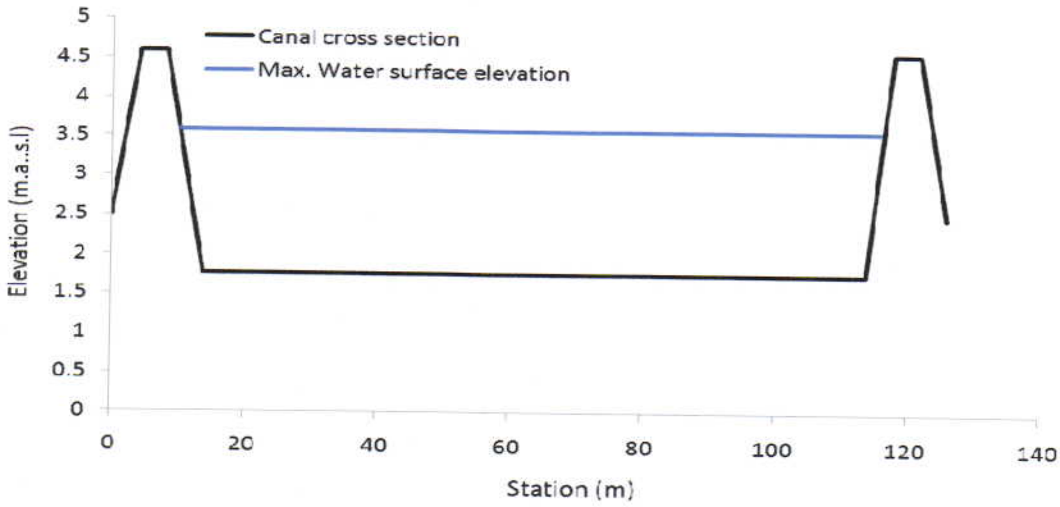

RS = -5000
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

ANNEX C

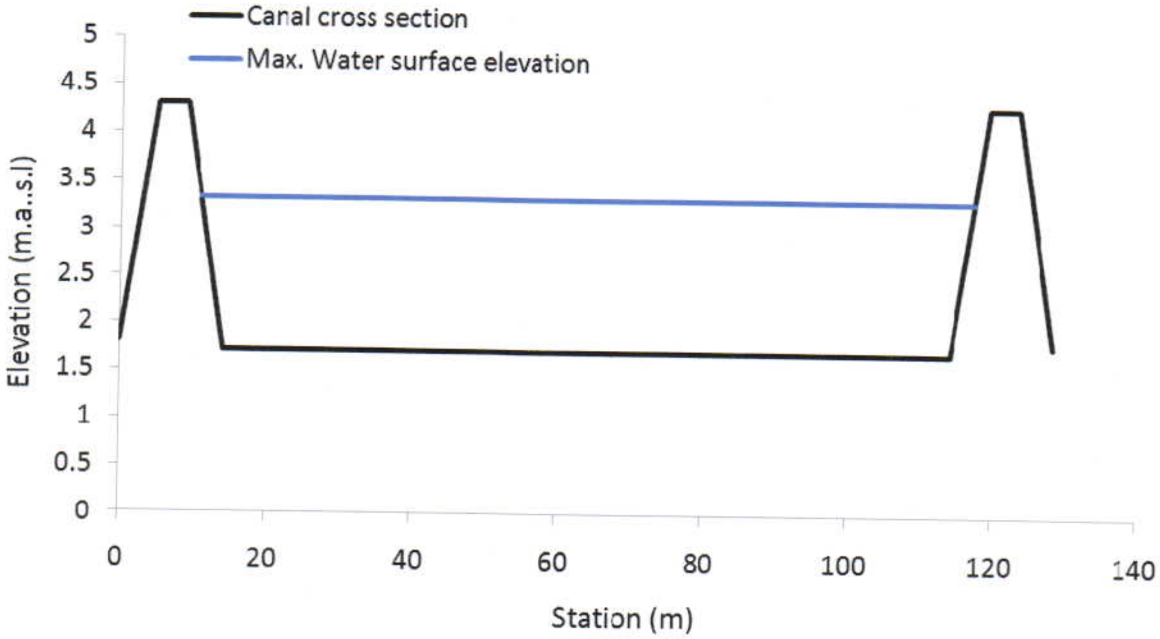
FINAL CROSS SECTIONS OF AL KHAMISSIYA CANAL



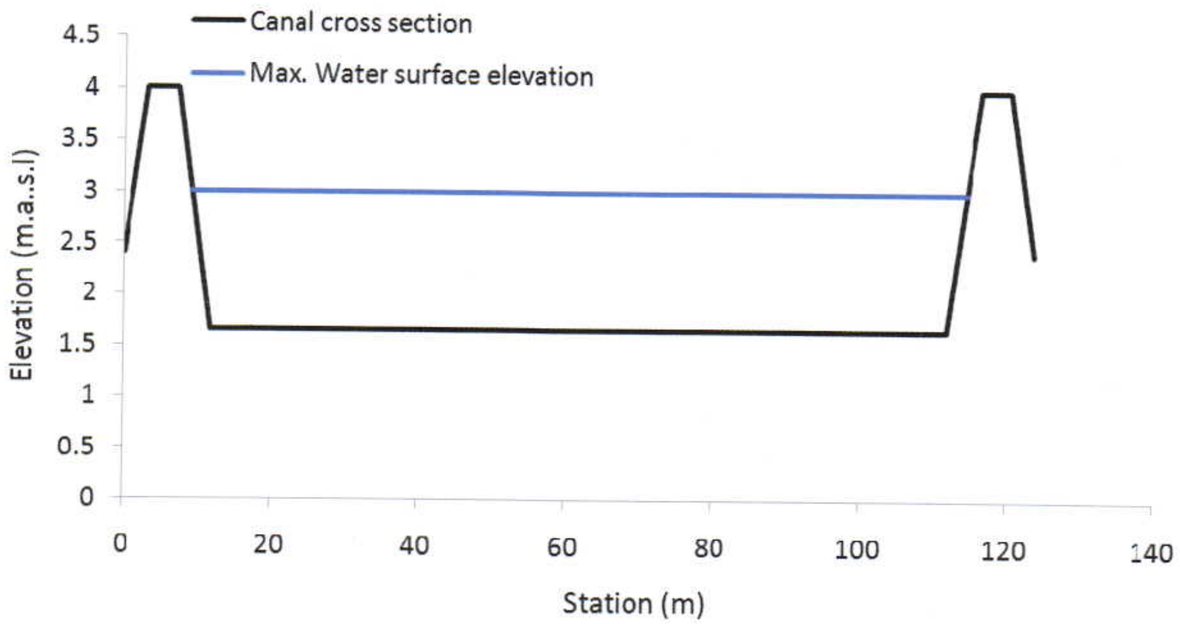
Station 2235



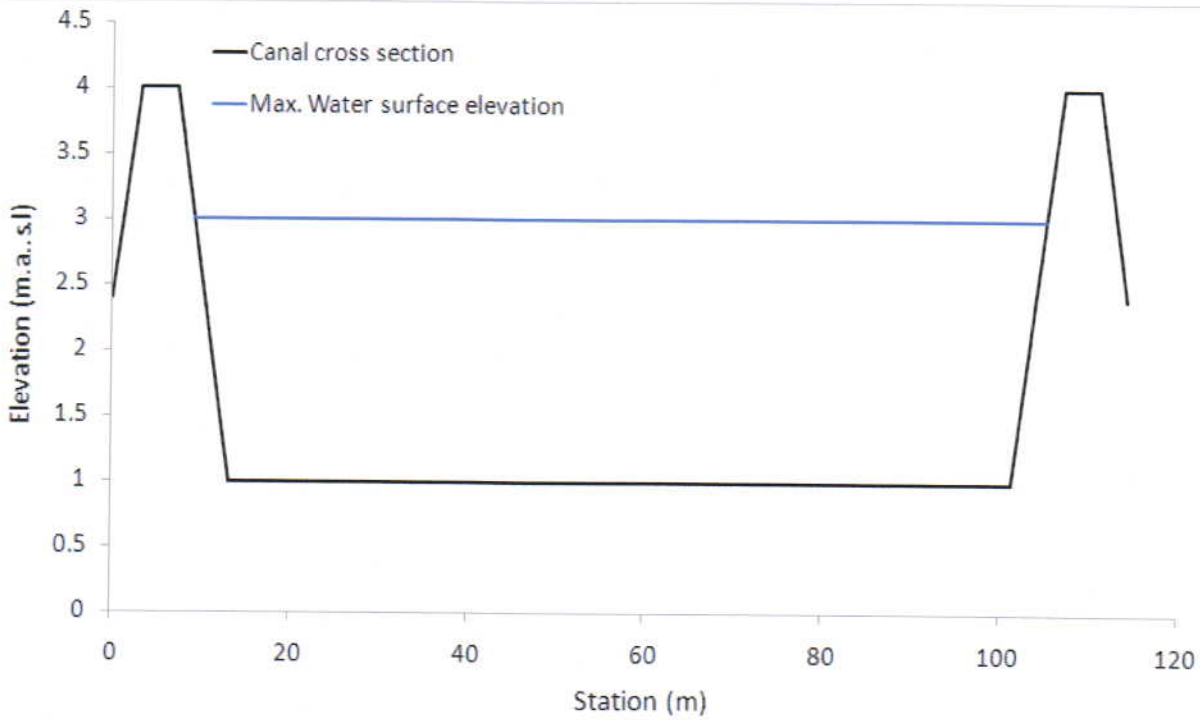
Station 3235



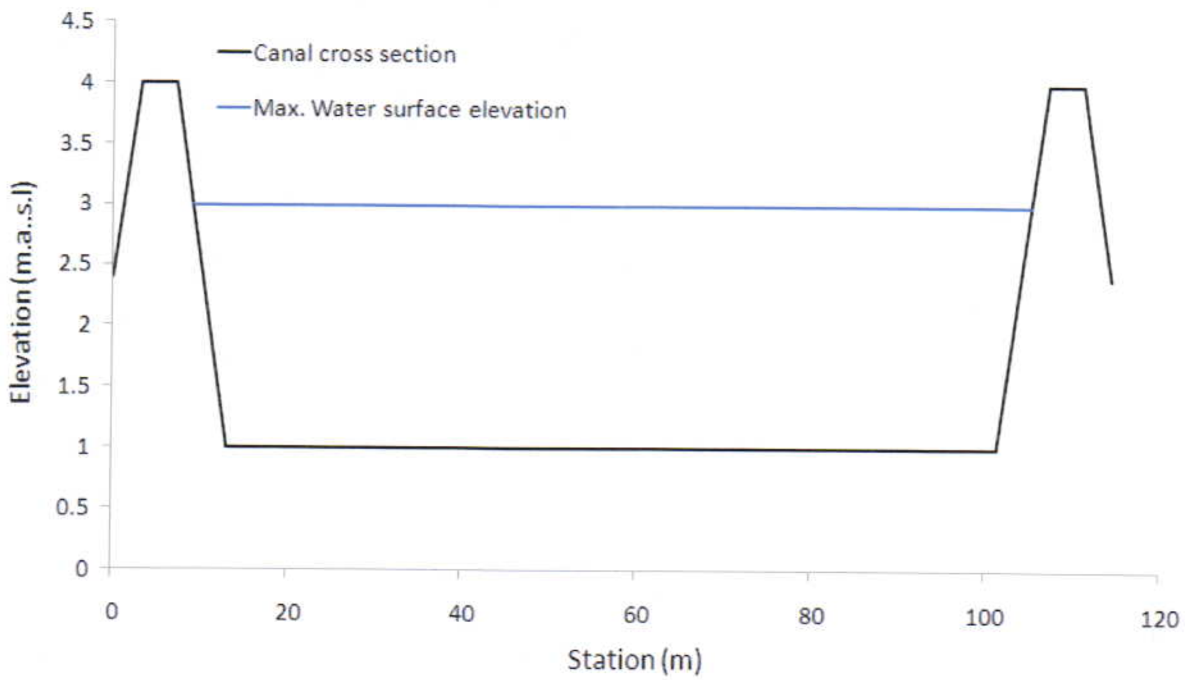
Station 4235



Station 5000



Station 6200



Station 6300

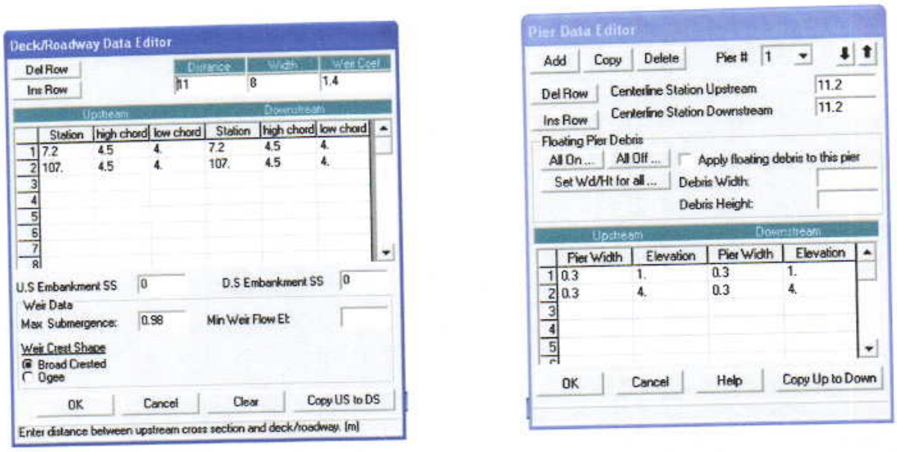


Figure 18. Geometric data of the proposed bridge, deck and pier data.

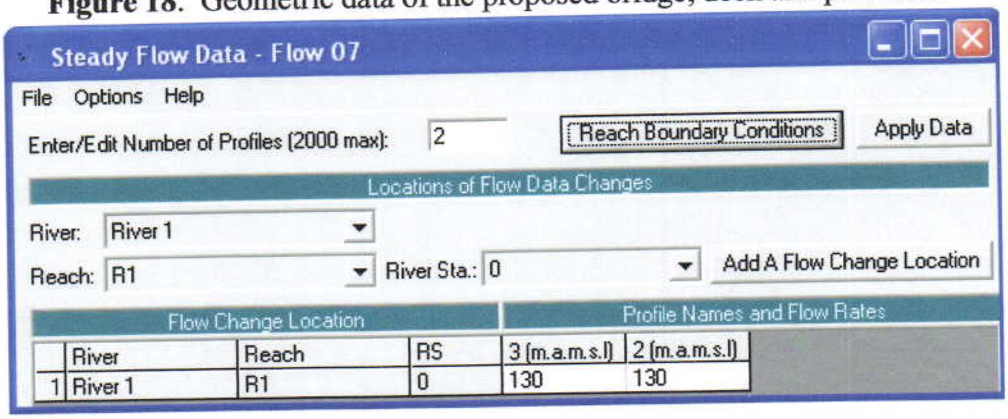


Figure 19. Al Khamissiya Canal steady flow data of the two scenarios, 130 m^3/sec.

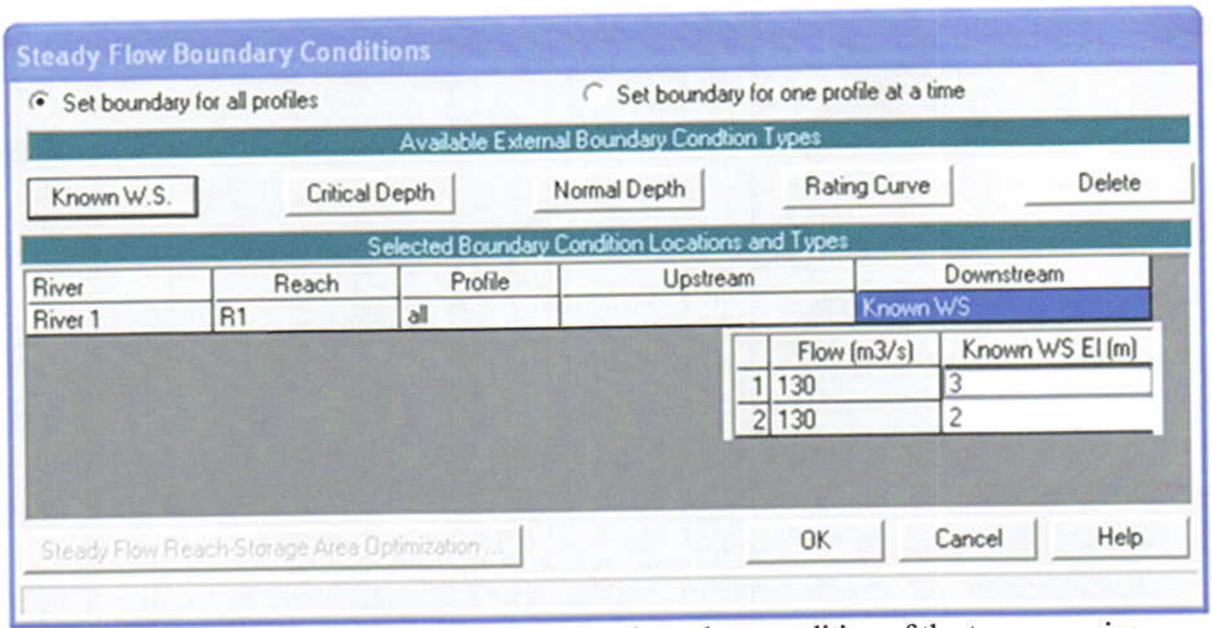


Figure 20. Al Khamissiya Canal downstream boundary condition of the two scenarios, 130 m^3/sec.