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EVALUATION OF IMPLEMENTED MEASURES SOLVING EL-MAX PUMP STATIONS AND DRAIN MOUTH PROBLEMS, NORTHWEST COAST, EGYPT

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ABSTRACT

The mouth of the drain-reach (DR), Egypt, discharges the wastewater of the El-Umum Drain and excess water from Mariout Lake into the Mediterranean Sea through El-Max Pump Stations (MPSs). During a strong downpour in November 2015, the pumped water returned to the MPS building. A hydraulic simulation modeling was created to ascertain why this occurred, provide remedies in January and October 2016, and assess the actual implemented measures in July 2021. The investigation found that the DR was shallow, narrow, and had numerous restrictions; it was advised that these limits be lifted. Even though the dredging and bed widening did not go exactly as planned, the final water sections can transfer a maximum flow of 185 m^3/sec less than intended. Reopening the Old El-Max Pump Station by 74 m^3/sec capacity is recommended as a long-term alternative to supplement the MPSs during anticipated critical conditions.

KEYWORDS: EL-MAX Pump Station, Flood, HEC-RAS Program, Hydrographic survey, Rain storms.

تقييم الإجراءات المنفذة لحل مشاكل محطات طلمبات المكس ومصب المصرف، الساحل الشمالى الغربى، مصر

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الملخص

يقوم مصب طرد طلمبات المكس فى مصر، بتصريف المياه العادمة من مصرف العموم والمياه الزائدة من بحيرة مريوط إلى البحر الأبيض المتوسط من خلال محطات طلمبات المكس. معتبراً تغير المناخ وأثناء هطول أمطار غزيرة في نوفمبر ٢٠١٥، عادت المياه التي تم ضخها إلى مبنى محطات طلمبات المكس. تم إنشاء نموذج محاكاة هيدروليكي للتأكد من سبب حدوث ذلك، وتوفير التدخلات في يناير وأكتوبر ٢٠١٦، وتقييم التدابير الفعلية المنفذة في يوليو ٢٠٢١. وخلص التحقيق والمعاينة إلى أن طرد طلمبات المكس كان ضحلًا وضيقًا وبه العديد من العوائق؛ وقد نصحت الدراسة برفع وإزالة هذه العوائق. على الرغم من أن عملية التكريك وتوسيع عرض قاع المجرى لم تتم كما هو مخطط لها تمامًا، إلا أن قطاعات المياه العرضية النهائية يمكن أن تنقل تدفقًا بحد أقصى قدره ١٨٥ مترًا مكعبًا في الثانية أقل من المخطط. يوصى بإعادة فتح محطة ضخ المكس القديمة بقدرة ٧٤ م٣/ثانية كبديل طويل الأجل لتدعيم محطات طلمبات المكس خلال الظروف الحرجة المتوقعة.

الكلمات المفتاحية : محطة طلمبات المكس، الفيضان، برنامج HEC-RAS، المسح الهيدروجرافى، العواصف الممطرة.

1. INTRODUCTION

1.1. Preamble

The phenomenon of climate change has emerged as a primary worry for the global community. As a result, the North Coast of Egypt's coastline zone and surrounding areas experience different rainfall rates. For a considerable time, the average annual precipitation rate was roughly 200 mm/year [1]. In November 2015, one intense rainstorm lasted seven days, with approximately 227 mm of precipitation [1]. Because of the storm's increasing rainfall, drainage systems in flood states have been overloaded. Pump stations in the drainage system suffer excessive drainage water lifting, particularly near the coast.

1.2. The El-Max coastal zone

Approximately 70% of the country's economic and industrial activity takes place in the Nile Delta (ND) region [2]. Alexandria, the country's second-biggest metropolis, accounts for over 40% of Egypt's total industrial output. El-Max Bay, depicted in **Fig. 1**, is a sizable coastal embayment situated to the west of Alexandria. It lies between Alexandria Harbor (Western Harbor) and El-Agami headland to the east and west, respectively, and stretches for approximately 15 km from the coast to a depth line of approximately 15 meters. Its coordinates are longitude 29° 45\ and 29° 54\ E and latitude 31° 07\ and 31° 15\ N. The average depth of the bay is 10 meters. It has a volume of 0.19 km^3 and a surface area of roughly 19.4 km^2 [3]. The bay serves as both a recreational area and a significant fishing field. It encompasses Alexandria Harbor (Western Harbor) as well as El-Dekhaila Harbor. It gets a lot of wastewaters (7 million m^3/year) from the El-Umum Drain (UD) industrial outfalls directly as well as indirectly through MPSs from Lake Mariout (LM) [4]. El-Max Bay's shoreline is considered rocky, with the embayment surrounded by small, sandy beaches. LM is a Salt Lake that is located at 29º 51\ 00\\ E to 29º 56\ 15\\ E and 31º 04\ 15\\ N to 31º 10\ 45\\ N. It is regarded as a significant coastal lake that forms the southern boundary of Alexandria city. It has traditionally served as Egypt's primary source of fish production. Around 700 km^2 made up LM's initial territory in 1801 [5]. From 32,160 feddan in 1950 to 16,240 feddan in 1981, reclamation for agriculture has taken away 48% of its surface [7]. Due to the construction of roadways and the annual Nile flood that was halted after the Aswan High Dam (AHD) was erected, the lake's surface is today less than 65 km^2 [8], and its depth ranges from 1.0 to 3.0 m [5]. The sources of water for the lake are the UD, which supplies an average of 6.7 million m^3/year for agriculture [9], and the El-Qalaa Drain, which supplies 920,000 m^3/year of mixed effluent [10]. Since the lake is not connected to the sea, it may experience anoxic conditions in wide regions. This could lead to the production of sulfurous and hydrogen-smelling gases, rendering the area unsuitable for human habitation. Due to the absence of interchange with the open sea, the lake functions as an evaporation pan, which causes organic and chemical contaminants to accumulate [7]. As a result of the lake's lack of interaction with the ocean, organic and chemical pollutants build up in it like an evaporation pan [7]. UD is a 45.8 km long canal with a bottom width of 20 m and an average depth of 3.4 m. MPS maintains the major West Nile Delta drain, or UD, at a depth of 2.6 to 2.9 meters below Mean Sea Level (MSL). The station's equipment was installed and delivered by a Japanese firm in the 1960s, and Voith Hydro later replaced it. The new propeller pumps' entire construction was composed of non-corrosive materials with a 45° angle and a 2 m runner diameter [11]. 1898 saw the construction of the former El-Max Pump Station [1].

1.3. The study area

The study area's general layout is depicted in **Fig. 1**. As seen in **Fig. 1** and **Fig. 2**, the DR of the MPS is a mouth at El-Max Bay on the Mediterranean Sea. It is situated 4.400 km west of Alexandria Harbor (Western Harbor), 4.300 km east of El-Dekhaila Harbor west of Nile Delta roughly, and 60.4 km west of Rosetta Nile Branch. Its coordinates are 29º 50\ 3.82\\ E and 31º 9\ 5.09\\ N [1]. The Egyptian Public Authority for Drainage Projects (EPADP) is in charge of overseeing the DR.

1.4. Problem description and objectives

During the strong rainstorm that struck the Nile Delta in November 2015, the drainage system of the agricultural areas and urban centers was overworked owing to flooding. As a result, the primary issue arose when the MPS attempted to operate at full capacity, pumping a significant volume of drainage water back into the MPS building. This study intends to analyze the effectiveness of measures put in place in 2021 to address the issues, as well as the primary causes of the incident that occurred at the DR and its mouth downstream of MPS in November 2015. The goals can be met by using data from field measurements of hydrographic surveys, sea level variation, waves, and drain parameters; following that, contour maps and data analysis can be performed; finally, a hydraulic simulation model can be created by using the HEC-RAS Program [12] to verify the permanent measures that have been implemented.

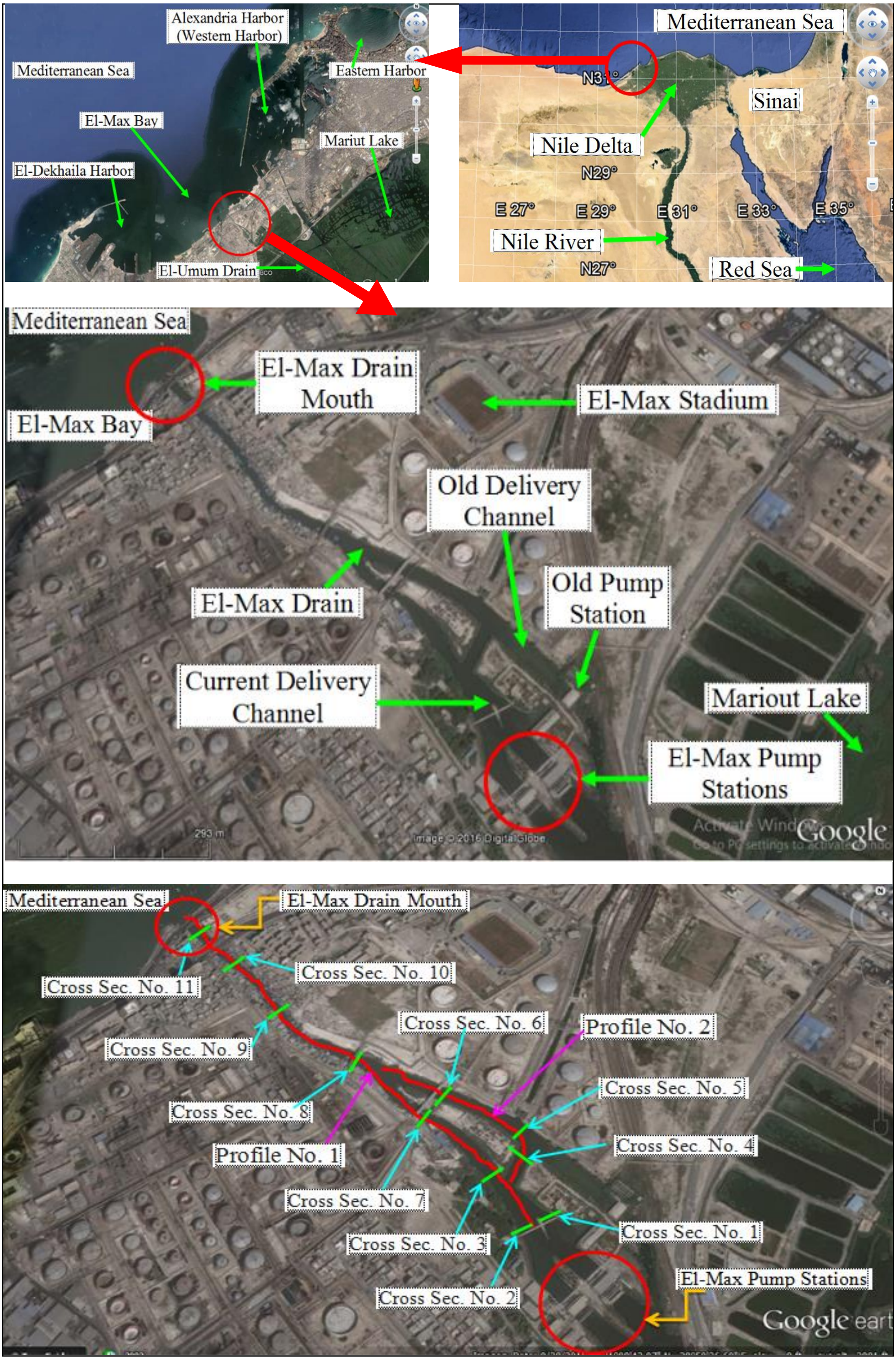


Fig. 1. Google Earth satellite image showing the general layout of El-Max Pump Stations and hydrographic survey profiles of the drain mouth on the Mediterranean Sea on 6th January 2016 [1].

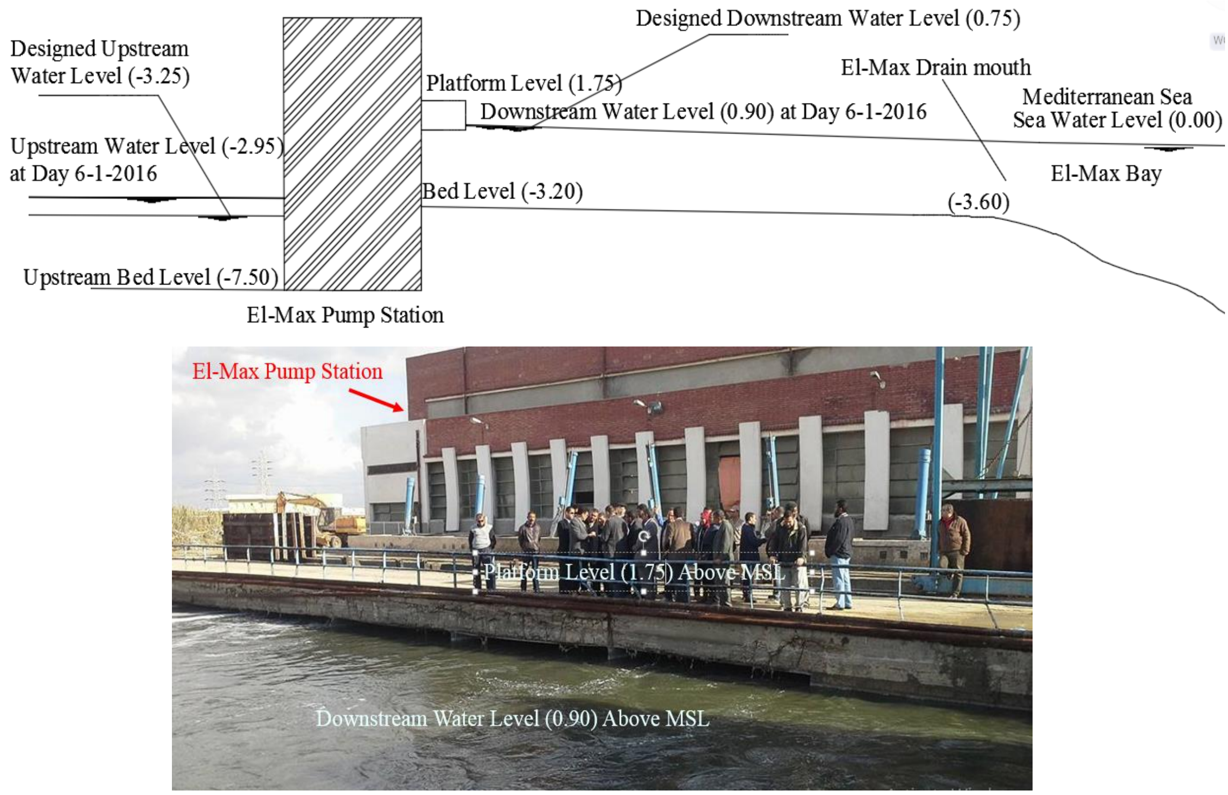


Fig. 2. Parameters schematic diagram, the platform just downstream of El-Max Pump Stations and the Drin Reach mouth on 6th January 2016 [1].

2. MATERIALS AND METHODS

2.1. Methodology

To achieve the study objectives, the following activities have been combined to evaluate the operation problem of the MPS, seek solutions, and evaluate its implementation in 2021.

- The compilation of area prior research, as well as fieldwork including hydrographic survey measures, sea level variations in Rosetta City in 2015, embankment levels downstream MPS, and wave measurements. These measured profiles were then used to create a contour map.
- Data and drain parameter analysis has been completed, and a simulation hydraulic model has been created by using the HEC-RAS Program to estimate the flow in the DR under all scenarios.

The US Army Corps of Engineers' Hydrologic Engineering Center (HEC) developed the HEC-RAS program, a computer application for the River Analysis System (RAS). This software facilitates the computation of both steady and unsteady flow river hydraulics in one dimension for an entire network of man-made and natural channels. It uses the standard step method to solve the energy equation to compute the water surface profiles from one cross-section to the next.

2.2. Data collection

The Coastal Research Institute of Egypt (CoRI) conducts an extensive program each year to collect coastal data for the ND and track any changes to the ND shore. The Mechanical and Electrical Authority (MEA) of MPS and the EPADP, as well as the local fisherman, were interviewed for the survey to hear about their concerns and recommendations. On January 6, 2016, a field study encompassing the drain up to its mouth on the Mediterranean Sea was conducted [1]. Eleven cross-sectional and four longitudinal marine profiles of the drain mouth have been used to collect field data on water depths and locations; these profiles are displayed in **Fig. 1**. Moreover, comprehensive field hydrographic studies covering 102 profiles at ten-meter intervals were conducted from October 10 to 13, 2016, and from July 1 to 3, 2021. The information is clarified as follows:

2.2.1. El-Max Pump Stations and their Drain-reach Parameters

About 81 m^3/sec is the average discharge of MPS that is transported to El-Max Bay in the Mediterranean Sea [13]. **Fig. 2** [1] illustrates the intended suction and delivery water levels, which are (-3.25) below MSL and (+0.75) above MSL, respectively. According to [13], the MPSs have six pump units with a capacity of 14.5 m^3/sec and an additional six pump units with a capacity of 12.5 m^3/sec. **Fig. 2** illustrates that the platform level at the MPS delivery side is (+1.75) above MSL. On January 6, the water level in the drain directly at the mouth of the drain is (+0.35) above MSL, whereas the water level upstream in the DR immediately downstream of MPS is (+0.90) above MSL. From MPS to the mouth, the DR stretches for approximately 1.0 kilometers. **Fig. 3** shows the variation in embankment levels along its path, which range from (+1.75) immediately downstream MPS and (+3.00) just downstream the drain outlet to (+4.00) to (+8.00).

Fig. 3. The DR's embankments, fishermen's nests, tethered boats, and oil company bridges on January 6, 2016.

2.2.2. Sea level data

When building harbors, designing protective works, and identifying shorelines, information about sea level changes is crucial. In coastal areas, they are employed in the estimation of coastal flooding water. When researching coastal projects, tide and ebb statistics are crucial, particularly when examining the locations where the sea and estuaries or drain mouths overlap. The typical tidal range is forty centimeters [14]. The observed daily variations in sea level at Rosetta City between January 2015 and January 2016 were based on their explanation of how the water surface level changes over time.

2.2.3. Marine Wave Data

The primary hydrodynamic forces are responsible for causing and generating the marine currents that transport sediment, which are thought to be marine waves. As a result, mouths are drained by erosion in certain locations and accretion in others along the shore. Long-shore currents caused by marine waves are very significant for the analysis of inshore operations. Beach erosion is caused by the ongoing action of waves and currents when there is no sediment supply to the coast [15]. In 1994 and 2004, the InterOcean S4DW directional wave-current meter device (S4DW) was used to measure the wave climatic data. This device was placed in front of the Idku Region [15] and the Dekhaila Harbor's navigation channel at a depth of roughly 12 meters [1]. The acquired data were statistically analyzed to determine the wave roses or the proportion of occurrence of specific wave heights from a given direction.

2.2.4. Shore-line data

One aspect of the dynamic coastal zone that is changing quickly is the shoreline. For coastal zone management, its movement as a result of erosion and accretion is a crucial concern [15]. For coastal scientists, oceanographers, and engineers, analyzing changes in the shoreline is essential to their research [16]. Sea-level rise assessment, numerical model calibration and verification, and coastal protection design are all aided by the shoreline data. Coastline changes can be examined using field data measurements or satellite pictures to determine the maximum annual retreat and the coastline change of the study region.

2.2.5. Hydrographic Marine Survey Data

The Coastal Research Institute (CoRI) started a program of surveying beach profiles in 1971. The profile lines run perpendicular to the coast and reach a maximum distance of 1200 meters from the fixed baseline, or roughly 6 meters below the surface of the water. Local fixed benchmarks with established elevations are used to calibrate the beach levels and water soundings to the MSL datum. The hydrographic profile surveys have been completed. During the marine survey, the MSL portion of this data was updated. The survey was conducted on January 6, 2016, October 10 to 13, 2016, and July 1 to 3, 2021.

3. RESULTS ANALYSIS AND DISCUSSIONS

3.1. The Drain-reach and El-Max Pump Stations

Numerous obstacles can be found along the DR's path [1]. These include:

- Several bridges on the DR are designated for transporting pipes for oil companies located west of the DR, and their foundations are located directly on the path and edges of the channel, as shown in **Fig. 3**.
- As seen in **Fig. 4A**, steel piles packed with plain concrete at the opening of the Mediterranean Sea cause the drain water level to rise.
- Restrictions are due to the massive reinforced concrete pier at the mouth that caused the channel throttle, as shown in **Fig. 4B**.

- Restrictions along DR owing to concrete platforms, fishermen's nests, and anchored boats induced the channel throttle, as shown in **Fig. 4C** and **Fig. 4D**.
- The bed width is narrow and shallow enough to convey the urgently pumped drainage water within the heavy rainstorm to the sea, with a width of less than 18.0 m.

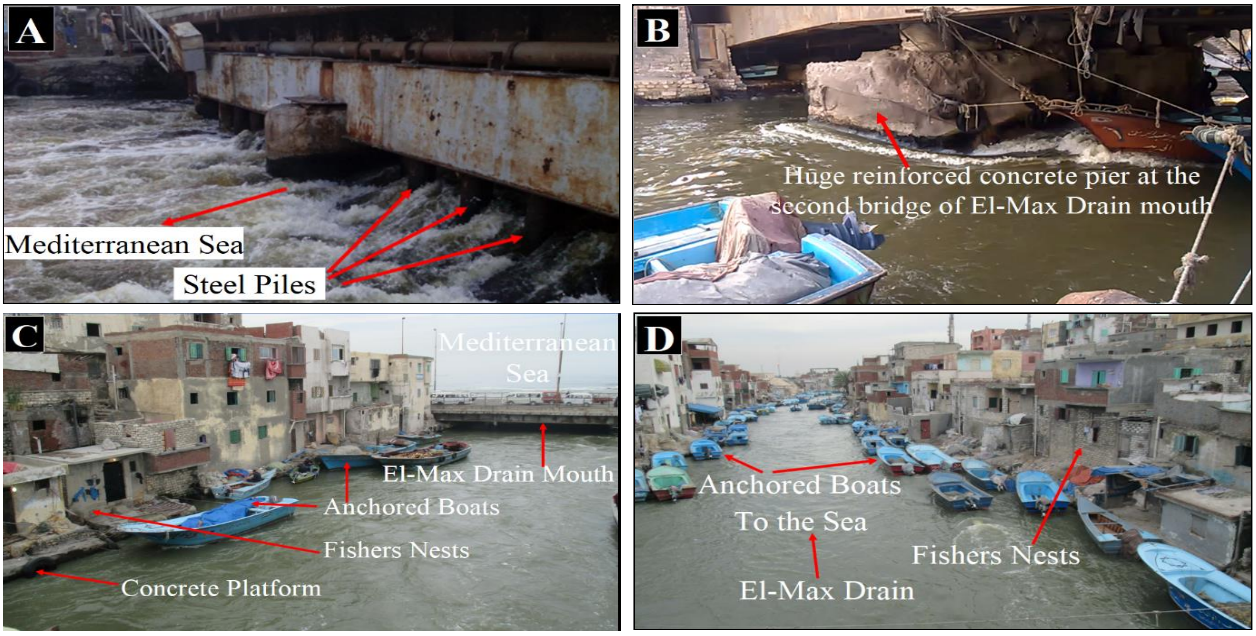


Fig. 4. Restrictions along the El-Max Drain path: (A) water level rising caused by steel piles filled with plain concrete at the mouth; (B) channel throttle caused by a large reinforced concrete pier at the second bridge at the mouth; (C) and (D) channel throttle caused by anchored boats, concrete platforms, and fisherman's nests on January 6, 2016 [1].

3.2. Sea level variation

Fig. 5 displays the daily variations in sea level recorded by CoRI [15, 17] in Rosetta City between January 2015 and January 2016. The data has been examined and analyzed. As a result, the analysis's findings indicated that, overall, the sea level was roughly +0.40 m, with November 2015 marking the highest level at +0.76 m above MSL and February 2015 marking the lowest level, which is estimated to have been 0.05 m below zero sea level. The coast of Egypt experiences half-daily tides in general.

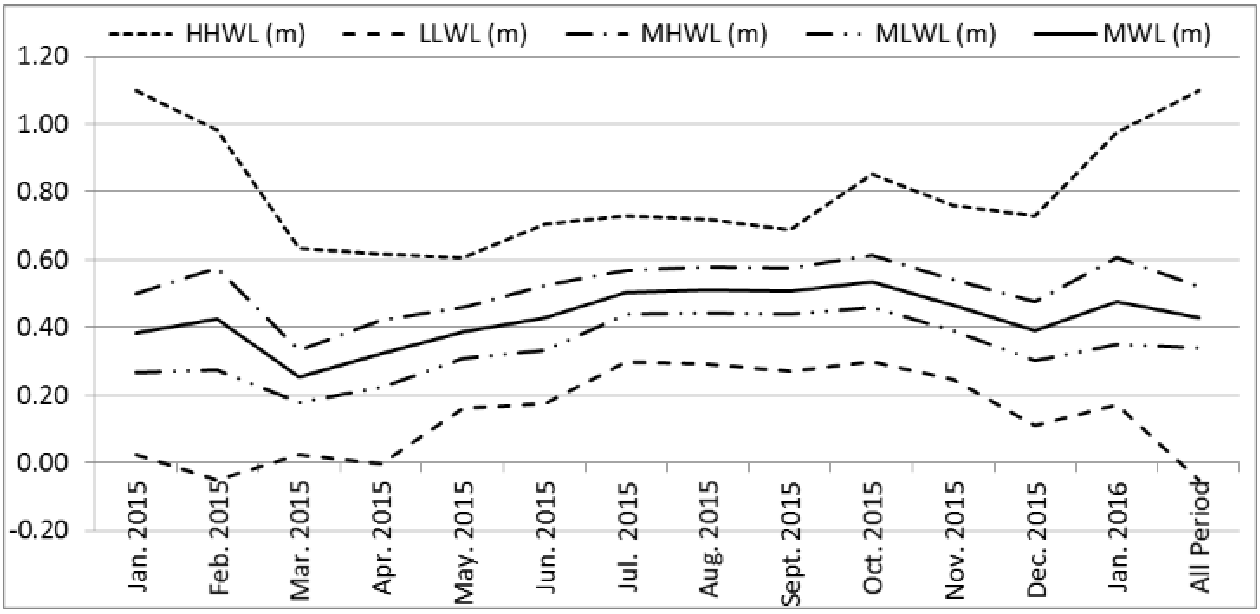


Fig. 5. The daily sea level changes that were recorded at Rosetta City between January 2015 and 2016 [15, 17].

3.3. Marine waves

According to [8], 22.5o NW is the research area's primary wind direction. About 3.75 m/sec is the wind speed there [8]. The wave's direction and characteristics have been verified through an analysis of the wave's data. Accordingly, the examination of these data has demonstrated that in 1994, the peak wave period was around 7.0 seconds, and the greatest wave height was approximately 6.85 meters [1]. Thus, because of their extended length, especially during the winter, the dominating wave approach from the WNW and W, as depicted in **Fig. 6A**, is accountable for producing the eastward-flowing long-shore current and morphological modifications [1]. Moreover, the peak wave period in 2004 was approximately 6.5 seconds, and the maximum wave height was almost 4.5 meters [15]. Thus, **Fig. 6B** shows the dominating wave approach from the WNW and NW.

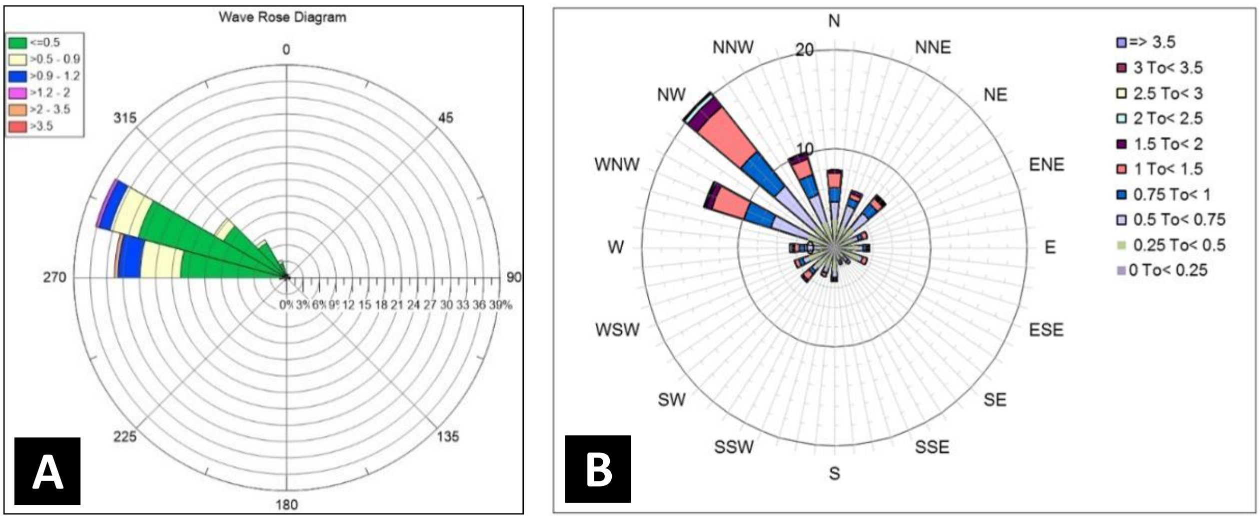


Fig. 6. Rose waves of (A), El-Dekhaila Harbor, 1994 and (B), Idku Region, 2004 [1, 15].

3.4. Shoreline

The coastline's alterations over time reveal the balance of the shoreline as well as how it responds to erosion and accretion. On January 6, 2016, the flow velocity of drainage water was 3.0 m/sec at the drain mouth, which was sufficient to flush the silt collected in the drain mouth. The drain mouth was perpendicular to the beach. The shoreline of El-Max Bay is rocky and is surrounded by narrow sandy beaches by an embayment [5]. El-Max Bay's shoreline is therefore seen as stable [1].

3.5. Hydrographic Survey Profiles, Model development and scenarios

Beach profiles serve as useful indicators of the evolution and behavior of shoreline changes. The stability of the beach profile is influenced by several factors. These are the type of bottom profile, over-nourished, under-nourished, or in equilibrium, wave characteristics, sediment characteristics in the breaker zone, on the shore, and offshore zone, and various currents like the tide and long-shore current [1].

3.5.1. on 6th January 2016

On January 6, 2016, the water level was (+0.90) above MSL at cross-section 1 at the MPS and (+0.40) above MSL at cross-section 11 near the entrance of the drain reach. The profiles of the marines are:

1) *Longitudinal profile 1;* This is displayed in **Fig. 7** near the center sector of the left branch of the DR along the approximately 940 m-long path that leads from the MPS to the mouth of the Mediterranean Sea. The bed level is between 1.52 m and 5.57 m below MSL, while the water depth varies from 2.31 m to 6.25 m. The bed level varies from 1.57 m to 4.11 m below MSL during the final 360 m of the route, and from 1.52 m to 3.86 m below MSL for the first 390 m. In addition, the bed level for the intermediate 190 m long varies from 3.51 m to 5.57 m below MSL. Consequently, dredging is required for the first 390 m and the last 360 m [1].

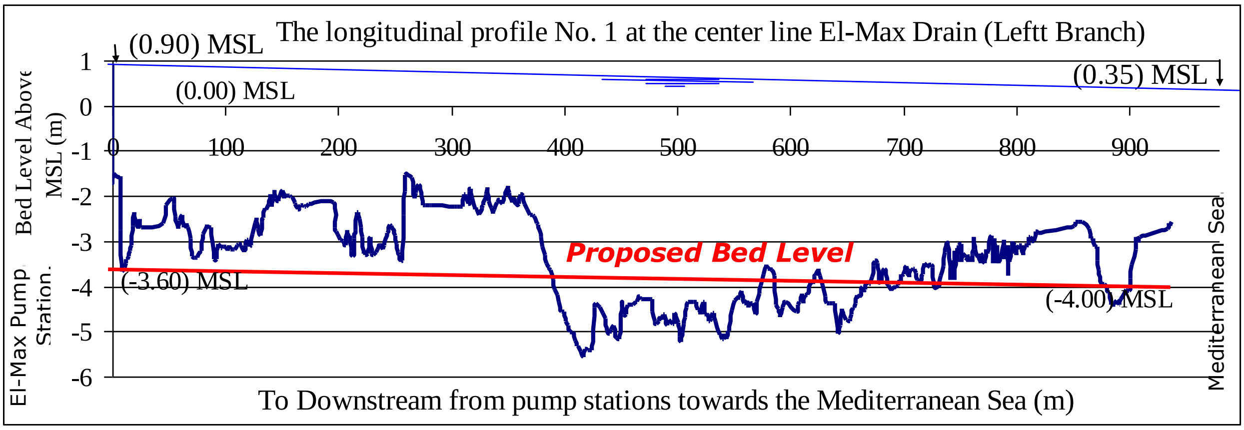


Fig. 7. Longitudinal profile 1 at the center line of the drain-reach (left branch) on 6th January 2016 [1].

2) *Cross-section 1;* **Fig. 8A** displays it. The maximum and average water depths (MAWD) of the DR are 3.51 and 2.91 meters, respectively, at the 960-meter upstream mouth

(UM). The water surface width (WSW) of the DR is around 20 meters. The MSL is 0.90 meters below the water surface level (WSL).

3) *Cross-section 2* is displayed at 960 m UM in **Fig. 8B**. The DR's WSW measures around 31.0 m, while the MAWD is 4.62 m and 3.73 m respectively. The WSL is 0.90 m above MSL.

4) *Cross-section 3* is displayed at 830 m UM in **Fig. 8C**. The DR's WSW is roughly 18 meters, while the MAWD is 4.48 m and 3.72 m respectively. The WSL is 0.82 m above MSL.

5) *Cross-section 4* is displayed in **Fig. 8D** at 865 m UM. The DR's WSW is roughly 23.8 m and the MAWD is 4.92 m and 3.89 m respectively. The WSL is 0.83 m above MSL.

6) *Cross-section 5* is displayed at 850 m UM in **Fig. 8E**. The DR's WSW is about 35.0 m and the MAWD is 7.3 m and 5.08 m respectively. The WSL is 0.82 above MSL.

7) *Cross-section 6* is displayed at 680 m UM in **Fig. 8F**. The DR's WSW is around 23.5 m, while the MAWD is 4.31 m and 3.55 m respectively. The WSL is 0.74 m above MSL.

8) *Cross-section 7* is displayed at 690 m UM in **Fig. 8G**. The DR's WSW is around 18 m, while the MAWD is 4.62 m and 4.0 m respectively. WSL is 0.75 m above MSL.

9) *Cross-section 8* is displayed at 500 m UM in **Fig. 8H**. The DR's WSW measures roughly 22.0 m, while the MAWD is 4.37 m and 3.58 m respectively. The WSL is 0.65 above MSL.

10) *Cross-section 9* is displayed at 380 m UM in **Fig. 8I**. The DR's WSW measures roughly 20.0 m, while the MAWD is 5.57 m and 4.85 m respectively. The WSL is 0.59 m above MSL.

11) *Cross-section 10* is displayed at 200 m UM in **Fig. 8J**. The DR's WSW measures around 20.0 m, while the MAWD is 4.57 m and 4.1 m respectively. The WSL is 0.50 m above MSL.

12) *Cross-section 11* is displayed at 30 m UM in **Fig. 8K**. The DR's WSW is around 19.25 m, while the MAWD is 4.28 m and 3.65 m respectively. The WSL is 0.40 m above MSL.

Consequently, utilizing spatial interpolation of the DR bed levels using the "Natural Neighbor" interpolation method in the Golden Software SURFER 13.0 computer application, a contour map was produced using measured hydrographic profiles (**Fig. 9A**).

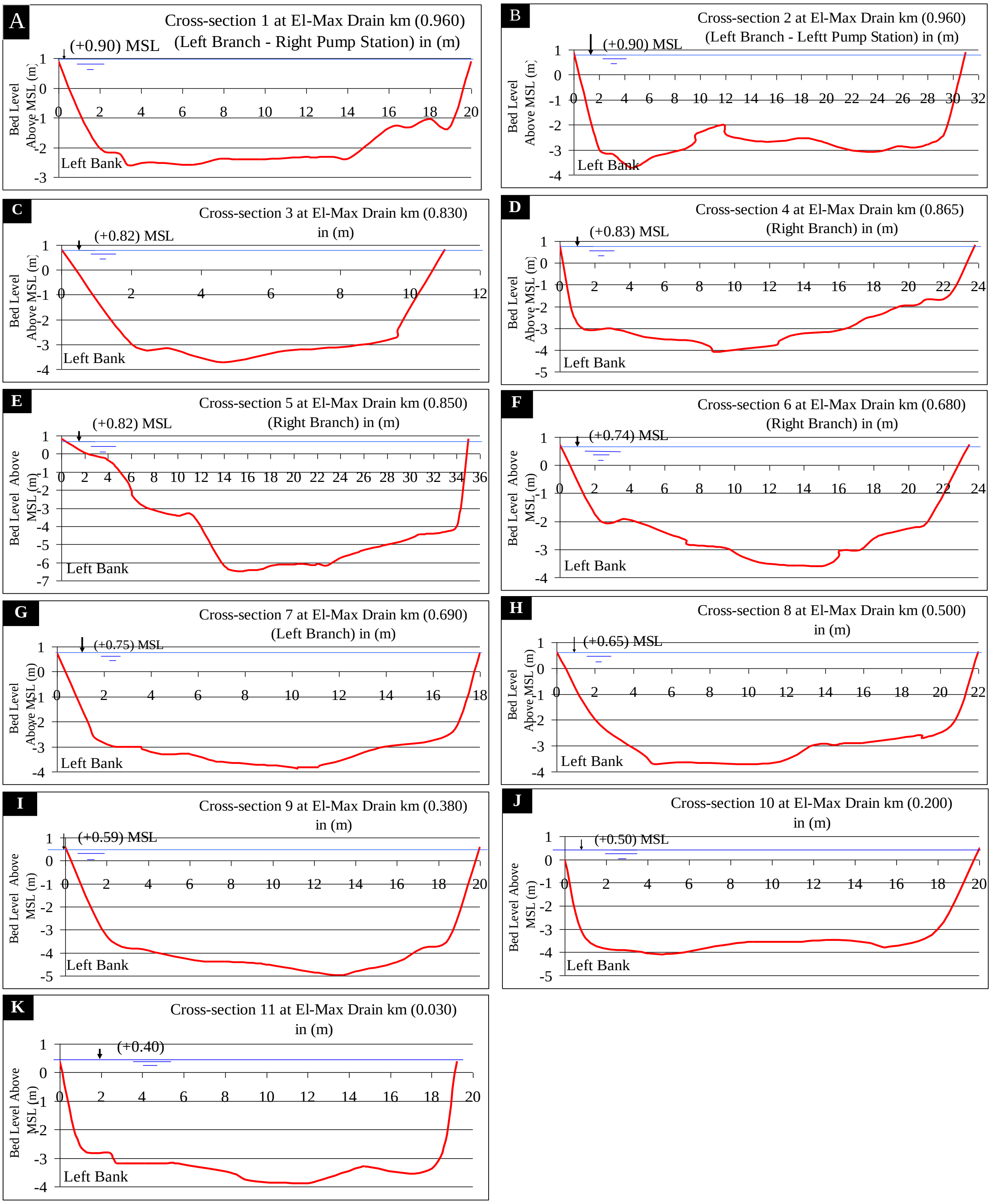


Fig. 8. Cross-sections 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 at the drain-reach on 6th January 2016 [1].

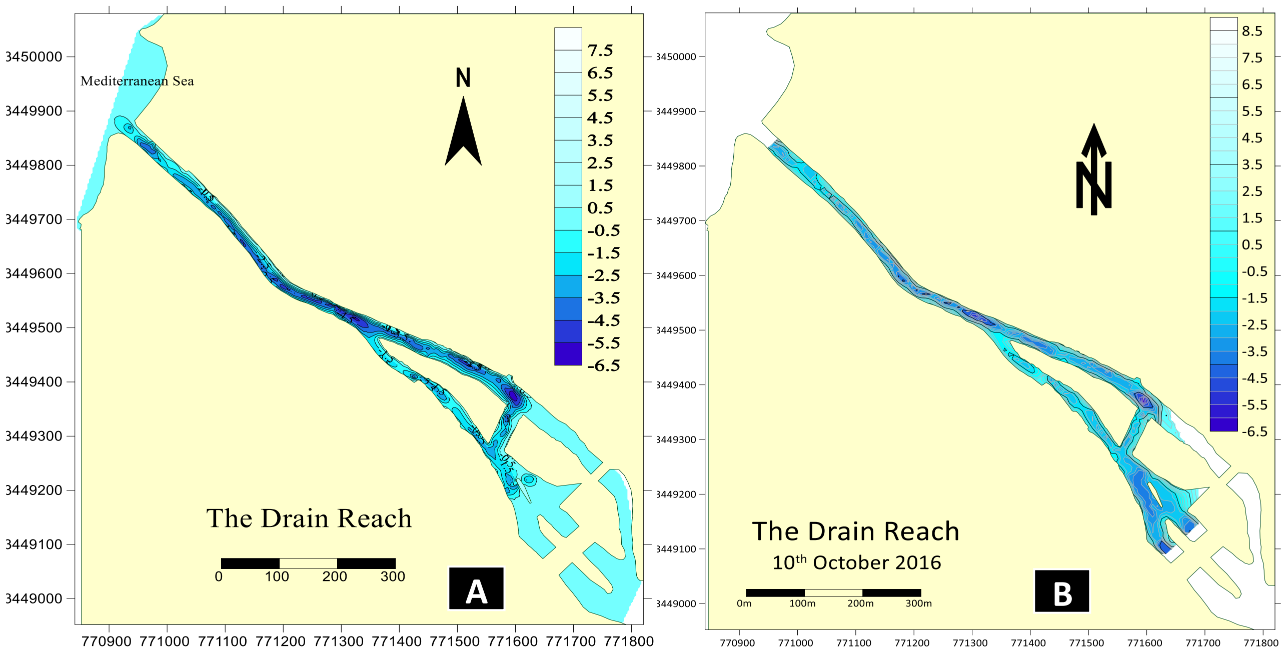


Fig. 9. Contour map of the study area (Bathymetry) A) on 6th January 2016, and B) on 13rd October 2016.

Based on the natural drainage water discharge of the agricultural area served by the El-Umum Drain (ASUD) and the proposed El-Qalaa Drain discharge of 10 m^3/sec, the study objectives are to perform the water surface of the DR and mouth under critical conditions. These conditions are at a precipitation rate of 227 mm/7 days for the ASUD, which is 408000 feddan (1713.6 km^2). This will allow for the proposal of appropriate measures, both immediate and long-term. The quantity of rainfall on the ASUD is determined by dividing the total precipitation rate by the percentage of the coastal area supplied by the ASUD (about one-third) and 100 mm/7 days for the other two-thirds far from the coast.

$$(227mm)*(1713.6\,\text{km}^2)*\frac{1}{3}+(100mm)*(1713.6\,\text{km}^2)*\frac{2}{3}=244*10^6\,m^3/7days.$$

Based on the drainage water duty of 12 m^3/feddan/day (2860 m^3/km^2/day), and with a proposed 25% efficiency to eliminate the flooded drainage water, the maximum discharge of three El-Max Pump Stations (two currently in operation and the proposed re-operation of the old one) under this critical state is:

$$Q=\left(244*10^6\frac{m^3}{7days}\right)*(25\%)+(1713.6\,\text{km}^2)*\left(12\frac{m^3}{feddan*day}\right)+10\frac{m^3}{\sec}=167m^3/\sec.$$

The hydrodynamic flow model, which simulates the flow, was created using the HEC-RAS Program (Ver. 4.1), USA. The hydraulic model is running in three scenarios (PF1, PF2, and PF3):

1) PF1 scenario for the current state on November 6, 2016, where the field measured flow rates are 32 m^3/sec at cross-section 3 of the left branch and 49 m^3/sec at cross-section 4 of the right branch, respectively, and the sea level is 0.35 m above MSL; the discharge of the current MPS is 81 m^3/sec.

2) The PF2 scenario for the condition of intense rainy storms and surges, where the maximum amount of drainage water that can be pumped through the two pump stations that are currently in place is 162 m^3/sec (6 pump units of 14.5 m^3/sec and 6 pump units of 12.5 m^3/sec), in addition to the measured maximum value of 0.76 m above MSL.

3) The PF3 scenario for the state of intense rainy storms and surges calls for 120.5 m^3/sec of pumped drainage water to be passed through the two pump stations that are currently in use and the reopened old one, respectively. This is in addition to the sea level being 0.76 m above MSL (4 pump units of 14.5 m^3/sec and 5 pump units of 12.5 m^3/sec) and 54 m^3/sec (2 pump units of 14.5 m^3/sec and 2 pump units of 12.5 m^3/sec). This means the maximum discharge is 174.5 m^3/sec.

Fig. 10 shows the water surface calibration between measured and predicted values for the PF1 scenario on January 6, 2016, representing eight different places where the model was calibrated: Cross-sections 2, 3, 4, 6, 7, 8, 9, and 10. Measured water levels were compared to model results throughout the calibration process. The goal was to get the best possible fit between the field measurements and the model by fine-tuning the roughness parameter. Throughout the model region, the Manning Roughness Coefficient was adjusted to provide the best fit between the data and model calculations. For Scenarios PF1, PF2, and PF3, the water surface level immediately downstream of the MPS is, respectively, 0.92, 2.06, and 2.14 m above MSL. As a result, under catastrophic circumstances with PF2 and PF3 scenarios, the pumped water will return to the MPS building, where it will elevate the water's surface level by 1.28 meters and by 0.71 to 1.18 meters along the DR. Consequently, it is evident from the model's outputs that the Drain-reach is unable to handle the flow rates of the PF2 and PF3 scenarios, in which the water surface profile rose above the platform level of 1.75 m above MSL and quickly approached the MPS building when responsible, on November 10, 2015, attempted to operate the MPS as fully as possible to confront the critical condition brought on by the aforementioned heavy rainstorm. The manning coefficient and the cross-sectional area appear to be the primary factors. In addition, enlarging the cross-section by widening the bed is necessary. As shown in **Fig. 11**, the hydraulic model was reapplied using the HEC-RAS Program with calibrated parameters for three scenarios:

1) Expanding the bed width to 20 m for discharges of 81, 162, and 174.5 m^3/sec, respectively, and dredging to a level 4.0 m below MSL.
2) Expanding the bed width by up to 25 meters for discharges of 81, 162, and 174.5 m^3/sec, respectively, and dredging to a level 4.0 m below MSL.
3) Expanding the bed width by up to 30 m for discharges of 81, 162, and 174.5 m^3/sec, respectively, and dredging to a level 4.0 m below MSL.

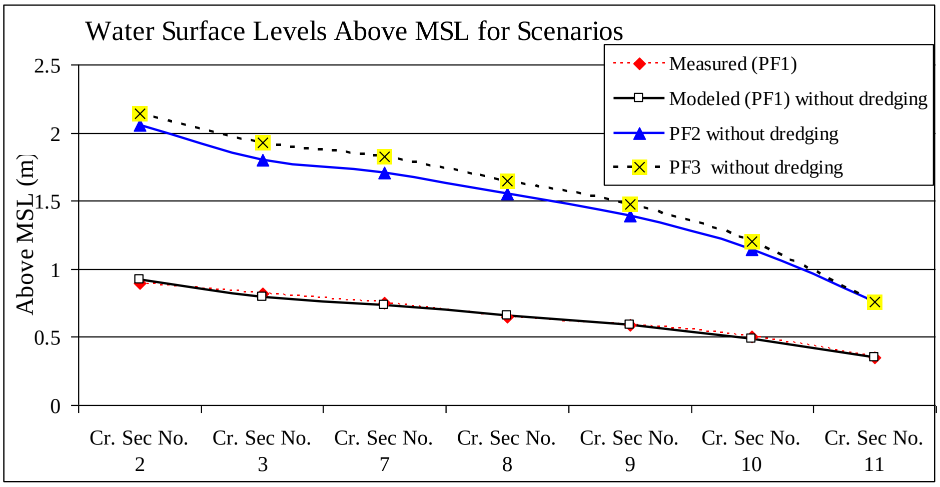


Fig. 10. Water surface calibration between measured and modeled values for 6th Jan. 2016 for PF1 scenario and scenarios without dredging [1].

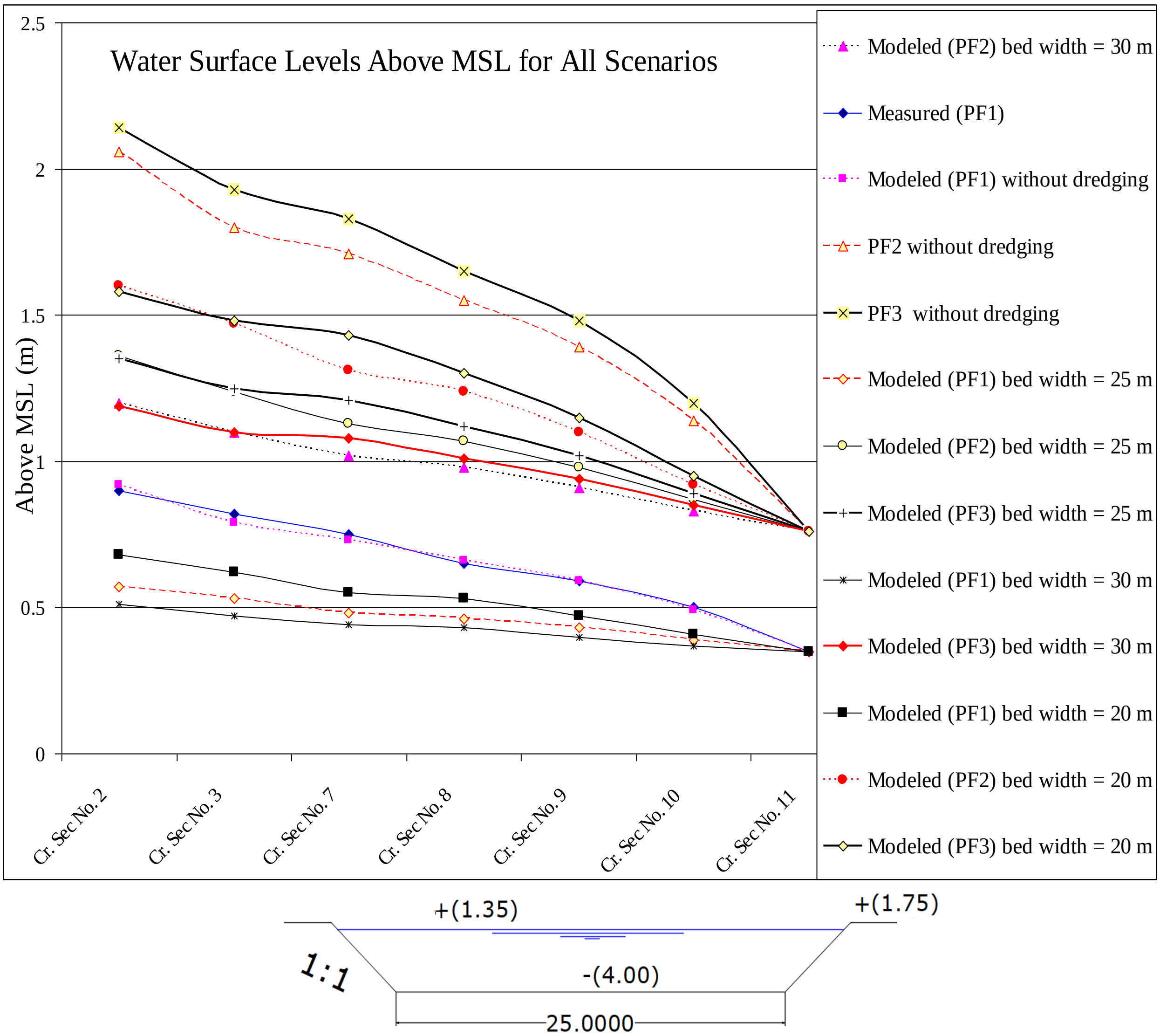


Fig. 11. Water surface for all scenarios in the hydraulic model operating and the designed parameters of cross-section No. 1 just downstream of El-Max Pump Station km (1.010) for a maximum discharge of 174.5 m³/sec. [1].

The optimum scenario, in which the water surface level downstream the MPS through scenarios PF2 and PF3 is 1.35 m above MSL less than the Platform level of 1.75 m above MSL, is described by the model output as involving the expansion of the bed width to 25 m and dredging of the bed to level 4.0 m below MSL, as shown in **Fig. 11**.

3.5.2 on 10th October 2016 to 13th October 2016

On December 1, 2016, the Central Administration of the West Delta Drainage Region requested the creation of new design cross-sections for the drain-reach downstream of the MPSs up to the mouth in the Mediterranean Sea. These sections were based on that request. The design discharge of 195 m^3/sec took future changes into account. Consequently, The CoRI started a field investigation for 102 cross-sectional profiles that were 10 meters apart from October 10 to October 13, 2016. Cross-section 1 at the MPS and cross-section 102 at the mouth of the drain reach had water levels that were, respectively, (+0.70 and (+0.28) above MSL. The following factors were considered in the development of the new sectors:

- The bed levels of the pumping station's expulsion basin are (-4.00) below MSL.
- The sea level during a heavy rainstorm in November 2015 was (+0.76) above MSL.
- The water surface level behind the pumping station does not exceed (+1.00) above MSL until it becomes lowered by at least 75 cm below the pumping station's expulsion platform whose level is (+1.75) above MSL. Consequently, the maximum water depth in the stream is limited to 5.0 meters due to the water surface's slope not exceeding 24 cm/km.
- Manning coefficient for the stream after dredging, based on the bottom soil calibration performed first on January 6, 2016. This is comparable to the results of the hydraulic model calibration performed with the HEC-RAS program [1].

Some cross-sections are shown in **Fig. 12A** and **Fig. 12B** as follows:

1) *Cross-section 6;* is at 960 m upstream mouth (UM) and the water surface level (WSL) is 0.68 m above MSL (**Fig. 12A**).
2) *Cross-section 17;* is at 850 m UM and the WSL is 0.63 above MSL (**Fig. 12B**).
3) *Cross-section 33;* is at 690 m UM and the WSL is 0.57 m above MSL (**Fig. 12C**).
4) *Cross-section 52;* is at 500 m UM and the WSL is 0.49 above MSL (**Fig. 12D**).
5) *Cross-section 64;* is at 380 m UM and the WSL is 0.44 m above MSL (**Fig. 13E**).
6) *Cross-section 82;* is at 200 m UM and the WSL is 0.36 m above MSL (**Fig. 13F**).
7) *Cross-section 100;* is at 30 m UM and the WSL is 0.28 m above MSL (**Fig. 13G**).

Consequently, using spatial interpolation of the DR's bed levels and the "Triangulation with Linear Natural Neighbor Interpolation" method in the Golden Software SURFER 13.0 computer program, a contour map was created using measured hydrographic profiles (**Fig. 9B**). Based on similar cross sections measured at 850 m, 690 m, 500 m, 380 m, 200 m, and 30 m upstream of the MPSs on January 6, 2016, and October 13, 2016, respectively illustrated in Fig. 8 for the previous investigation on January 6, 2016, and **Fig. 12A** and **Fig. 12B** for the new investigation on October 13, 2016, the hydrographic profiles are sufficiently similar and the difference is not significant.

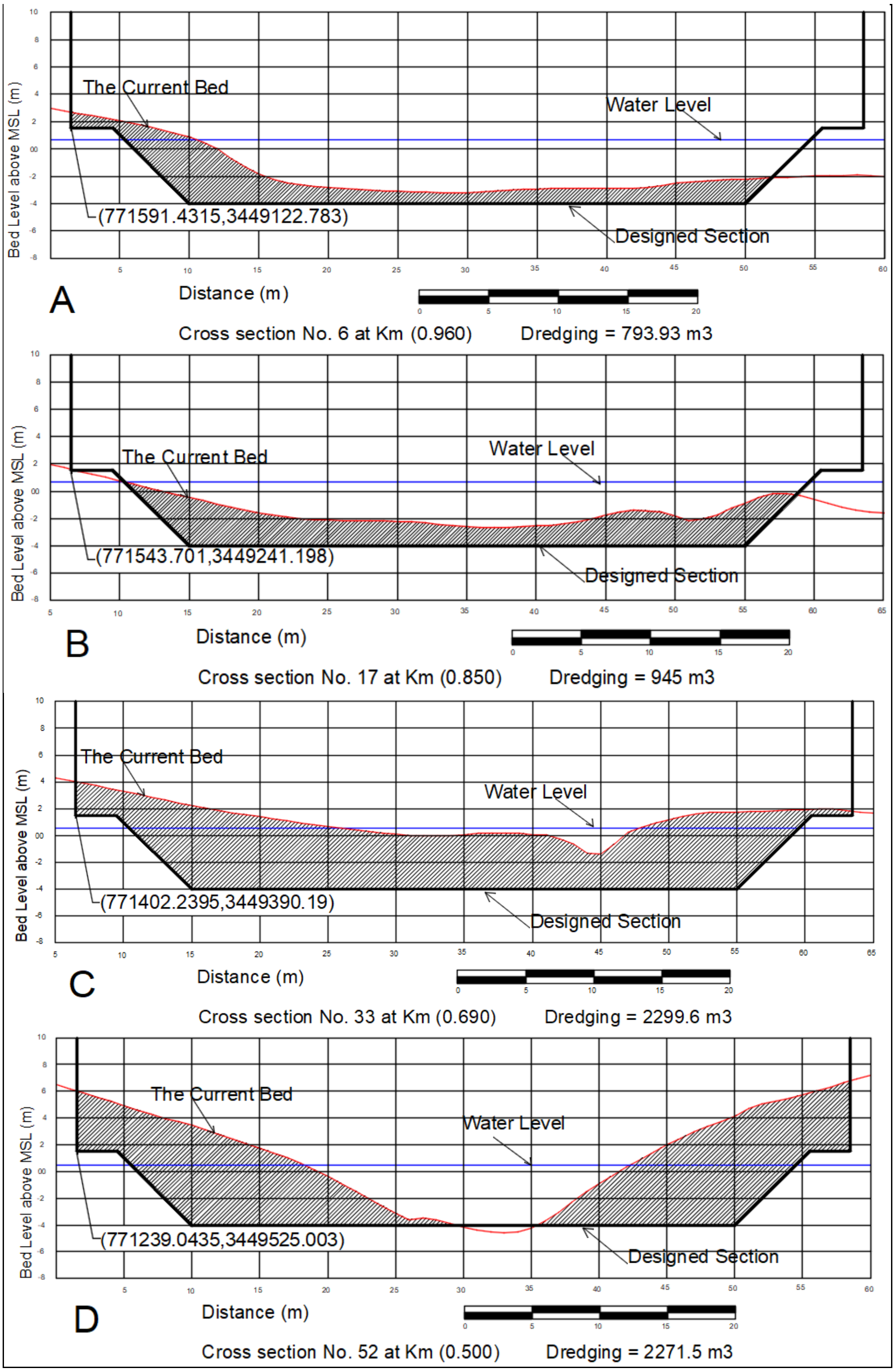


Fig. 12A. Cross-sections 6, 17, 33, and 52 at the drain-reach on 13th October 2016.

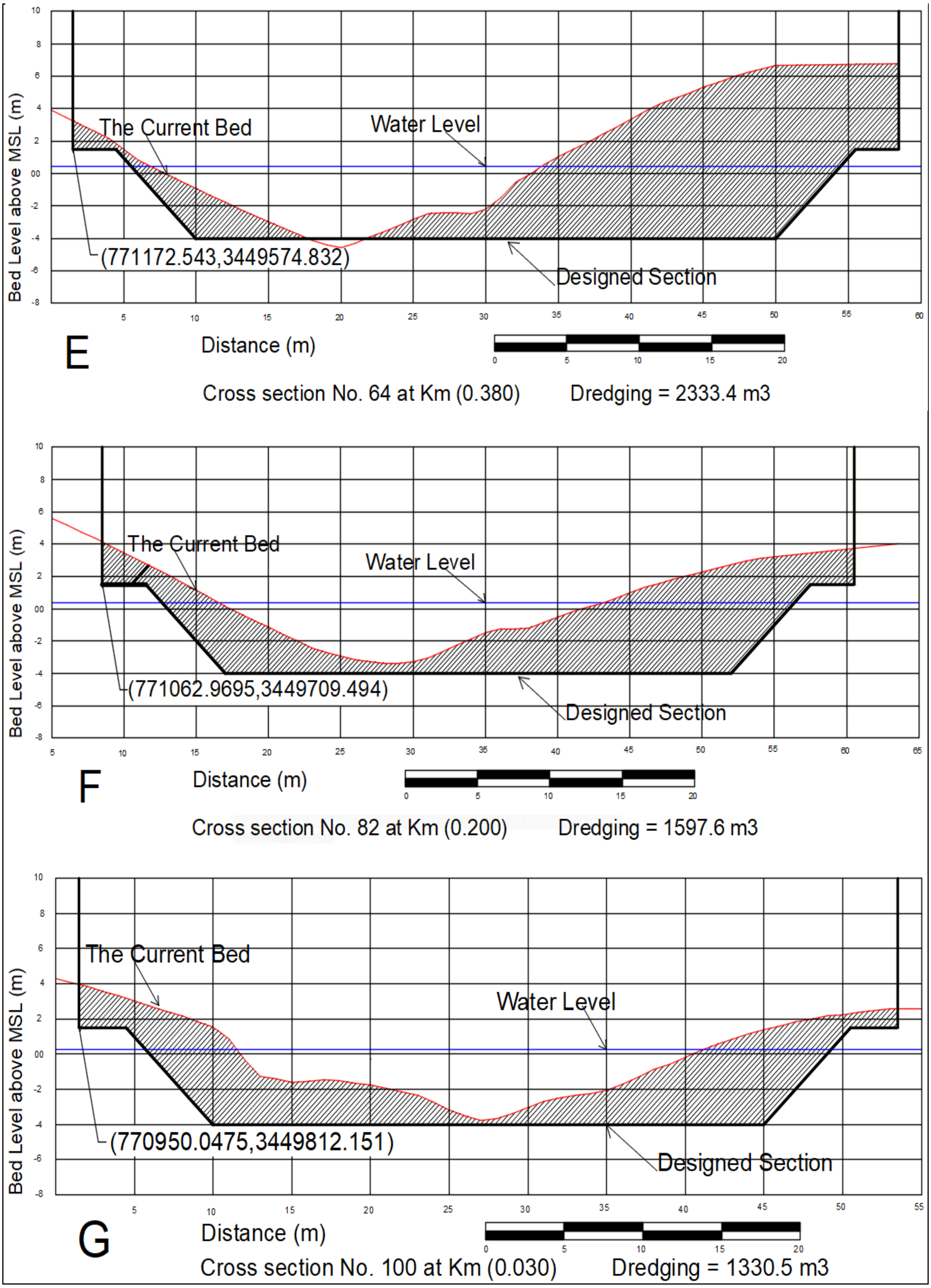


Fig. 12B. Cross-sections 64, 82, and 100 at the drain-reach on 13th October 2016.

Under updated settings, the hydraulic simulation model was run for the new scenario PF3. The conditions are as follows: the water level immediately downstream of the MPS does not exceed (+1.00) above MSL; the maximum discharge is 195 m^3/sec; and the sea water level is (+0.76) above MSL. This scenario takes into account the state of intense rainy storms and surges. A total of 120.5 m^3/sec of pumped drainage water must pass through the two pump stations that are currently in use and the reopened old one, respectively (4 pump units of 14.5 m^3/sec and 5 pump units of 12.5 m^3/sec) and 74 m^3/sec (3 pump units of 14.5 m^3/sec and 3 pump units of 12.5 m^3/sec). According to the model outputs, the best course of action is to widen the drain reach's bed to 40 m for the first 650 m of its length, as seen in **Fig. 13A**, and 35 m for the final 350 m, as depicted in **Fig. 13B**. The locations of the newly designed cross-sectional water in **Fig. 12A** and **Fig. 12B** depict the necessary dredging as well as its location and amount at each sector. About 158726 m^3 of dredging is required. In addition, it is advised to remove any obstructions in the drain reach's path, particularly the oil company bridges' piers and foundations. About $ 8 is needed for the suggested job.

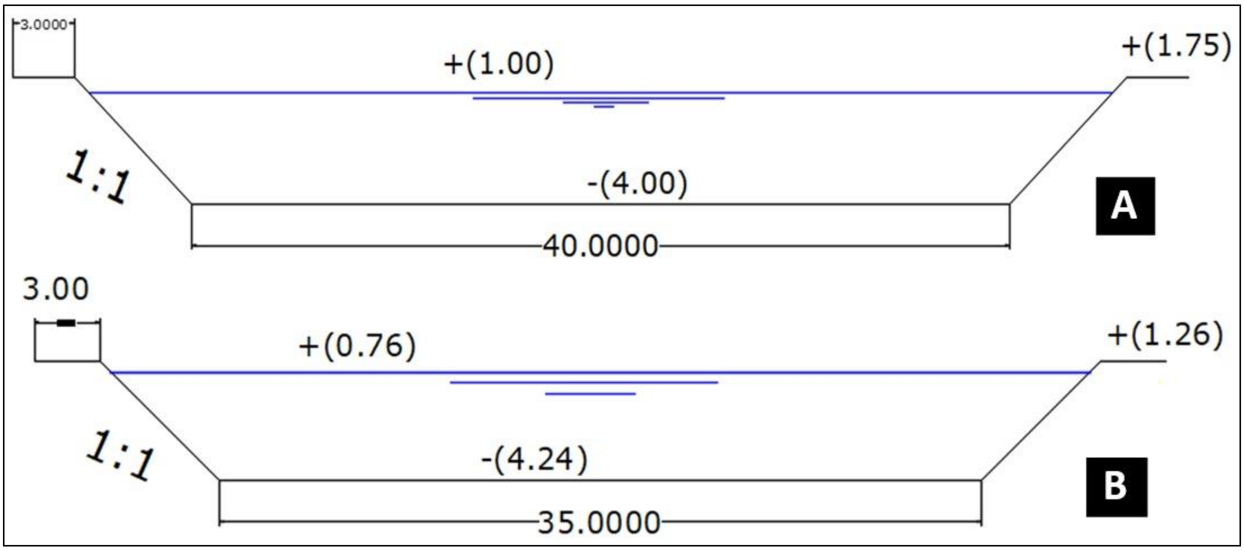


Fig. 13. Designed parameters of cross-sections A) No. 1 just downstream of El-Max Pump Station km (1.010); and B) No. 102 at the mouth of the drain-reach km (0.000) for a maximum discharge of 195 m^3/sec.

3.5.3 on 1st July 2021 to 3rd July 2021

The process was put forward for implementation in 2020. The contractor encountered challenges throughout construction, including opposition to the oil firms' bases and foundations for the bridges inside the drain path (**Fig. 14**). Additionally, the contractor encountered difficulties in implementing the 180-meter dredge near a sports club wall on the right bank. As a result, the designs for this section were modified, and the drain's axis was moved to the west, as depicted in **Fig. 14**.

Fig. 14. A) and B) Obstacles in implementation, objections to the bases and foundations of the bridges of the oil companies; C) and D) The contractor encountered difficulties in implementing the 180-meter dredge near a sports club wall on the right bank of the drain path.

The arrangement of the drain reach and the recently created plan for the dashed regions to be dredged, as well as implementation challenges and objections to the bases and foundations of the oil firms' bridges inside the drain channel, are depicted in **Fig. 15**.

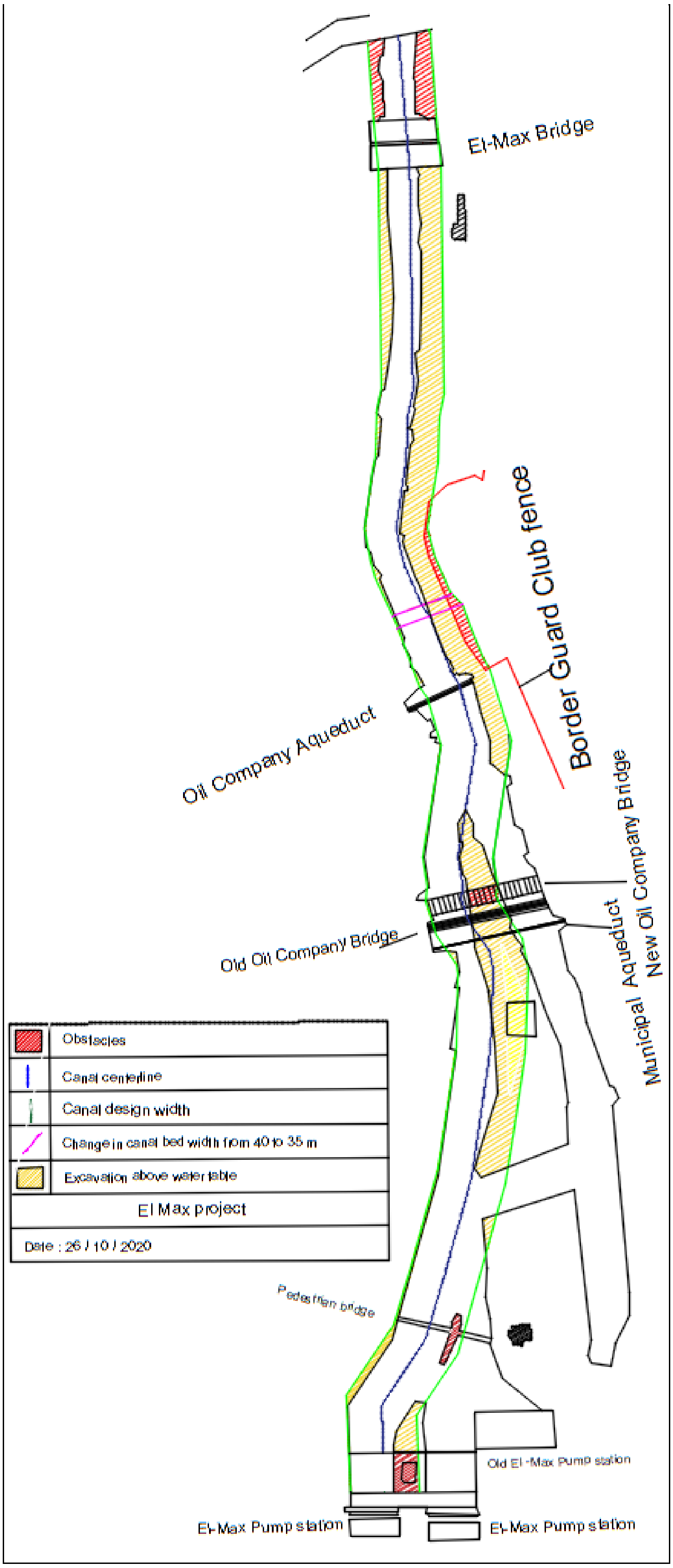


Fig. 15. The layout of the drain reach and the newly designed plan for the dashed areas to dredge, the obstacles in implementation, and objections to the bases and foundations of the bridges of the oil companies inside the drain path.

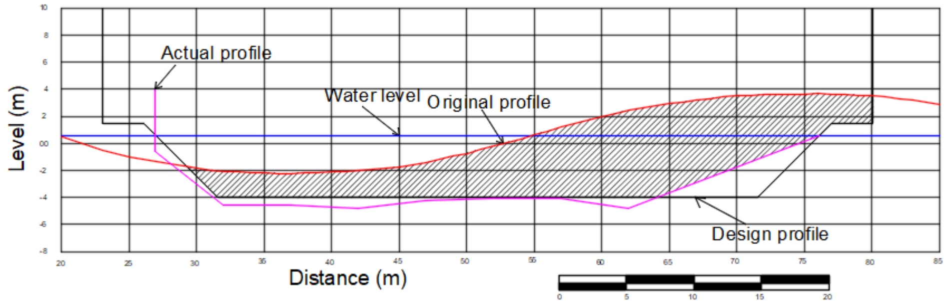
The figures for the newly planned sections, the original profiles measured on December 13, 2016, and the bed levels for the actual profiles in December 2020 are shown in **Fig. 16** of profiles 27, 33, and 38, and **Fig. 17** of profiles 48, 78, and 93, respectively. The ratio of the actual quantity of dredging implemented to the planned quantity at each profile can be found in **Fig. 16** and **Fig. 17**. It is approximately 91.4% at Profile 27 (km 0.750), 65% at Profile 33 (km 0.690), 76.7% at Profile 38 (km 0.640), 98% at Profile 48 (km 0.540), 58.1% at Profile 78 (km 0.240), and 94% at Profile 93 (km 0.090). It is not surprising that the actual implemented dredge ratio, with an average of 78%, varies from 58% to 98% concerning the planned dredging. The piles supporting the oil company-owned bridges, the sporting club wall in the middle sector, and the sector's foundations posed difficulties for the contractor.

Operating the simulation hydraulic model according to the real profiles for the identical conditions resulted in a maximum discharge of 185 m^3/sec through the current drain reach.

The figures for the newly planned sections, the original profiles measured on December 13, 2016, and the bed levels for the actual profiles in December 2020 are shown in **Fig. 16** of profiles 27, 33, and 38, and **Fig. 17** of profiles 48, 78, and 93, respectively. The ratio of the actual quantity of dredging implemented to the planned quantity at each profile can be found in **Fig. 16** and **Fig. 17**. It is approximately 91.4% at Profile 27 (km 0.750), 65% at Profile 33 (km 0.690), 76.7% at Profile 38 (km 0.640), 98% at Profile 48 (km 0.540), 58.1% at Profile 78 (km 0.240), and 94% at Profile 93 (km 0.090). It is not surprising that the actual implemented dredge ratio, with an average of 78%, varies from 58% to 98% concerning the planned dredging. The piles supporting the oil company-owned bridges, the sporting club wall in the middle sector, and the sector's foundations posed difficulties for the contractor.

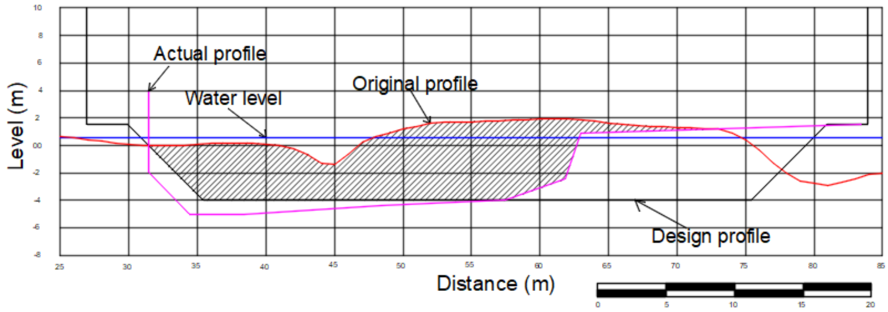
Operating the simulation hydraulic model according to the real profiles for the identical conditions resulted in a maximum discharge of 185 m^3/sec through the current drain reach.

A



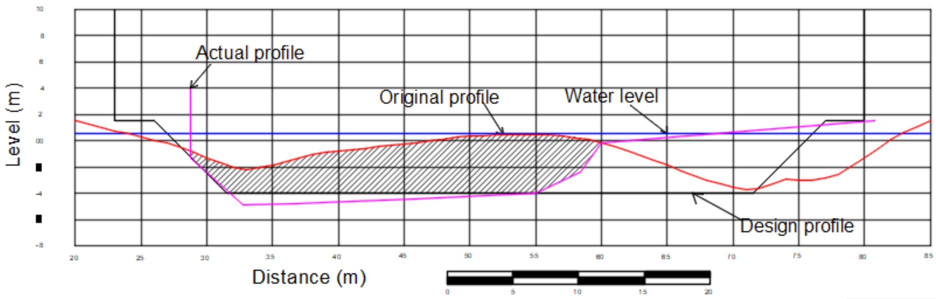
Required excavation		Actual excavation				El Max project
Above water table (m3)	Under water table (m3)	Above water table (m3)	Under water table (m3)	Kilometer scaling	Section	Date: 23 / 12 / 2020
538	1478	536.1	1307.2	0.750	27	Section type : Cross section

B



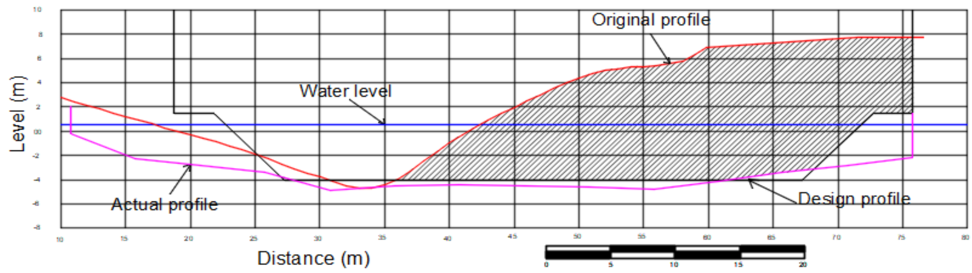
Required excavation		Actual excavation				El Max project
Above water table (m3)	Under water table (m3)	Above water table (m3)	Under water table (m3)	Kilometer scaling	Section	Date: 21 / 12 / 2020
259	1848	202.5	1166.7	0.690	33	Section type : Cross section

C



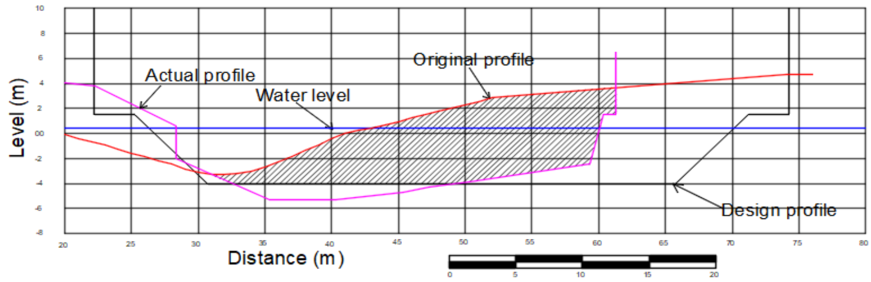
Required excavation		Actual excavation				El Max project
Above water table (m3)	Under water table (m3)	Above water table (m3)	Under water table (m3)	Kilometer scaling	Section	Date: 21 / 12 / 2020
0.00	1280	0.00	981.6	0.640	38	Section type : Cross section

Fig. 16. The bed levels for actual profiles in December 2020, original profiles measured on the 13th of 2016, and the newly designed sections A) Profile 27; B) Profile 33; and C) Profile 38.



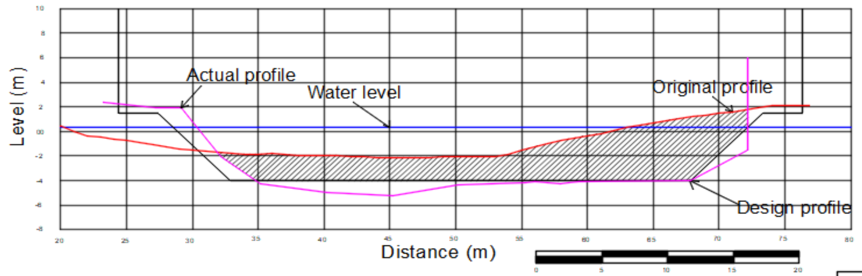
D

Required excavation		Actual excavation				El Max project
Above water table (m3)	Under water table (m3)	Above water table (m3)	Under water table (m3)	Kilometer scaling	Section	Date: 5 / 12 / 2020
1680	1427	1700.8	1349.2	0.540	48	Section type : Cross section



E

Required excavation		Actual excavation				El Max project
Above water table (m3)	Under water table (m3)	Above water table (m3)	Under water table (m3)	Kilometer scaling	Section	Date: 21 / 12 / 2020
835	1377	364.8	920.9	0.240	78	Section type : Cross section



F

Required excavation		Actual excavation				El Max project
Above water table (m3)	Under water table (m3)	Above water table (m3)	Under water table (m3)	Kilometer scaling	Section	Date: 5 / 12 / 2020
102	1049	70.9	1012.6	0.090	93	Section type : Cross section

Fig. 17. The bed levels for actual profiles in December 2020, original profiles measured on the 13th of 2016, and the newly designed sections D) Profile 38; E) Profile 78; and F) Profile 93.

SUMMARY AND CONCLUSIONS

As a result of the effects of climate change, a strong rainy storm that struck the Nile Delta in November 2015 produced a lot of rain over a short period at a depth of about 227 mm. As a result, the drainage system of urban areas and agricultural areas was overloaded with water, causing flooding. The mouth of El-Max Pump Stations' delivery reach releases surplus water from Mariout Lake and effluent from the El-Umum Drain into the Mediterranean Sea. Pumped water was brought back to the El-Max Pump Stations building in November 2015.

To propose appropriate, immediate, and long-term solutions, the study's objectives examine the elements contributing to this problem. To ascertain why this occurred, a hydraulic simulation modeling was created. These results were obtained by assessments of drain parameters, marine profile surveys, measurements of water levels, sea level variations, embankment levels of the El-Max Pump Stations' delivery reach, and waves. Up to December 2020, the investigation found that the drain reach was narrow, shallow, and had many restrictions along its path. The following are some of the reasons behind the rise in the drain water level:

1) The massive reinforced concrete pier at the mouth and concrete platforms, fishermen's nests, and anchored boats cause the channel to throttle.
2) Multiple bridges on the drain reach are used to transport pipes for oil companies located west of the reach, and their foundations are directly on the path and edges of the channel.
3) The bed width is narrow and shallow enough to convey the urgently pumped drainage water within the heavy rainstorm to the sea, with a width of less than 18.0 m.

When the drain sections were first designed in January 2016, they had to meet certain important requirements. These included a maximum flow rate of 174.5 m^3/sec and a water level just downstream of the El-Max Pump station that was 40 cm below the pump station platform and not more than 1.35 m above the MSL. The plan showed that the drain would deepen to a depth of 4.0 meters below MSL and widen its bed to a width of 25 meters.

The second design was based on a request made on December 1, 2016, by the Central Administration of the West Delta Drainage Region to create new design cross-sections of the drain reach, with a discharge of 195 m^3/sec taking into account future modifications. The terms of the new design were as follows: the water surface level behind the pumping station does not exceed (+1.00) above the MSL until it is lowered by at least 75 cm below the pumping station's expulsion platform, whose level is (+1.75) above the MSL. The sea level was taken to be the same value as that during a heavy rainstorm in November 2015 (+0.76) above the MSL. Thus, the water surface slope of the stream cannot be greater than 24 cm/km, limiting the maximum water depth to 5.0 meters. The Manning coefficient for the stream following dredging is determined by the bottom soil calibration that was completed in January 2016, among other factors. This is similar to the output of the HEC-RAS program's hydraulic model calibration. Based on the model outputs, expanding the drain reach's bed to 40 m for the first 650 m of its length and 35 m for the last 350 m is the optimum solution of action. Approximately 158726 m^3 would be dredged.

The contractor commenced work implementation in October 2020. The contractor encountered challenges during construction, including resistance from the bridges' bases and foundations of the oil companies located inside the drain path. Additionally, it's advised to clear any obstructions that stand in the drain's way. About $8 is the price of this task. Furthermore, the contractor faced challenges when constructing the 180-meter dredge close to a sports club wall on the right bank. As a result, the drain's axis was shifted to the west, and the designs for this portion were modified. For each profile, the difference between the amount of dredging that was done and the amount that was anticipated ranges from 58% to 98%. On average, this ratio is 78%. At the present drain reach, the maximum discharge via the simulation hydraulic model was 185 m^3/sec when operating by the real profiles under the same conditions.

The study recommends that the Old El-Max Pump Station be put back into service with six pump units, three of which have a capacity of 14.5 m^3/sec and the other three have a capacity of 12.5 m^3/sec. This will allow the operation of the pump station at 74 m^3/sec for the maximum pump discharge during anticipated heavy rainy storms and will directly lift drainage wastewater of the El-Qalaa Drain at roughly 10 m^3/sec.

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CONFLICT OF INTEREST

The authors have no financial interest to declare concerning the content of this article.

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