PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 21 No. 1 March 2017 pp. 59:67

A Hydrodynamic Model for the Water Renewal In The Damietta Port Basin

E. Tolba[1]/ E. Galal[2] /T. Abou Lila[3]/ H. Zaki[4]

ABSTRACT

Planning and alignment of man-made maritime water areas such Damietta Port, have to be carefully designed to guarantee adequate water exchange between the port basin water and the open sea fresh water. Stagnant water areas could consist in isolated areas, artificial canals, islands, connection channels and structures that block the natural water flow. The properties of the water exchange rate of Damietta Port basin has been investigated as a response of relevant natural hydrodynamic drivers. A two-dimensional numerical model uses the equations of continuity and conservation of momentum was used to simulate the flow circulation patterns and tracking the pollutants transport in the port basin, depending on both water levels and wind data. The core of the work was to set up a hydrodynamic model for Damietta port, to determine the port basin hydrodynamic characteristics attitude. The tidal and wind data were used as input to the hydrodynamic model to simulate tidal currents in the port basin. Then, the results of the hydrodynamic model were analyzed to detect the tidal current characteristics and the general current patterns during a typical tidal cycle were simulated. Finally, the transport of pollutant particles in the port basin was simulated using the particle tracking technique in order to predict the pollutant particles movement. The results showed that the attitude of hydrodynamic characteristics of the port basin helps to make a good exchange of the fresh water between the port basin and the Mediterranean Sea.

Keywords: Damietta port; water renewal; hydrodynamic model; tidal current; particle tracking.

1. INTRODUCTION

One of the most important achievements of the beginning of the new millennium is the development of the computer hardware from what it was in the past, and it is still developing at a rapid pace until this day. This development, in turn, led to help the numerical models to simulate the processes of nature in a better way, to increase their use, and to rely on them for decision-making. One of these professional modeling softwares is Mike 21. It is a versatile 2D free-surface flow modeling platform developed by Danish Hydrodynamic Institute (DHI) [9]. Mike 21 designed to aid hydraulic engineers in coastal works analysis.

The coastal areas and ports may expose to pollutions, waves, tsunamis, sedimentations, sea level rise… etc. Therefore, this coastal areas and ports should be subject to coastal management studies, which depend on available meteorological data records, seasonal variations measurements.

This coastal management studies using numerical modeling provides the coastal engineers with the possibility to check and analyze the coastal problems and hazards with a minimal amount of errors. It also allows them to change the input parameters and observe the consequences. Damietta Port is considered one example of many ports located in the Mediterranean region that may suffer from some or all hazards mentioned before.

According to its brilliant geographical location, Damietta Port may consider as one of the essential Egyptian Ports, where it deals with a wide range of cargoes. Slower water exchange can lead to a buildup of pollutants, increased temperature and salinity, altered dissolved Oxygen ranges, and increased tendency for anaerobic conditions [2]. Therefore, it must assure that the port basin hydrodynamic characteristics would not lead to the formation of stagnant water areas; thereby ensuring water movement and exchange throughout the basin, and avoiding traps for floating trash and seaweed. Therefore, Damietta Port should be checked to guarantee natural renewal of water affected by tidal and wind action.

A hydrodynamic (HD) model has been set up using Mike 21 to cover Damietta Port basin area with grid spacing chosen to be 10x10 m cover area of 2.5 x 5.0 km. The purpose of the simulations is to produce HD model that can be used to investigate the attitude of the port basin hydrodynamic characteristics.

2. STUDY AREA

Damietta Port lies between longitudes 31° 30' to 32° 6' E and latitudes 31° 20’ to 31° 34' N as an inland port on the north coast of Egypt as shown in Figure 1. The port established in the early 1980s to increase the trade potential along the Mediterranean coast, which becomes

[1] *Associate Professor, Faculty of Engineering, Port Said University, Egypt, Email: tolba_1966@yahoo.com*
[2] *Assistant Professor, Faculty of Engineering, Port Said University, Egypt, Email: Elsayed.galal@eng.psu.edu.eg*
[3] *Lecturer, Faculty of Engineering, Port Said University, Egypt, Email: eng_tarek_selim@yahoo.com*
[4] *Coastal and Port Eng., Suez Canal Research Center, Ismailia, Egypt, Email: eng.hzy@gmail.com*

later one of the biggest container ports in the Mediterranean sea with trading capacity up to 1.5 million Twenty-foot Equivalent Units (TEU) /year [4].

Damietta Port has been decided to construct some distance inland to protect it from winter storms so that it could be employed year-round and avoid the downtime of the port. This location were selected in a coastal embayment with minimal effects from waves and currents. This stretch also is characterized by more than one dune belt over its backshore plain and traces of old shorelines for a distance of 15 kilometers west of Ras EI Bar to a depth of 0.7 kilometers inland [5].

Figure 1: Location map of Damietta port

The port handle exports of agricultural products, fertilizers, and furniture as well as receiving imported goods such as LNG, cement, grains, flour, and general cargoes with a total capacity of about 5.6 million tons annually [3].

The port occupied about 11.8 km^2 area and divided into two main parts; the first part is the water area which occupies about 3.3 km^2, and consists of the main basin (turning basin) - with a diameter of 500 m wide and 14.5m depth - and two other sub-basins. The land area is the second part, which occupies about 8.5 km^2 and containing areas of goods handling or exchange and berths [4].

In order to facilitate access to inland navigation, the port's basin has connected to the Damietta branch of the River Nile through a man-made canal of 4.5 km long, 90m width and 5 m depth [5].

3. OBJECTIVES

Water quality in the port basin depends on the attitude of the hydrodynamic characteristics of the basin to mix the water and grantee adequate exchange with the open sea water. Man-made structures such as piers and breakwaters affect the movement of water exchange during the typical tidal cycle. Water movement is controlled by tides and the wind. Stagnant flows occur when the rate of tidal exchange diminishes. The objective of the present research is to make sure that such facilities do not cause either obstacle or drop that might negatively affect the water renewal in the port basin.

4. METHODOLOGY

The main objective of the study was to investigate the hydrodynamic characteristics of the water inside the port basin using HD model. The study was conducted using a simulation model which takes into consideration the features governed by the combined effects of tide and wind.

- Firstly, the relevant hydrodynamic drivers in the study such as tide and wind were collected.
- Then, the tidal and wind data was used as input to the HD model to simulate tidal currents in the port basin.
- Finally, the results of the HD model were analyzed to get the attitude of the port basin hydrodynamic characteristics.

The main outcomes of this simulation study were:

- Simulate the flow patterns of the port basin water exchange with the open Sea water.
- Simulate the general current patterns in a typical tidal cycle.
- Perform the necessary analysis of current speed and direction.
- Simulate the transport of pollutant in the port basin using the Particle Tracking technique, to predict the pollutant particles movement.

4.1 Water level Variations Data

Coastal Research Institute (CoRI) had recorded the data of the water level variations by the Automatic Tide Gauge during the period from April to December 1997. Figure 2 shows the water level variations for the measured data. They found that the tides in the area were semi-diurnal [1].

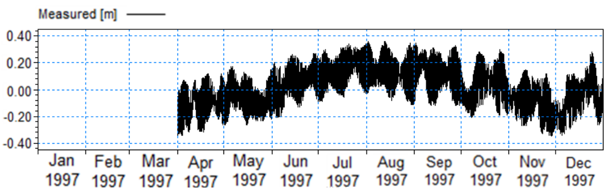

Figure 2: Measured tide data provided by the CoRI

The following characteristics deduced from the average values of the nine-month records:

Highest High Water Level	(HHWL)	=	36 cm
Lowest Low Water Level	(LLWL)	=	-36 cm
Main Low Water Level	(MLWL)	=	-8.5 cm
Main High Water Level	(MHWL)	=	14.6 cm
Main Water Level	(MWL)	=	3.5 cm
Average Tidal Range	(TR)	=	23.1 cm

According to CoRI, the average tidal range (MHWL - MLWL) was 23 cm, and the maximum tidal range (HAT–LAT) was 80 cm [1].

In order to get a water level continues changes in the study area, the time series data was obtained using Mike Zero Tide prediction tool for the period from January to December 1997 (as show in Figure 3). This data was obtained at a point with a location of 976087.375 N and 686841.13 E on the western side of the navigation channel in the open water at a depth of 12 m.

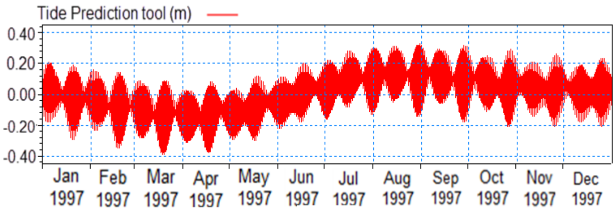

Figure 3: Tide levels from Mike Zero Tide prediction tool

Then a comparison was made between field measurements and predictions to determine the reliability of the data to be entered into the HD model. Figure 4 shows an example for the comparison through the entire August 1997. The results of the Mike Zero Tide prediction tool clearly predicts the tides very well compared with tide data measured by CoRI (i.e. same mean value, amplitude, and phase). Therefore, the data that computed using Mike Zero Tide prediction tool were used later to run and calibrate the HD model.

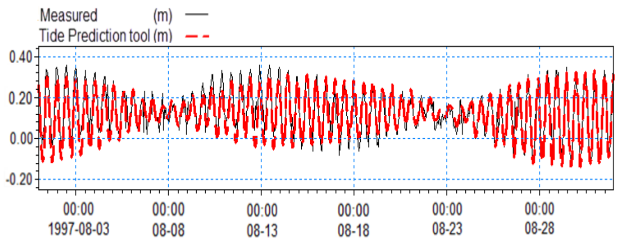

Figure 4: Comparison between field measurements and predictions, through the entire August 1997

4.2 Wind data

The wind plays a significant role in the dispersion of the pollutions where it decreases the concentration and disperses the pollutions in the wider areas.

Wind speed and direction data were extracted from the metrological database of European Centre for Medium-Range Weather Forecasts (ECMWF) at the location of the port and 10 m above sea level, every 3 hrs [6]. Then these measurements were interpolated to be hourly-based time series data.

Figure 5 provides the wind rose plot measured clockwise from the north direction. It can be observed that the predominant wind direction is within the sector defined from WNW to NNE with wind speed of 4-6 m/s has the highest probability.

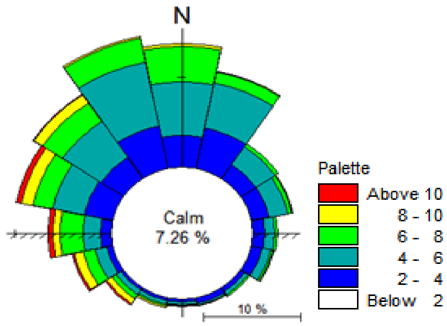

Figure 5: The wind rose of Damietta

4.3 Bathymetric Data

The most important task in a modeling process is setting up the bathymetry model [6]. The bathymetric data used in this study obtained from the Admiralty Chart No. 2578 (as shown in Figure 6) that covers the port area. Then, it was digitized within the Mike21 bathymetry wizard. Finally, a computational grid, with a constant spacing of 10 m in the both directions was set up in Grid Editor Wizard [6] (Figure 7).

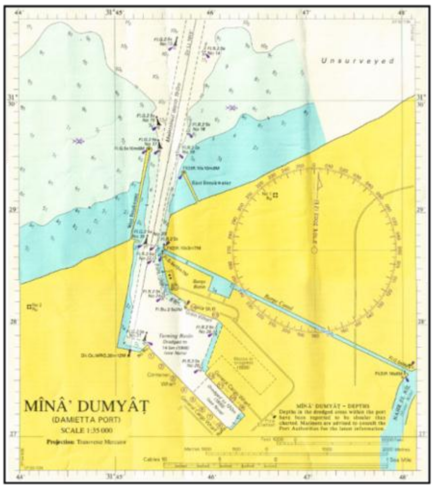

Figure 6: The Admiralty chart used to detect the bathymetry

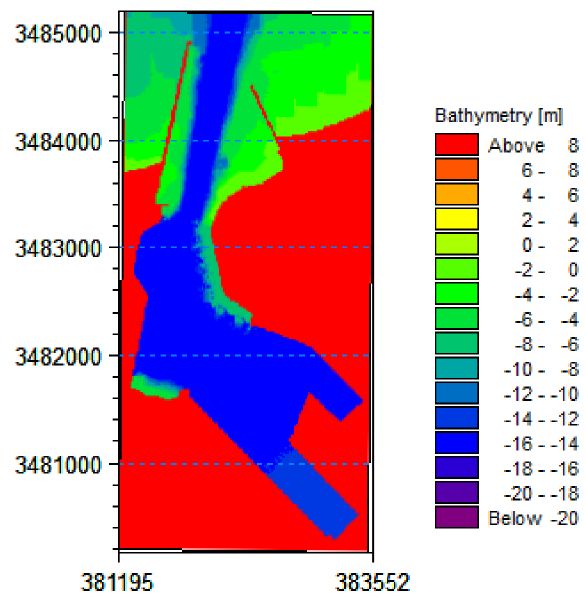

Figure 7: The result of bathymetry digitizing.

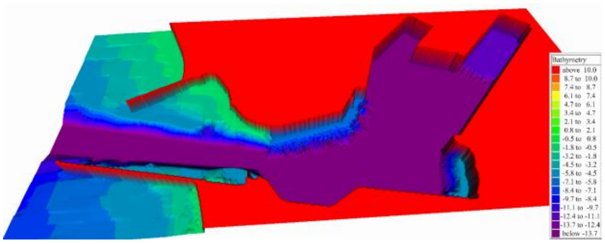

Figure 8: 3D representation of the bathymetry after rectification as it appears in Mike Zero Animator

4.4 Governing Equations

The basic equations of continuity and conservation of momentum are well known in hydrodynamics; the problem is how to solve them. The governed equations in Mike21 are like the majority of hydrodynamic equations, which stem from the three-dimensional Navier-Stokes equations [7] that read:

Continuity Equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (1)$$

Momentum Equation

$$\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial uv}{\partial y}+\frac{\partial uw}{\partial z}=\frac{-1}{r}\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \qquad (2)$$

$$\frac{\partial v}{\partial t}+\frac{\partial uv}{\partial x}+\frac{\partial v^2}{\partial y}+\frac{\partial vw}{\partial z}=\frac{-1}{r}\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \qquad (3)$$

$$\frac{\partial w}{\partial t}+\frac{\partial uw}{\partial x}+\frac{\partial vw}{\partial y}+\frac{\partial w^2}{\partial z}=\frac{-1}{r}\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)-g \qquad (4)$$

Where u, v, and w are the instantaneous velocities in vertical and horizontal dimensions; μ is the viscosity coefficient, and P is the Water pressure.

The continuity equation expresses the mass conservation, while the momentum equation is the fundamental law of dynamics, written for fluids. In Mike21 many sorts of simplifications have been proposed, the most popular being the Shallow Water equations which Mike21 based on it [7].

Shallow Water Equations

The 2D Shallow Water equations are obtained by averaging of the 3D Stokes equations over the depth. The new variables obtained are mean values over the depth which can be written as:

$$U(x,y,t)=\int_{-h}^{z} udz \qquad V(x,y,z)=\int_{-h}^{z} vdz \qquad (5)$$

Where z is the free surface, and h is the bottom elevation. Solving the equations aimed to find the values of U, V, and h everywhere in the study area, during a given time interval, as functions of initial conditions and the boundary conditions [7].

Numerical Formulation

The numerical model is a finite-difference scheme using an Alternating Direction Implicit (ADI) technique to integrate the equation for mass and momentum conservation in the space-time domain. The equation matrices are resolved by a Double Sweep algorithm. The difference terms are expressed on a staggered grid in x, y-space as shown below in Figure 9. Where p and q are the flux densities in x and y directions [7].

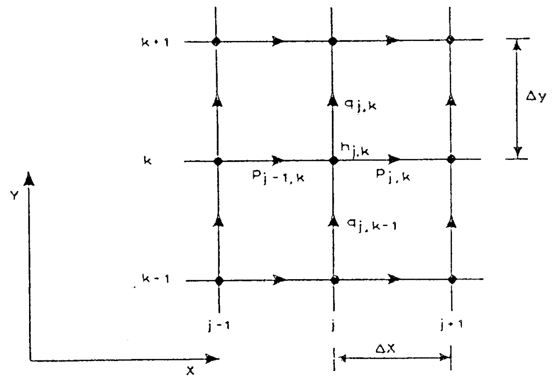

Figure 9: Difference Grid in x, y space [7].

4.5 Hydrodynamic Module Setup

The hydrodynamic simulations have been driven by wind forces in the port domain and the tidal water levels at the open boundary. In order to study the hydrodynamic characteristics of the port basin, the simulation covering a period of 25 days began from the first of August 1997, as an investigation of the tidal flushing study of Damietta Port basin. This duration covers approximately two tidal cycles.

The bathymetry grid spacing was chosen to be 10x10m cover area of 2.5 x 5.0 km. The flow model has been divided into two sub-periods: A warm up period (one-day simulation) to avoid choke effects and the main simulation period (24 days simulation).

The starting time of the simulation was 1/8/1997 00:00:00. A time step interval of 1 second was selected and the duration time of the simulation is 25 days (2160000 time steps, 86400 time steps of them for the warm-up period).

The horizontal eddy viscosity type has been chosen to solve with Smagorinsky formula with constant values of C_S= 0.1, 0.2, 0.3 and 0.4 m^2/s [6]. The bed resistance type has been determined according to Chezy number with constant values of C = 30, 50 and 65 $m^{1/2}/s$.

The wind was specified as varying in time and constant in the domain. A data file containing time series of wind speed and direction data was given. The tidal elevations were applied at the open boundary along the North section. The only open boundary defined was a line in the far north of the modeling area, at grid points located between (0,500) to (230,500).

A three monitoring points (P1, P2, and P3) were positioned in the main parts of the port basin (port entrance, turning basin and inside the southern sub-basin) to monitor and record the variation of the water surface elevation, current and tracking floating particles with time under tide and wind forces , as shown in Figure 10.

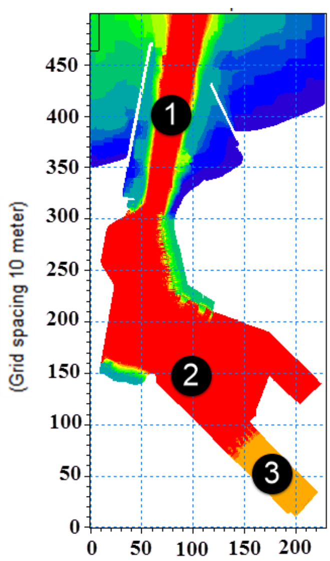

Figure 10: Hydrodynamic characteristics monitoring points

4.6 Calibration, Validation and Harmonization

The calibration has been carried out based on matching the measured and the calculated water levels. A number of trials have been made to tone the model to reproduce satisfactorily results. Finally, the model calibration showed that the model reproduces the hydrodynamics of the port basin very well. After the last calibration of Chezy Number and Eddy Viscosity, there was almost no difference between the measured and computed water levels. Therefore, we can assure that the model is well calibrated for the water elevation.

The best results were obtained after applying horizontal eddy viscosity using Smagorinsky constant (C_S) of 0.4 m^2/s. The bed resistance best result was obtained to stabilize the model after applying Chezy number (C) of 65 $m^{1/2}/s$ as a constant value in the domain of study area, as shown in Figure 11.

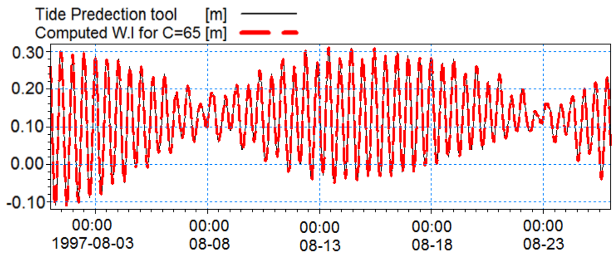

Figure 11: Comparison between W.L data vs. calculated W.L due to C_S= 0.4 m^2/s and C=65 $m^{1/2}/s$

After that, a validation process for eight days of water level and wind data with the same eddy viscosity and bed resistance values are used for the model validation, for simulation period starting from the 16th to the 23rd of October 1997, and the model was well validated for the water elevation

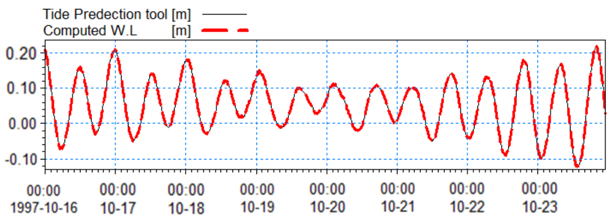

Figure 12: Model validation

Another eight days of water level and wind data are used for the model harmonization, for simulation period starts from the first to the 8th of May 1997. Figure 13 shows that the calculated water levels resulted from the model are synchronized well with the results of the Mike Zero Tide prediction tool, and there is almost no difference between them.

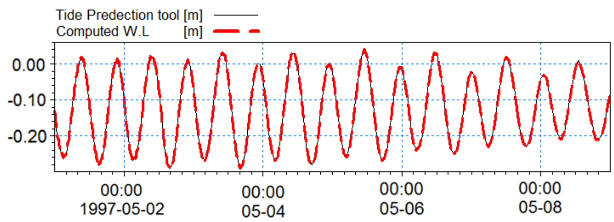

Figure 13: Model Harmonization

The calibration, validation and harmonization processes of the model results show that there was almost no difference between the computed and entered data. Therefore, these three processes had been confirmed that the product model behaved well and ensured that it also operates on clean, correct and useful data.

5. RESULTS AND DISCUSSIONS

5.1 Analysis of Current Speed and Direction

- At the port entrance (as shown in Figure 14-a), currents mainly directed towards the North direction, due to the effect of the exchanged currents between the entrance channel and the open sea, with maximum velocity reaching 10 cm/s and average velocity 2.3 cm\s.
- At the turning basin (Figure 14-b), the currents in the turning basin are governed with the reaction between basin shape and tide forces. Which indicates a good distribution inside the port basin, with maximum velocity reaches 3.3 cm/s and average velocity of 1.5cm\s.
- At the southern sub-basin (Figure 14-c), the currents mainly directed to the entrance towards the North West direction, which indicates a good distribution in spite of current weakness inside the southern basin with maximum velocity reaches 0.3 cm/s and average velocity 0.08 cm\s.

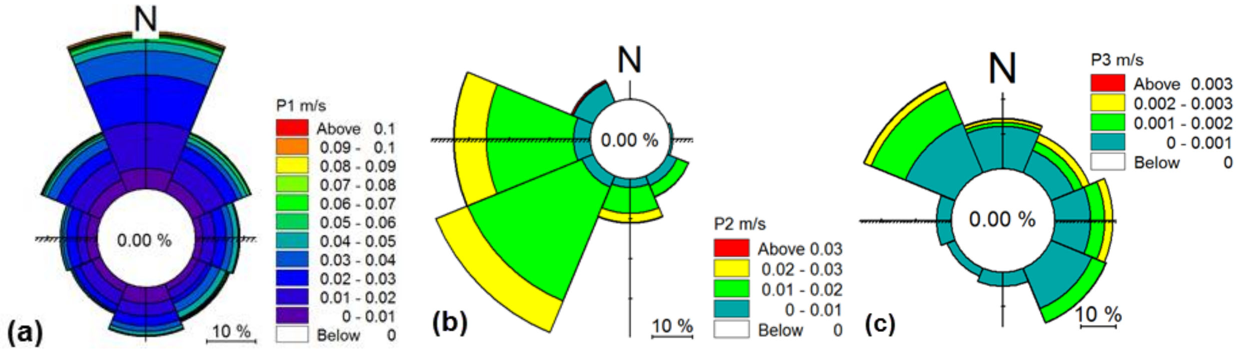

Figure 14: Current Rose (going to direction) shows the velocities and directions at (a) Port Entrance, (b) Turning Basin, and (c) Southern Sub-basin

5.2 General Current Pattern

A complete cycle of ebb, low, flood and high tide phases, respectively, have been observed for one day to show the behavior of the tidal currents using 2D surface current velocity and direction patterns distribution during this tide phases, as shown in Figure 15. All current patterns demonstrate that the current speed at the eastern and southern sub-basins is very small; causing an area to accumulate pollutants, or it will take a long time to be cleaned under natural flushing forces. After the future extension of the eastern basin, the situation will be aggravated worse; which could make it a stagnation point where pollutants accumulate more, compared to other parts of the port basin.

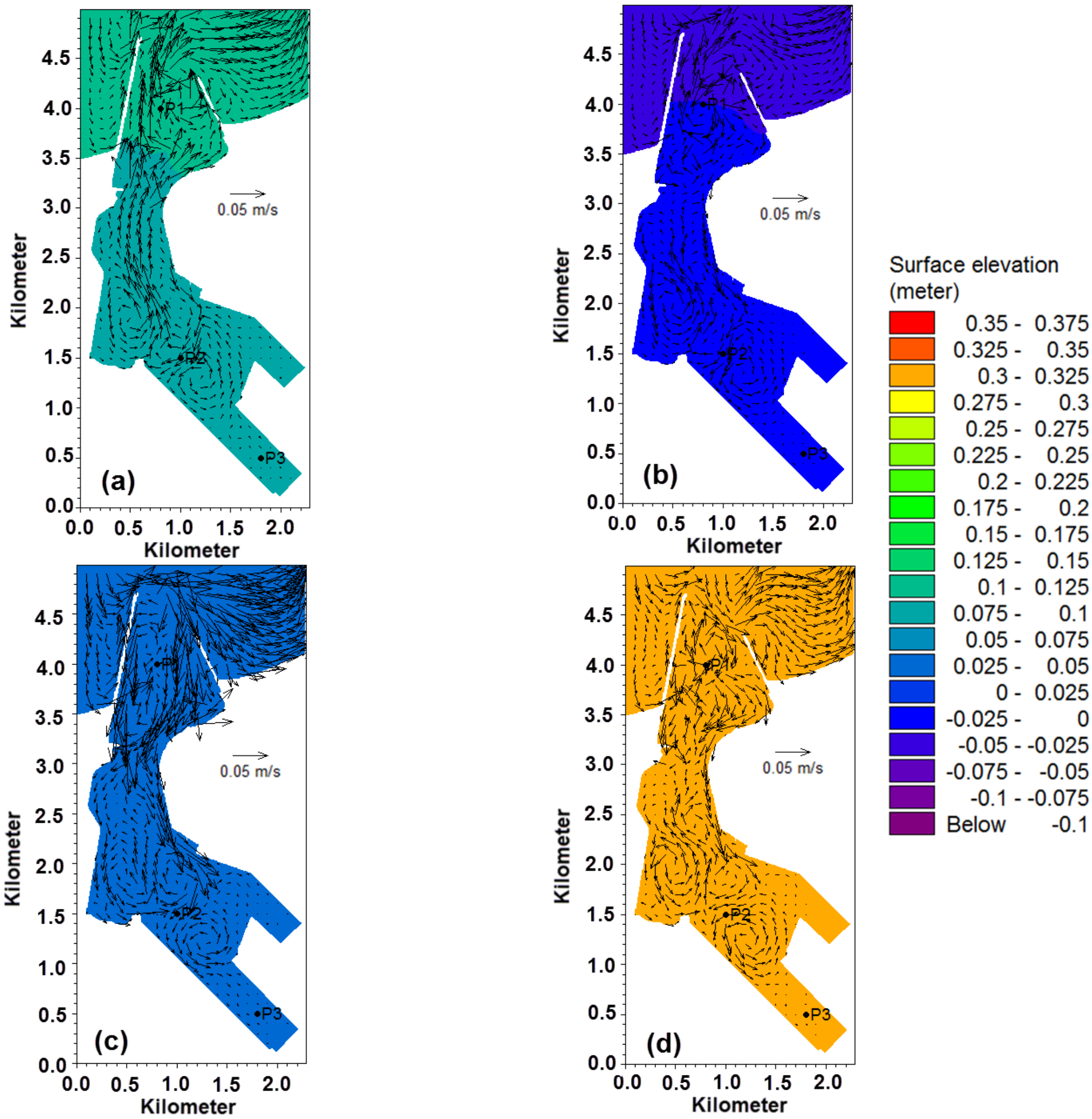

Figure 15: Snapshots of the Flow Visualization During (a) Ebb, (b) Low Tide, (c) Flood and (d) High Tide

5.3 Particle Tracking Results

Based on the 2D plots of the Particle Tracking technique, which was used to simulate the transport of pollutant in the port basin, in order to predict the pollutant particles movement (as shown in Figure 16), in the case of any spill at the bunkering wharf, the particle tracking pattern simulation shows that there is no fear from pollutants to enter and reside inside the basin where current flows through that region takes it on its way out of the port basin.

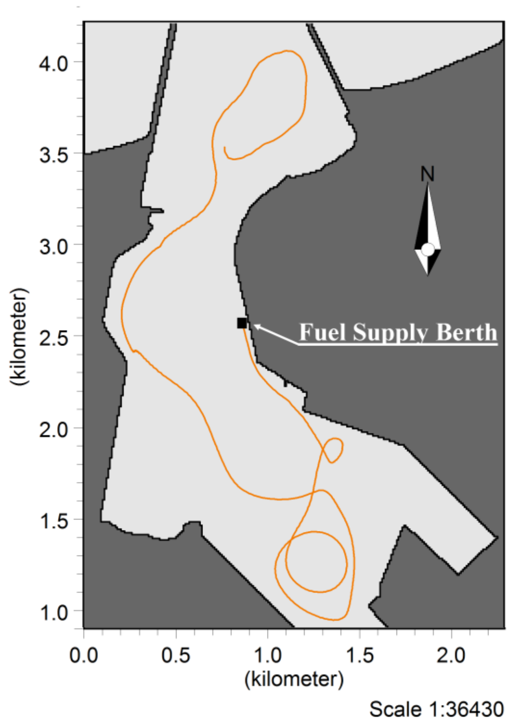

Figure 16: The track of the floater thrown in front of the fuel supply berth

6. CONCLUSIONS

- At the port entrance, the current speeds are larger compared with the turning sub-basins current speeds, and it decreases as we head to the eastern and southern basins at the closed ends of the water body.

- It is clear from the results that the flushing of the port basin is better due to the higher exchange with the Mediterranean Sea. Fortunately, this good exchange of the fresh water explains the reason behind that there is no pollution problems informed from the port beginning date of operation in July 1986.

- For the stagnate areas of the port where the water has been observed almost stopped for some time at the eastern and southern sub-basins, the continuous process of Vessels berthing and leaving navigation movement inside these basins (which does not appear in this simulation) will easily help to fix this problem.

7. RECOMMENDATIONS

- It is highly recommended that in the case if the future extension in the eastern sub-basin is constructed, to observe the environmental situation regularly, through testing water samples and surface bed soil samples from multiple locations in the new eastern sub-basin. In this way, we will know the seasons, which represent a greater stagnation risk on the basin the environmental situation, and to remedy any hazard in the case of pollutants percentage increase.

- This mathematical model could be developed to determine the impact of any planned offshore facilities created, or the effect of the port future extensions, or dredging some areas for the purpose of deepening on the hydrodynamic characteristics of the basin.

- This study was conducted on a short time of the year randomly chosen to represent the summer season. Therefore, it is recommended to conduct three additional mathematical models to represent the other three seasons of the year. In order to determine the whole picture about the hydrodynamic characteristics attitude around the year.

8. REFERENCES

[1] CoRI. Coastal Research Institute. "Sedimentation Problems of Damietta Harbor Navigation Channel." Consulting Report to Damietta Port Authority. 1998.

[2] Daoud, A. H. and A. G. Abul Azm. "Modeling Tidal Current and Pollutant Concentration of a Tidal Lagoon in Hurghada, Egypt. "Proceedings of the 8th International Conference on Coastal and Port Engineering in Developing Countries. India, 2012.

[3] Daoud, A.H. A Two-Dimensional Hydrodynamic Model for Coastal Areas Based on Finite Volume Technique. Ph.D. Dissertation. Giza, Egypt: Cairo University, 2004.

[4] Damietta Port Authority Official Website. n.d. 01 2016. <http://www.dpa.gov.eg/?page_id=561>.

[5] Frederie Harris, H. Ismail, M. Morsi. "Master Planning and Infrastructures Development for the Port of Damietta." Consulting Report to Ministry of Reconstruction and new Communities. July 1979.

[6] Klein, R. "Hydrodynamic Simulation with MIKE21 of Mele Bay and Port Vila, Vanuatu". SOPAC Technical Report 263. Nabua, Suva, Vanuatu, August 1998.

[7] MIKE 21 Flow Model FM HD Module User Guide. DHI Water & Environment Ltd., 2007.

[8] MIKE 21 Tide Analysis and Prediction Module - Scientific Documentation. DHI Water & Environment Ltd., 2007.

[9] Wikipedia the free encyclopedia. n.d. 2 2016. <www.wikipedia.org>.