Numerical Modeling for Improving the Hydraulic Efficiency of El-Max Delivery Canal Reaches, Alexandria, Egypt

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Abstract

A 1-D mathematical model was developed to simulate and identify solutions to the hydraulic carrying capacity problems of the delivery canal that is currently used to deliver drainage water pumped out form EL-Max station to the Mediterranean Sea. A major reason for this problem was found to be the illegal socio economic activities at the canal banks that changes the geometrical and hydraulic conditions of the canal. These bottlenecks increase the water level affecting negatively the efficiency of the pump stations, which leads to the inundation of large agriculture areas and industrial plants around Lake Mariout and flooding of number of Alexandria's districts. In this paper, SOBEK software was used to develop hydrodynamic model for El-Max pump station and its delivery canal up to the Mediterranean Sea. The model objective is to identify optimum mitigation measures to increase the efficiency and analyze the canal hydraulic conditions before and after removing all bottlenecks. The study proved that if dredging started from the Sea side, water level will decrease quickly and give better hydraulic conditions than starting from the downstream of the station. The canals capacity will increase, and will be able to pass the design discharge.

Keywords: El-Max Delivery Canal, Pump Station, Discharges, Dredging, Modelling, 1-D Software (SOBEK).

1. INTRODUCTION

The governorates of Alexandria and Beheira, in Egypt are suffering from water level rise of Lake Mariout especially during the winter season. High water levels within the lake are caused by the pumping stations not running at full capacity due to the insufficient capacity of the delivery canal to accommodate the design discharges. El-Max pump stations consisted of 2 stations, the combined design discharges (maximum capacity) for both of them is about 130 m3/s.

Figure (1) shows the layout for the two pumping stations and Lake Mariout. The railway line bridge serving Alexandria-Mersa Matrouh crosses the suction canal. The suction level should not exceed (-2.80) m to prevent rising Lake Mariout's water level, which would flood the farms, buildings, factories and roads surrounding the lake.
According to the general authority of Alexandria port, every winter Alexandria faces at least 18 rainstorms. During these events, water levels in Mariout Lake and El-Omoum drain increased and the pumping stations were sinking in water due to the insufficient capacity for the delivery canal. On October 2015, it rained continuously for nine hours with unprecedented rates that led to the accumulation of 3.2 million m3 of water. This causes the death of seven people, according to the administrative prosecution. These floods covered the streets, homes, cars, hospitals, roads especially Corniche road and train stations. Trucks with pumps were used to pump out water floods from the main streets and squares in Alexandria. Improving the efficiency of the delivery canal will help solve the problem of the flooded area around the lake and El-Max pump station.

Figure (1): General Layout for El-Max Pumping Stations Site

1.1. Problem Definition and Identification

El-max stations were not able to perform under their design capacity due to following various reasons:

- The suction canal of the station has been designed on the basis of the existence of banks between canal and Lake Mariout and on the basis that the level of suction design is (- 3.20) m.
- As a result of sewage and industrial drainage and fishing works in the lake, many parts of the canal banks have been removed and it became necessary to adjust the levels of the lake in addition to the level of the drain by using El-Max pump stations.
- There was intense pressure from fishermen and fisheries association to increase the level of suction from (-3.20) m to (- 2.50) m.
- This increase in suction levels lead to the increase of the flow more than the allowable limit between the blades of the pumping units and the occurrence of cavitation and erosion of the internal parts of the pumping units and reducing the efficiency and increasing the overall rates and the consumption of electricity and spare parts.
- Raising the suction level lead to a rebound in the water inside El-Omoum drain and negatively impacting the safety of El-Qalaa, El-Hares, El-Deshoudy and Trouga stations, and become a danger to the safety of these stations towards the delivery levels.
- El-Max pumping stations have been designed to give a discharge of about 100 m3/s at a level of (0.75) m.
- Field Studies carried out by the Hydraulics Research Institute in 1999 and 2011 showed that as a result of bottleneck and encroachment by the people on the banks of the delivery canal of the station led to the increase of the water level to (1.20) m at a discharge of 100 m^3/s. The comparison between measured and designed cross sections showed that, there are a lot of bottlenecks along the delivery canal as shown in **Figure (2)** at km 0.125 from the Sea as an example.
- Due to exacerbating the problem of encroachment and the bottlenecks along the canals, the delivery water level corresponding to the discharge of 100 m3/s increased from (1.20) m in 1999 to (1.40) m during Qasim storm in 2010 and 2015.

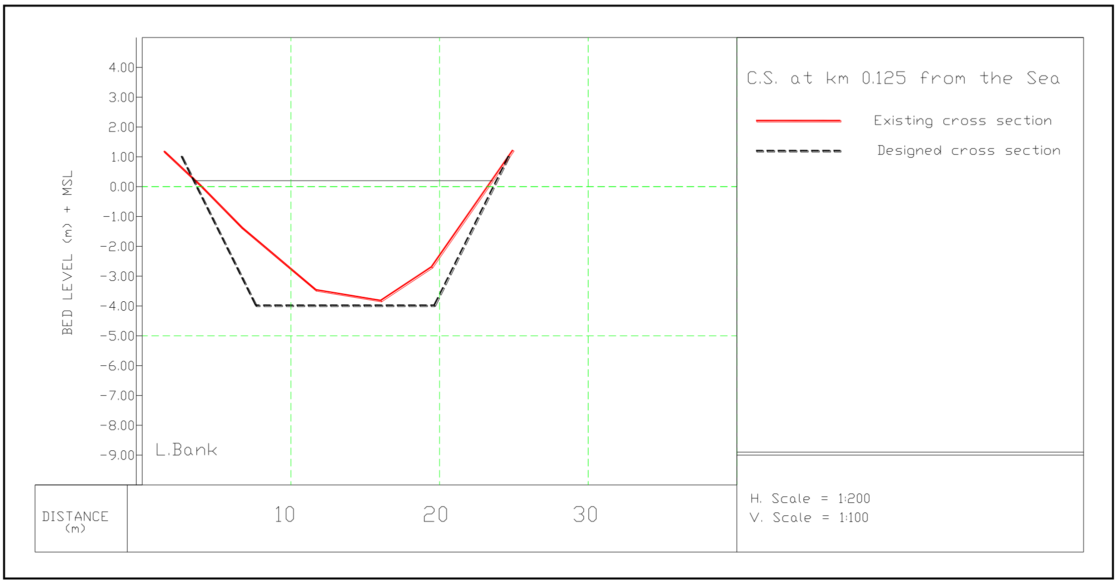

Figure (2): Measured and Designed Cross Section at km 0.125

This study was carried out using a one dimensional mathematical model, named SOBEK-1D, Delft Hydraulics (2009), which was used for simulating the canals as 1-D. The model simulated water flow downstream of El-Max pumping stations. The aim of the study is to assess the hydraulic performance of the El Max channel and dredging required to accommodate drainage discharges for extreme weather events. The study would define the following:

- Current capacity for the delivery canal at design water level of (0.75) m.
- The water level corresponding to the design discharge of 100 m3/s.
- The required work which is needed to increase the capacity of the canal to the design discharge and decreasing the delivery water levels for all reaches.
- The priority of dredging for all reaches.

2. THE STUDY AREA

Layout for the study area from El-Max pumping stations to the Sea, locations of the pump stations and reaches lengths are presented in **Figure (3)**. Delivery canal consists of four reaches. The suction canal of the two pumping stations is connected to Lake Mariout, while the delivery canal is connected to the Mediterranean Sea as shown in Figure (3). There is an island between reach (2) and reach (4), reach (3) is connecting the pump stations and reaches (2) and (4). Reach (1) is connecting Mediterranean Sea and reaches (2) and (4).

2.1. El-Max Pumping Station Campus Description

El-Max pumping station campus consists of two sets of lifting units as follows: The first set is Austrian-made consists of 6 units (5 in operation + 1 standby), the design discharge of each unit is about 12.50 m3/s. The second set is German-made consists of 6 units connected in parallel (5 in operation + 1 standby), the design discharge of each unit is about 14.10 m3/s.

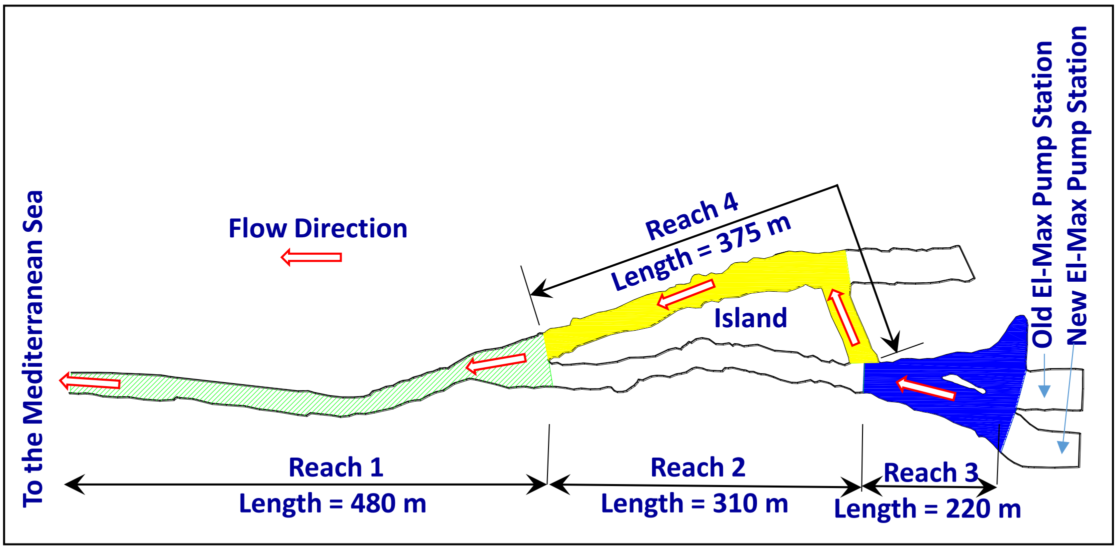

Figure (3): Reaches of the Study Area

Using the mathematical model to define the previous parameters will help the decision makers to make their decisions about the priority of dredging the canal reaches which will help in reducing the water level in a short time.

3. METHODOLOGY

SOBEK- Rural is a one and two dimensional integrated modelling framework for integral water solutions. SOBEK-Rural gives regional water managers a high-quality tool for modelling irrigation systems, drainage systems and natural streams in lowlands and hilly areas. Applications are typically related to optimizing agricultural production, flood control, irrigation, canal automation, reservoir operation, and water quality control. SOBEK-Rural offers the support needed for effective planning, design and operation of new and existing water systems. G. S. Stelling et al. (1998), W. A. Bishop and C. L. Catalano (2001), A. Verwey (2001) and delft Hydraulic (2001) summarized that a one dimension mathematical model (1-D) could simulate the flow in the channels. SOBEK was used to study many projects with different objectives. It was used to define the hydraulic dimensions and operation rules for Sue dam in South Sudan, A. M. Elbelasy (2016). A. M. Elbelasy et.al, (2012) used SOBEK to determine the critical time of canal storage capacity controlled by cross pump stations While Heba et.al, (2013) used it to study the effect of barrages failure along the Nile River. In this study SOBEK will be used to improve the efficiency of the delivery canal and to define the dredging priorities for all reaches.
As for the canal and pump stations simulations, the most relevant model that can be used is the Flow Module. The Flow Module is capable of simulating fully unsteady flow. The flow module in SOBEK that is used for Regular River applications could be described by the full Saint-Venant equations for unsteady open channel flow, Delft Hydraulics (2009). For the delivery canal model, the Manning's roughness coefficient provides a good representation of the hydraulic roughness for a wide range of discharges. The aim of using the model is to test different scenarios to increase the discharge of the canals and forecast the corresponding maximum water level, taking into account the variation in the Mediterranean Sea water levels.

3.1. Model Construction

A mathematical model for the study area was constructed as described in **Figure (4)**. The measured field data, (Elbelasy and et. al, 2011) was used during constructing the model. Data include cross sections for all canal reaches, pump stations design and operational head and discharges, and the boundary conditions. These elements are displayed here as follows:

- Reach No. (1): The total length of the first reach is about 480 meters, which starts almost from the mouth of the drain at the Mediterranean Sea at kilometer zero and ends at kilometer 0.480. This reach was simulated in the model by 19 cross-sections, spaced about 25 meters.

- Reach No. (2): The total length of this reach is about 310 meters, which represents the left canal behind El-Max pumping station and starts at kilometer 0.480 and ends at kilometer 0.790. It was simulated by 9 cross-sections spaced about 30 meters.
- Reach No. (3): The total length of the third reach is about 220 meters. It begins just behind the station directly at kilometer 0.790 and ends at kilometer 1.010 and there is a small island in this reach. It was represented by 6 cross-sections spaced about 30 meters.
- Reach No. (4): Its total length is 375 meters and is considered as the right canal behind El-Max pumping stations. It joins the left delivery canal at kilometer 0.480. This reach was simulated in the model by the surveyed cross sections from No. 30 to 48. Figure (4) shows a horizontal plane for the model schematization.
- Old El-Max pump station consists of 6 units (5 in operation + 1 standby), the design discharge of each unit is about 12.50 m3/s.
- New El-Max pump station consists of 6 units connected (5 in operation + 1 standby), the design discharge of each unit is about 14.10 m3/s.
- The designed delivery water level is (0.75) m and the suction level is (-3.20) m.

3.2. Boundary Conditions

Boundary conditions are needed here to solve the unsteady flow basic equations.
The discharge values of the current conditions of 100 m3/s and the extreme discharge value (storms during winter season) of 130 m3/s will be used as an upstream boundary. While, Mediterranean Sea water levels were considered the downstream boundary. The Sea water levels at the drain outlet range from (0.00) to (0.55) m.

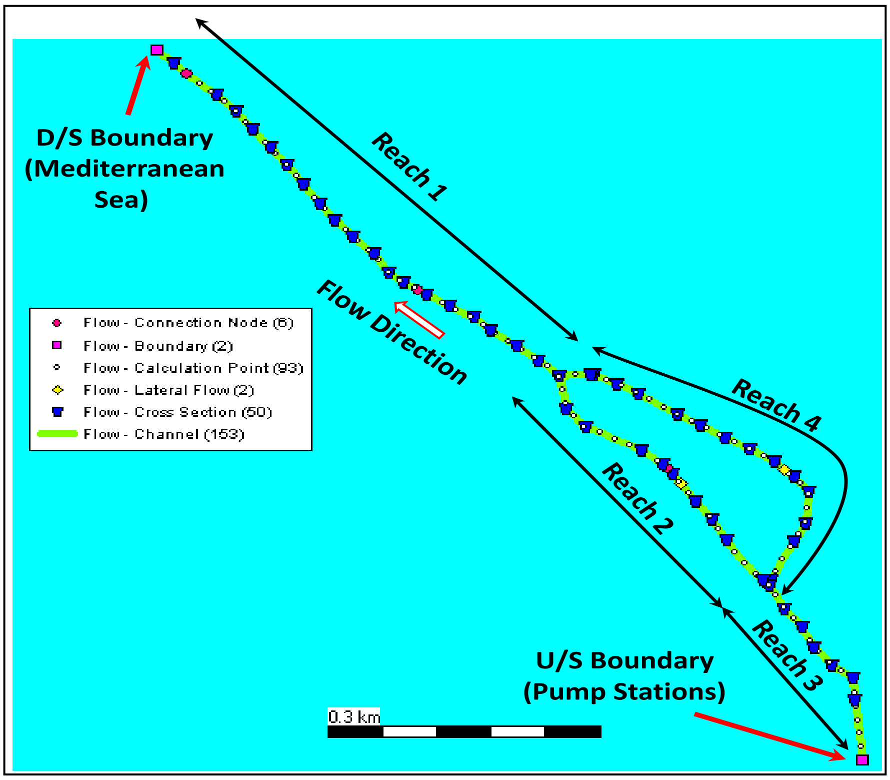

Figure (4): Layout of the SOBEK 1-D Model

4. RESULTS AND DISCUSSION

4.1. Model Calibration and Verification

The model has been calibrated using the following measured field data:

- The discharge of the working units of El-Max pumping stations during the measurements was 51.3 m3/s.
- Water levels along the delivery canal.

The computed water levels from the model were compared to the measured ones, the comparison showed the presence of a very large convergence between measured and computed water levels obtained from the model, which proves the model accuracy. **Figure (5)** shows a comparison between the measured and computed water levels by the model. The model was verified with another measured set of data for discharge and water level downstream of the pump station. The results of the model showed that, the computed water level is (1.096) m which is very close to the measured value (1.10) m at discharge 84 m3/s.

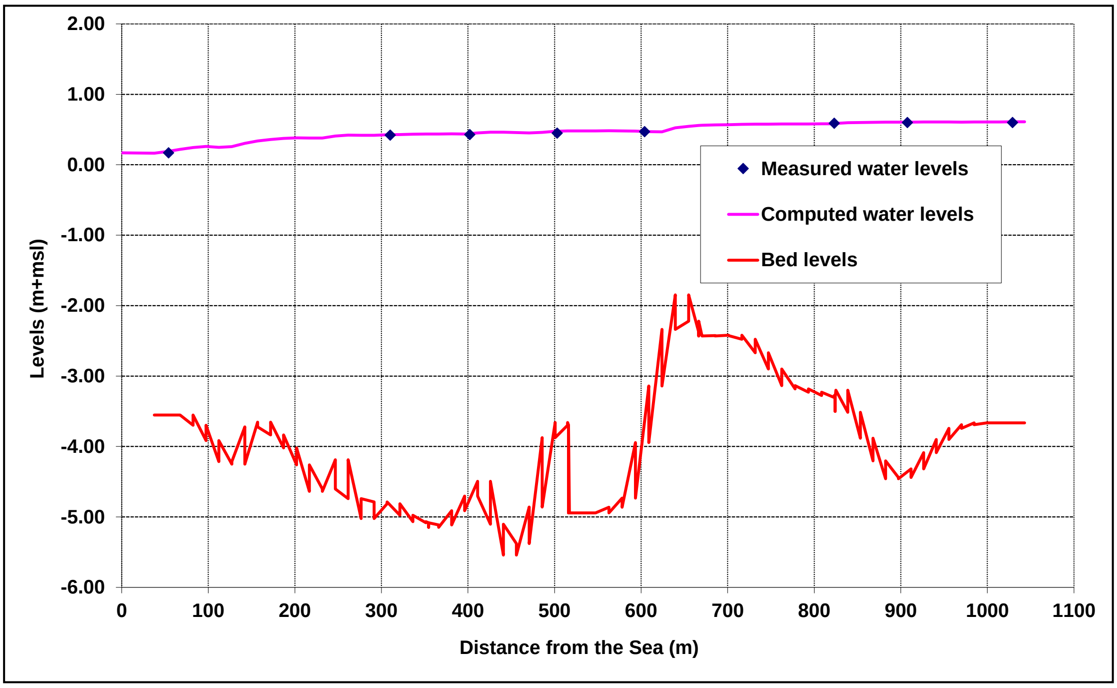

Figure (5): Measured and Computed Water Levels

4.2. Model Scenarios and Results

After calibrating the model, it was run for many scenarios to predict the water surface profiles along the canal for current conditions with the presence of bottlenecks and after dredging the canal and applying the designed cross section is shown in **Figure 6**.

Flow discharges of 100 to 130 m3/s were tested by the model for two cases before and after dredging all reaches. The flow discharge of 100 m3/s is considered the maximum discharge while 130 m3/s is the discharge at extreme events during storms. Also, variations of Sea water levels from (0.25) m to (0.55) m were considered.

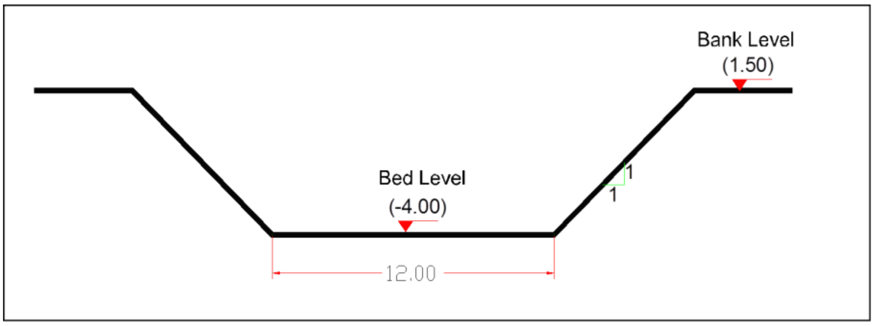

Figure (6): Design Cross-Section for the Delivery Canal

Five scenarios were tested to define the best dimensions for the canal and the priorities for dredging all reaches of the delivery canal. Table (1) presents all model tested scenarios.

Table (1): Model Scenarios Before and After Dredging the Delivery Canal

Scenario	**Canal Conditions**	**Pump discharge (m^3/s)**	**Remarks**
Scenario (1)	• Existing condition	100	Testing the efficiency of the canal at current condition
Scenario (2)	• Dredging the canals started from Sea side • Bed level is -4.0 m	100	Dredging reaches (1), then (2), then (3) and finally reach (4)
Scenario (3)	• Dredging the canal started from the pump station side • Bed level is -4.0 m	100	Firstly dredging reach (3), then reach (4), reach (2) and finally reach (1)
Scenario (4)	• Dredging all Reaches • Bed level is -4.0 m • Increasing Sea water level	100	Increasing Sea water level to level (0.55) m
Scenario (5)	• Dredging all Reaches • Bed level is -4.0 m	130	Predicting water level at extreme events during storms

4.2.1. Scenario (1): Testing the hydraulic efficiency of the delivery canal

This scenario was tested to define the hydraulic efficiency of the delivery canal within the existing conditions prior to any dredging. There are many bottlenecks along the canal reaches. The results of this scenario was used as a base to compare to results of the other scenarios.

The maximum discharge of 100 m3/s for El-Max pump stations was tested by the model at a corresponding Sea water level of (0.25) mean Sea level. **Figure (7)** shows the water levels along the delivery canal. It is clear from the model results that water level just downstream of the stations reached (1.36) m, which is exceeding the design water level by 61 cm. The results of the model also showed that the current capacity of the canals at the design water level of (0.75) m is about 61 m3/s which is about 61% of the design discharge and about 47% of the emergency discharge. When the tested discharge was increased to 105 m3/s, the water level reached to (1.40) m and led to the pump stations to be flooded and caused the stations to stop, therefore, dredging the canal is a must to remove all bottlenecks to decrease water levels to the safe water levels.

Two alternatives have been tested by the model for selecting the starting point and prioritizing canal reaches for dredging. In the first alternative, dredging begins from the Sea side at kilometer zero and ends at El-Max pumping stations at kilometer 1.010. While in the second alternative, the dredging starts from the downstream of the stations at kilometer 1.010 and ends at kilometer zero at the Sea, and the following are the scenarios results.

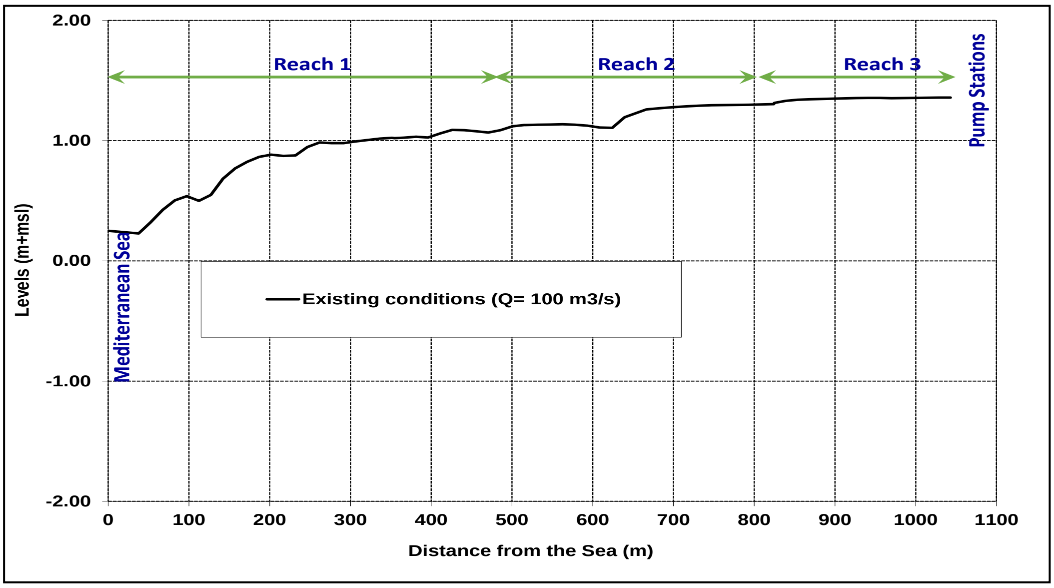

Figure (7): Water Levels Along the Left Canal - Existing Conditions

4.2.2. Scenario (2): Testing dredging the canals when starting from the sea side

In this step, alternative 1 for dredging the delivery canal has been applied by the model. The canal is dredged starting from the Mediterranean Sea side in the direction of the pump stations. Firstly, dredging started by reach (1), then reach (2), after that reach (3) and ended by reach (4). Dredging has been implemented in the model based on the cross-section dimensions shown in **Figure (6)**. The results of the model based on the priorities of the reaches dredging were as follows:

Firstly: dredging reach (1)

In this step, reach (1) with a length of 475 m has been dredged beginning from Sea side. Comparing the designed cross section with the existing one as shown in **Figure (2)**, an amount of 8800 m3 dredging has to be removed from this reach. The results showed that, water level downstream of El-Max pumping station decreased from level (1.36) m before dredging to the level of (1.00) m after dredging the first reach. Water level has dropped by 36 cm from the current situation which is higher than the design one by 25 cm as shown in **Figure (8).**

Secondly: dredging reach (2)

Dredging reach (2) was assumed, in addition to reach (1), comparing the designed cross section with the existing one, an amount of 10709 m3 dredging has to be removed from reach (2). After dredging the two reaches, the maximum discharge of 100 m3/s was tested by the model and the results are shown in **Figure (8)**. Water level downstream of the station reached to (0.85) m which is higher than the design one by 10 cm.

Thirdly: dredging reach (3)

In this step, reach (3) has to be dredged in addition to reaches (2) and (1). To reach to the designed cross-section, an amount of 7711 m3 dredging has to be removed from reach (3). After dredging the three reaches, the maximum discharge of 100 m3/s was tested and the results showed that after dredging, the water level downstream of the stations was not affected by any sensible value that reached (0.85) m as in the previous case as shown in **Figure (8)**.

Finally: dredging reach (4)

In this step, reach (4) has to be dredged in addition to reaches (1), (2) and (3). To reach to the designed cross-section, an amount of 4484 m3 dredging has to be removed from reach (4). After dredging all reaches, the maximum discharge of 100 m3/s was tested by the model and the results showed that the water level downstream of the stations has decreased by 1 cm from the previous case to reach to a level of (0.84) m, as shown in **Figure (8)**.

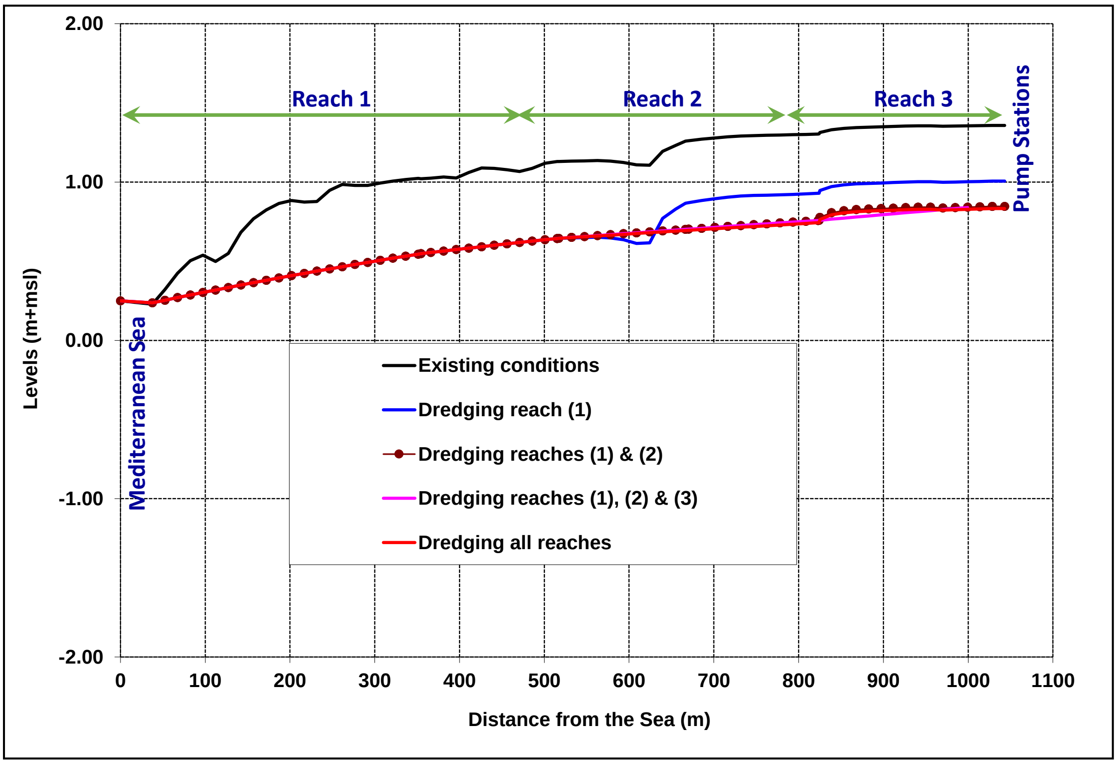

Figure (8): Water Levels along the Left Canal, before and after Dredging

4.2.3. Scenario (3): Dredging started from downstream of el-max pump stations

In this step alternative 2 for dredging the canal has been applied by the model. Dredging the delivery canal started from the pump stations side towards the direction of the Sea. Firstly dredging started by reach (3), secondly reach (4), after that reach (2) and finally reach (1). Dredging has been implemented in the model by using the dimensions of the design cross-section shown in **Figure (6)** and here are the results of the model based on the priorities of reaches dredging:

Firstly: dredging reach (3)

Dredging reach (3) in accordance with the proposed cross-section, **Figure (6)** and the volume of dredging is 7711 m3. After dredging, the maximum discharge of 100 m3/s was tested by the model and **Figure (9)** illustrates the water levels along the right and left canals. It is clear from the Figure that the water level after the dredging was not affected.

Secondly: dredging reach (4)

In this simulation, reach (4) was dredged in addition to reach (3). **Figure (9)** illustrates water levels along the canals. It is clear from the Figure that the water level downstream of the station reached level (1.345) m (i.e. it decreased by 1.5 cm only).

Thirdly: dredging reach (2)

In this simulation, reach (2) has been dredged in addition to reach (3) and reach (4). After dredging the three reaches, the maximum discharge of 100 m3/s was tested by the model, and water levels after dredging were compared to the levels before dredging as shown in **Figure (9)**. It is clear that the water level behind the station reached a level of (1.27) m, which is less than the level before dredging by 9 cm.

Finally: dredging reach (1)

In this simulation, reach (1) has been dredged in addition to reach (3), reach (4) and reach (2). To reach to the designed cross-section, an amount of dredging of 4484 m3 has to be removed from reach (3). After dredging all reaches, the maximum discharge of 100 m3/s was tested by the model and the results showed that the water level downstream of the stations dropped to a level of (0.84) m compared with (1.36) m before dredging as showed in **Figure (9).**

4.2.4. Scenario (4): Increasing sea water level

In this simulation, it has been taking into account the change in the Mediterranean Sea water level when it reaches the maximum water level, which is (0.55) m and dredging all reaches to the level of (-4.00) m, and running the model by considering the maximum discharge of 100 m3/s. The results of the model are shown in **Figure (10)**. The results showed that the water level downstream of the station reached to a level of (1.03) m compared to level (0.84) m when the Sea water level was (0.25) m.

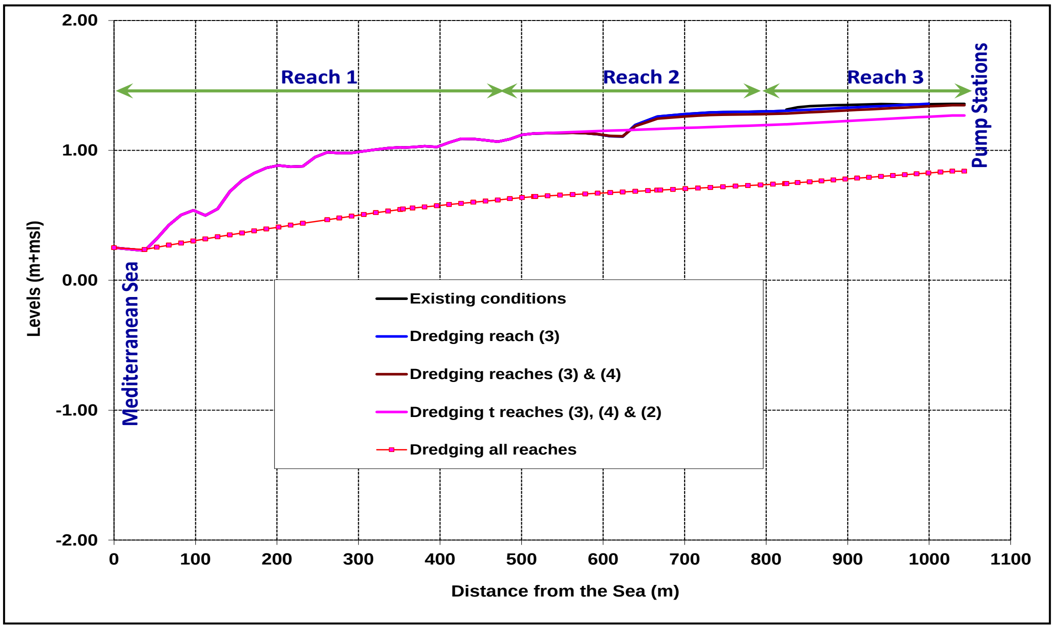

Figure (9): Water Levels along the Delivery Canal, before and after Dredging

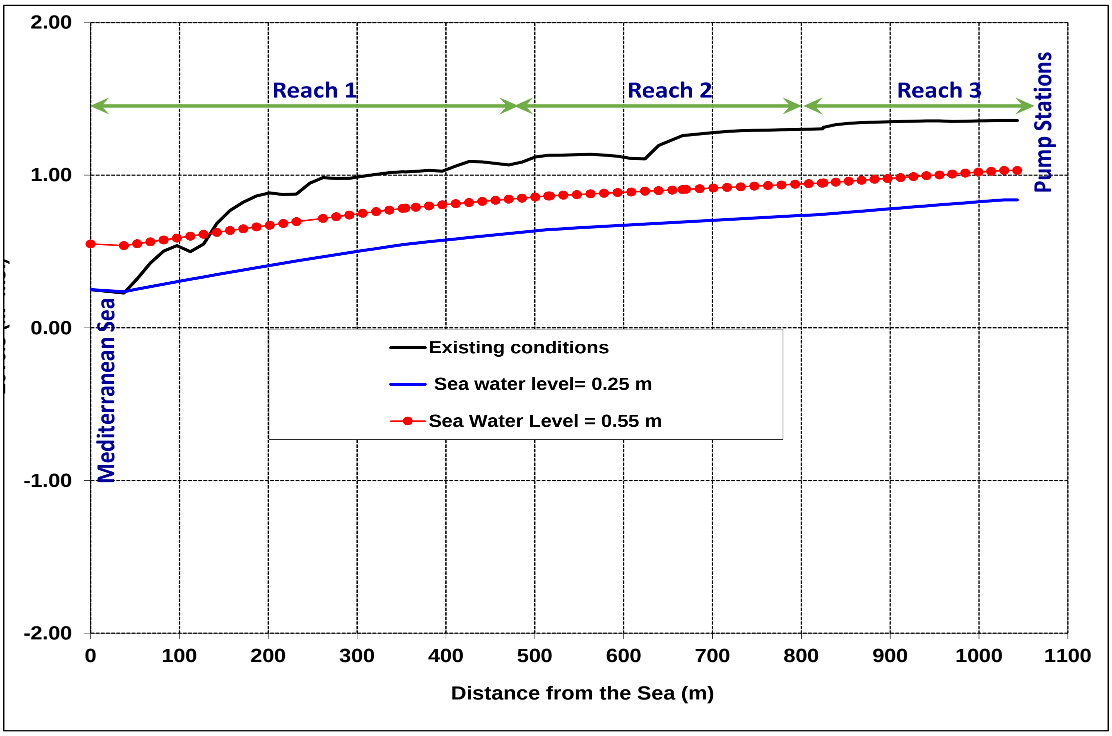

Figure (10): Water Levels after Dredging All Delivery Canal Reaches

4.2.5. Scenario (5): Extreme events during storms

During the winter season and at the extreme events (Nawat), the required discharge which is needed to reduce the drain and lake water level could reach 130 m3/s. In this scenario, the extreme discharge of 130 m3/s was tested by the model and the water levels were compared with the water levels corresponding to the discharge of 100 m3/s as shown in **Figure (11)**. The water level downstream of the station reached to level (1.15) m compared to (0.84) m when the Sea water level was (0.25) m and when Sea level increased to the level of (0.55) m, the model results showed that the water level downstream of the station reached to level (1.30) m.

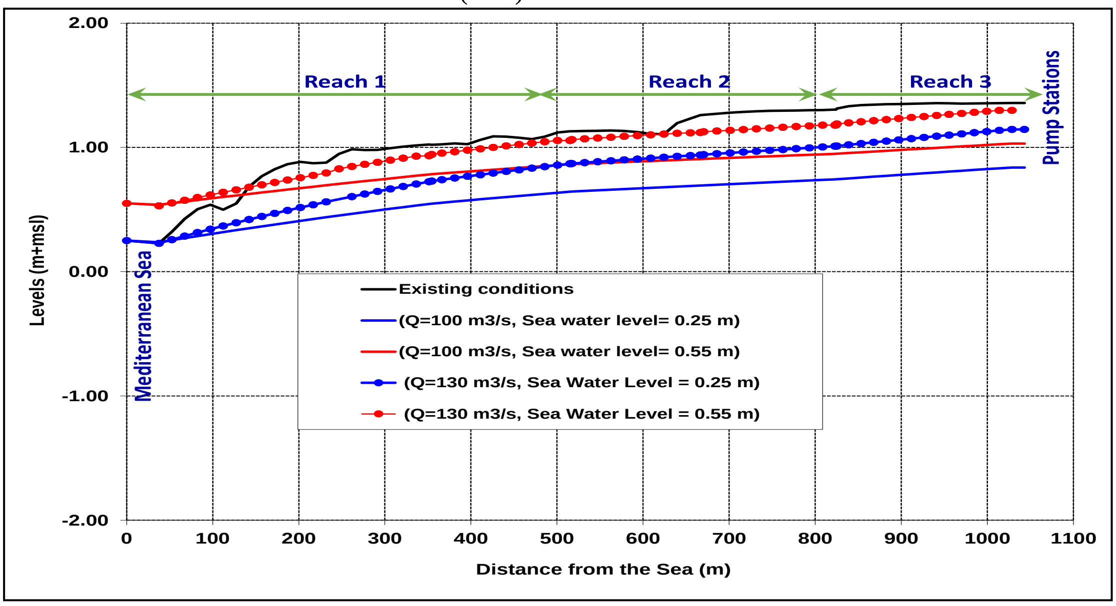

Figure (11): Water Levels after Dredging All Delivery Canal Reaches

4.2.6. Discussion of dredging reaches priorities

When dredging the delivery canal reaches, starting dredging from the Sea side, the change in water levels has been significantly affected more than starting from the downstream of the pump stations. For example, after dredging reach (1) the water level downstream of the stations decreased by 36 cm. When dredging reach (2) in addition to reach (1), the water level reached to (0.85) m. After dredging reaches (1), then (2), then (3) and finally (4) the water level decreased to (0.84) m. **Table (2)** shows the amount of dredging and water levels behind the station during the stages of dredging.

Table (2): Dredging and Water Levels Starting from Sea Side

Stage	Dredging Priorities for Reaches	Volume of Dredging (m3)	Level Downstream of Pump Stations (m)	
			After Dredging	Before Dredging
1	(1)	8800	(1.00)	(1.36)
2	(1) and (2)	19509	(0.85)	(1.36)
3	(1), (2) and (3)	27220	(0.85)	(1.36)
4	(1), (2), (3) and (4)	31704	(0.84)	(1.36)

When starting dredging of the reaches from the downstream of the stations, after dredging reach (3), water level downstream of the station was not significantly affected and remained constant at (1.36) m, and when dredging reach (4) in addition to the reach (3), the water level dropped by 1.5 cm and when dredging reach (3), then (4), and then (2), the water level decreased by 7.5 cm. When dredging reach (1) in addition to the foregoing, the water level reached (0.84) m. Table (3) shows volume of dredging and water level downstream of the stations, starting dredging from pump stations side.

Table (3): Dredging and Water Level starting from Pump Stations Side

Stage	Dredging Priorities for Reaches	Volume of Dredging (m3)	Level Downstream of Pump Station (m)	
			After Dredging	Before Dredging
1	(3)	4484	(1.360)	(1.36)
2	(3), and (4)	12197	(1.345)	(1.36)
3	(3), (4) and (2)	22904	(1.270)	(1.36)
4	(3), (4), (2) and (1)	31704	(0.840)	(1.36)

5. CONCLUSIONS AND RECOMMENDATIONS

The following set of conclusions are based on the field investigation, hydrographic survey and modeling work for El Max pump stations delivery canal:

- At the current situation for the delivery canal, the water level downstream of El-Max pump station reached to level (1.36) m at the maximum discharge while the designed value is (0.75) m and reached to level (1.43) m at discharge 105 m3/s when the sea level rise to (0.25) m. The discharge corresponding to the designed water level (0.75 m) is about 61 m3/s.
- The model showed that, there is no need for dredging reaches (3) and (4), as their effect on decreasing water level is very minimal.
- The model succeeded in prioritizing dredging for all the reaches of the delivery canal.

Removal for all bottlenecks and dredging the bed of the canals reaches at a level of (-4.00) m and width of 12.0 m and side slopes 1:1, the canal capacity will be increased. Therefore, problems related to increasing Lake Mariout and El-Omoum drainage will also be solved.

The study recommended that:

- To pass the design discharge and decreasing the water level in El-Omoum drain and lake Mariout, reaches (1) and (2) must be dredged at a bottom level of (-4.00) m and a bed width of 12.00 m and side slope of 1:1.
- Removing the violation of houses located at the course of the delivery canal.
- Removing the bottlenecks and dredging should start from the Sea side.
- Dredging reaches (3) and (4) is not necessary.

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