REPORT Nº 4: DISPERSION AND RECIRCULATION STUDY

Document history:

Rev.	DATE	Notes
0	16/09/2021	First edition

ÍNDICE

1. INTRODUCTION

This document was written to describe modelling studies carried out to assess the intake and outfall pipelines offshore position in the desalination plant in Aqaba, Jordan, with a 300 M m^3/year capacity for two conversion rates: 42% & 45%.

The objective is to determine the hydrodynamics and saline dispersion (brine path) from the outfall and estimate the possible brine recirculation potential through the intake's pipelines. The concentration above the ambient will be assessed at different distances too.

In **Report 3** a Near Field study and diffuser design was developed with brIHne model for the defined production and the two conversion rates. The far field modelling results will show what will be the brine path after the near field (it is expected that brine plume will flow along the bathymetry down slope), and what will be concentration above the ambient at different distances:

i) End of near field (assumed the same as near field model)
ii) 500m from the diffusers
iii) 1000m from the diffusers
iv) 2000m from the diffusers
v) 3000m from the diffusers

The MOHID digital model, which will be described further below, will be used for this purpose.

2. DESCRIPTION OF THE MODEL

The desalination reject water has a salinity of around double that of seawater which means it is much denser. When this water is discharged into the sea, it sinks (negative buoyancy) due to the higher density and forms a dense and hypersaline layer that moves along the bottom of the sea following the local bathymetry.

When the discharge collides against the seabed, a hydraulic jump forms and, after this, the dense layer moves as a density current. This dense and hypersaline layer can be harmful to benthic organisms in the affected area which requires a discharge system that is capable of adequately diluting the brine to ensure there is no damage to the marine environment.

The highest dilution levels are achieved during the initial dilution process when the turbulent discharge water is mixed with the receiving body. The initial dilution process mainly depends on the discharge parameters (diffuser type, number of outlet ports, diameter of the outlet ports, etc.) meaning this is the process where the designer can work to improve the discharge dilution.

Later, the dilution in the far field is more conditioned by the local hydrodynamics with much lower dilutions.

After making the diffuser design and the Near Field study in the Report 1, a widely contrasted model shall be used to study the dispersion along the far field: MOHID.

MOHID is the short name for Modelo Hidrodinâmico which means Hydrodynamic Model in Portuguese that was the original purpose of the model when it was created back in 1985. MOHID Water Modelling System is a modular finite volumes water modelling system written in ANSI FORTRAN 95 using an object-oriented programming philosophy, integrating diverse numerical models, and supporting graphical user interfaces that manage all the pre- and post-processing. It is an integrated modelling tool able to simulate physical and biogeochemical processes in the water column as well as in the sediments and is also able to simulate the coupling between these two domains and the latter with the atmosphere.

The MOHID system includes a baroclinic hydrodynamic module for the water column and a 3D for the sediments and the correspondent eulerian transport and lagrangian transport modules. Parameters and processes involving non-conservative properties are object of specific modules (e.g. turbulence module, water quality, ecology and oil transformation). The turbulence module uses the well-known GOTM turbulence model.

The model is being developed by a large team from Instituto Superior Técnico in close cooperation with Hidromod Lda and includes contributions from the permanent research team and from a large number of Ph.D students on Environmental and Mechanical Engineering and from IST master course on Modelling of the Marine Environment. Contributions from other research groups have also been especially important for the development of the model.

With the growing model complexity, it was necessary to introduce an object-oriented programming in FORTRAN like described in Decyk (Decyk, et al., 1997). The philosophy of the new Mohid model (Miranda, et al., 2000), further on simple designated Mohid, permits to use the model in any dimension (one-dimensional, two-dimensional or three-dimensional). The whole model is programmed in ANSI FORTRAN 95, using the objected orientated philosophy.

The subdivision of the program into modules, like the information flux between these modules was object of a study by the Mohid authors.

Mohid model is composed by over 40 modules which complete over 150 mil code lines. Each module is responsible to manage a certain kind of information. The main modules are the modules listed below. Another important feature of Mohid is the possibility to run nested models. This feature enables the user to study local areas, obtaining the boundary conditions from the "father" model. The number of nested models is just limited by the available computer power.

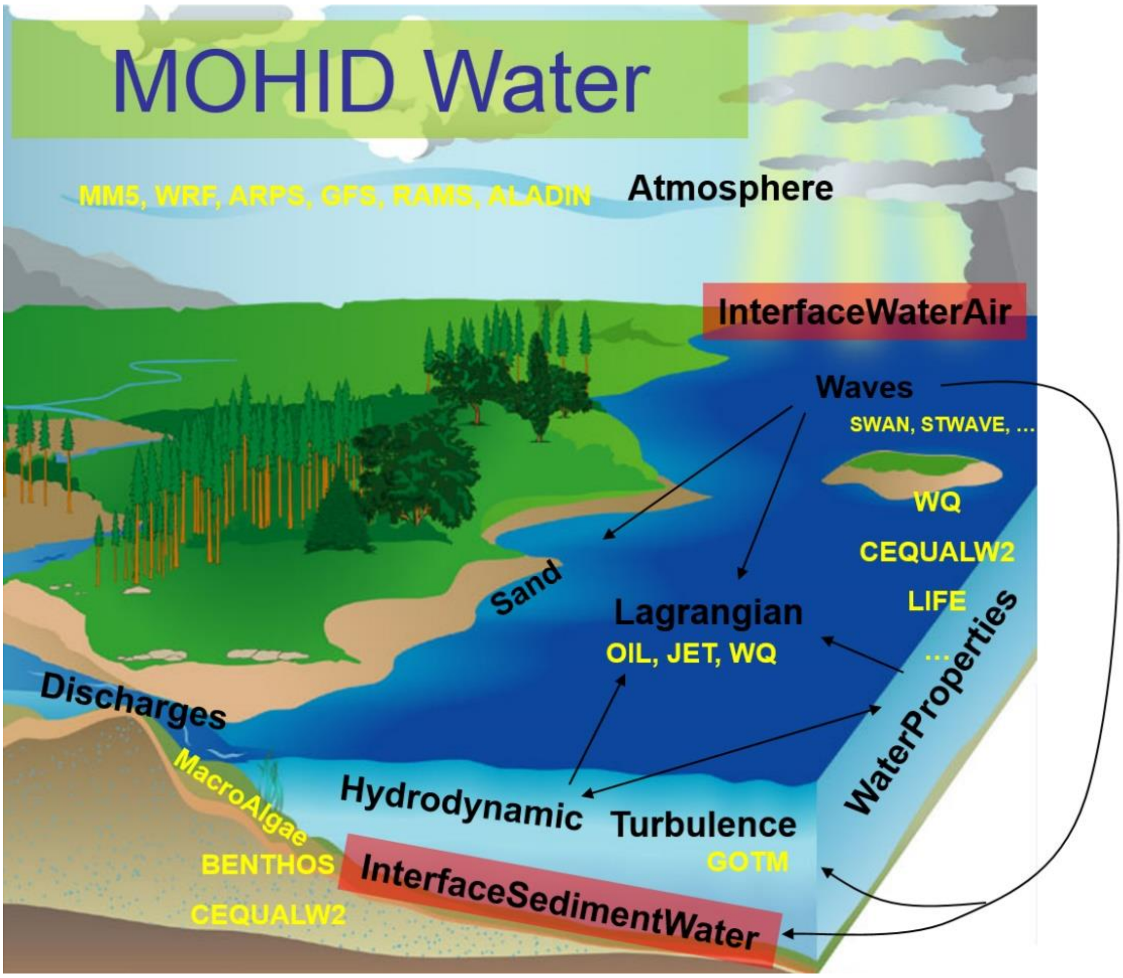

Figure 1. MOHID functioning scheme

The main MOHID modules are defined below:

Model This module manages the information flux between the hydrodynamic module and the two transport modules and the communication between nested models.

Hydrodynamic Full 3D dimensional baroclinic hydrodynamic free surface model. Computes the water level, velocities and water fluxes.

Water Properties Eulerian transport model. Manages the evolution of the water properties (temperature, salinity, oxygen, etc.) using a eulerian approach.

Lagrangian Lagrangian transport model. Manages the evolution of the same properties as the water properties module using a lagrangian approach. Can also be used to simulate oil dispersion.

Water Quality Zero-dimensional water quality model. Simulates the oxygen, nitrogen, and phosphorus cycle. Used by the eulerian and the lagrangian transport modules. Based on a model initially developed by EPA (Bowie, et. al., 1985).

Oil Dispersion Oil dispersion module. Simulates the oil spreading due thickness gradients and internal oil processes like evaporation, emulsification, dispersion, dissolution and sedimentation.

Turbulence One-dimensional turbulence model. Uses the formulation from the GOTM model.

Geometry Stores and updates the information about the finite volumes.

Discharges River or Anthropogenic Water Discharges

The Lagrangian and oil dispersion modules were not used in this study given that the discharge was water.

The MOHID model has been applied to several coastal and estuarine areas and it has showed its ability to simulate complex features of the flows. Several different coastal areas have been modelled with MOHID in the framework of research and consulting projects.

Along the Portuguese coast, different environments have been studied, including the main estuaries (Minho, Lima, Douro, Mondego, Tejo, Sado, Mira, Arade and Guadiana) and coastal lagoons (Ria de Aveiro and Ria Formosa), INAG [2001]; Martins et al. (2000). The model has been also implemented in most Galician Rías: Ría de Vigo by Taboada et al., (1998), Montero, (1999) and Montero et al. [1999], Ría de Pontevedra by Taboada et al. [2000] and Villarreal et al. [2000] and in other Rías by Pérez Villar et al [1999].

Far from the Atlantic coast of the Iberian Peninsula, some European estuaries have been modelled - Western Scheldt , The Netherlands, Gironde, France by Cancino and Neves, [1999] and Carlingford, Ireland, by Leitão, [1997] - as well as some estuaries in Brazil (Santos SP and Fortaleza).

Regarding to open sea, MOHID has been applied to the North-East Atlantic region where some processes including the Portuguese coastal current, Coelho et al. (1994), the slope current along the European Atlantic shelf break, Neves et al. (1998) and the generation of internal tides, Neves et al. (1998) have been studied and also to the Mediterranean Sea to simulate the seasonal cycle, Taboada, (1999) or the circulation in the Alboran Sea, Santos, (1995).

More recently MOHID has been applied to the several Portuguese freshwater reservoirs Monte Novo, Roxo and Alqueva, (Braunschweig, 2001), to study the flow and water quality.

The hydrodynamic model solves the primitive continuity and momentum equations for the surface elevation and 3D velocity field for incompressible flows, in orthogonal horizontal coordinates and generic vertical coordinates, assuming hydrostatic equilibrium and Boussinesq approximations.

Module WaterProperties is the 3D eulerian transport module included in MOHID. Module WaterProperties is responsible for computing the properties evolution in the water column. To do so, this module uses other modules, responsible for specific processes like Module AdvectionDiffusion, which computes properties transport, or Module WaterQuality which is one of the three available modules to compute biogeochemical processes, and so on. MOHID is prepared to simulate properties such temperature, salinity, cohesive sediments, phytoplankton, nutrients, contaminants, etc.

Density is computed depending on salt, temperature, and pressure, by the UNESCO equation of state (UNESCO, 1981). The model uses an ADI (Alternate Direction Implicit) time discretization scheme which minimizes stability restrictions and is defined in an Arakawa-C type grid. In the bottom, shear stress can be computed with the assumption of a logarithmic velocity gradient.

3. INPUT DATA

3.1. FLOW DESIGN PARAMETERS

Following the desalination process study by the plant engineering team, the volume of water for the two possible recovery varies as follows considering a recovery during the process:

- Case 1: Recovery = 42%; Brine discharge = 48,756 m^3/h
- Case 2: Recovery = 45%; Brine discharge = 43,152 m^3/h

3.2. GRID REFERENCE

The horizontal coordinates used are Easting and Nothings relative to UTM WGS84 Zone 36 N.

The vertical datum is relative to Lowest Atmospheric Tide (LAT), which is assumed to be equal to the Datum of Soundings at the site.

3.3. BATHYMETRY

The bathymetry was obtained from different sources.

The detailed bathymetry is obtained from local surveys (see Figure 2).

This bathymetry is complemented with a major-scale bathymetry obtained from GEBCO. The General Bathymetric Chart of the Oceans (GEBCO) consists of an international group of experts who work on the development of a range of bathymetric data sets and data products, with the aim of providing the most authoritative, publicly available bathymetric data sets for the world's oceans.

GEBCO operates under the joint auspices of the International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

The GEBCO_2014 Grid is a continuous terrain model for ocean and land with a spatial resolution of 30 arc seconds.

The GEBCO information used in the study is shown in Figure 3.

The vertical datum and chart datum are at the same level as the Lowest Astronomical Tide (LAT), which is the lowest levels which can be predicted to occur under average meteorological conditions.

Figure 2. Bathymetry in the Project Area.

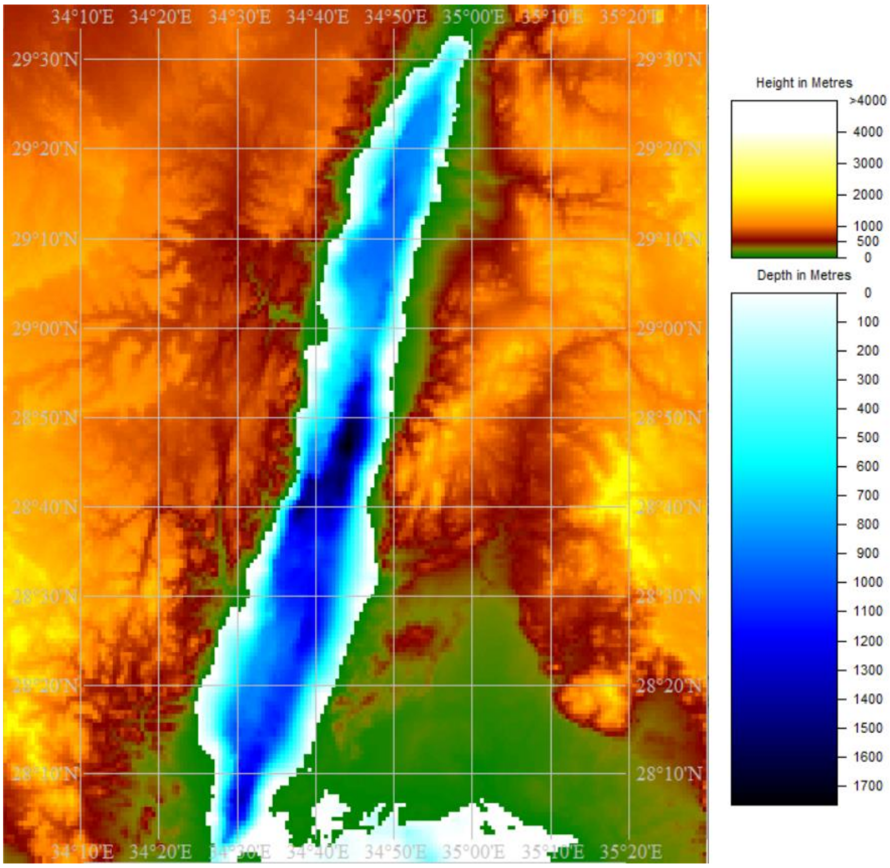

Figure 3. GEBCO bathymetry in the Gulf of Aqaba.

3.4. DIFFUSER AND INTAKE DEFINITION

Regarding the diffuser design, two cases were analyzed based on the recovery rates.

Diffuser system features for each case are shown below:

Diffuser system features -Case 1	
Parameters	
Number of Diffusers	30
Diameter of the Diffuser Port (ID):	300 mm
Velocity of each diffuser:	6.40 m/s
Separation between diffusers:	15.5 m
Diffuser angle to the horizontal:	60 º

Diffuser system features -Case 1	
Parameters	
Depth of seabed at the diffusers	- 25 m

As can be seen, 30 outlet ports with an ID 300 mm comprises the diffuser system. Each port is separated 15.50 m (total length of 217 m). Outlet ports are arranged by pairs, back to back.

For this case, the **dilution achieved is 1: 68.60** at the end of the near filed region (spreading layer) which is higher than required. The salinity obtained at the same point is 41.20 psu which represents an increment of **1.06%** concerning seawater salinity, resulting lower than the admissible salinity (2% more than ambient salinity, i.e 41.616 psu).

Diffuser system features -Case 2	
Parameters	
Number of Diffusers	30
Diameter of the Diffuser Port (ID):	300 mm
Velocity of each diffuser:	5.65 m/s
Separation between diffusers:	12.70 m
Diffuser angle to the horizontal:	60 º
Depth of seabed at the diffusers	- 25 m

Same concept is used for case – 2 diffuser set-up in terms of total number of diffusers and outlet port inner diameter.

For this case, the **dilution achieved is 1: 56.90** at the end of the near filed region (spreading layer) which is higher than required. The salinity obtained at the same point is 41.38 psu which represents an increment of **1.44%** concerning seawater salinity, resulting lower than the admissible salinity (2% more than ambient salinity, i.e 41.616 psu).

More details are given in Report nº 3.

In Figure 4 are shown the locations of the four intake towers and diffusers line-up.

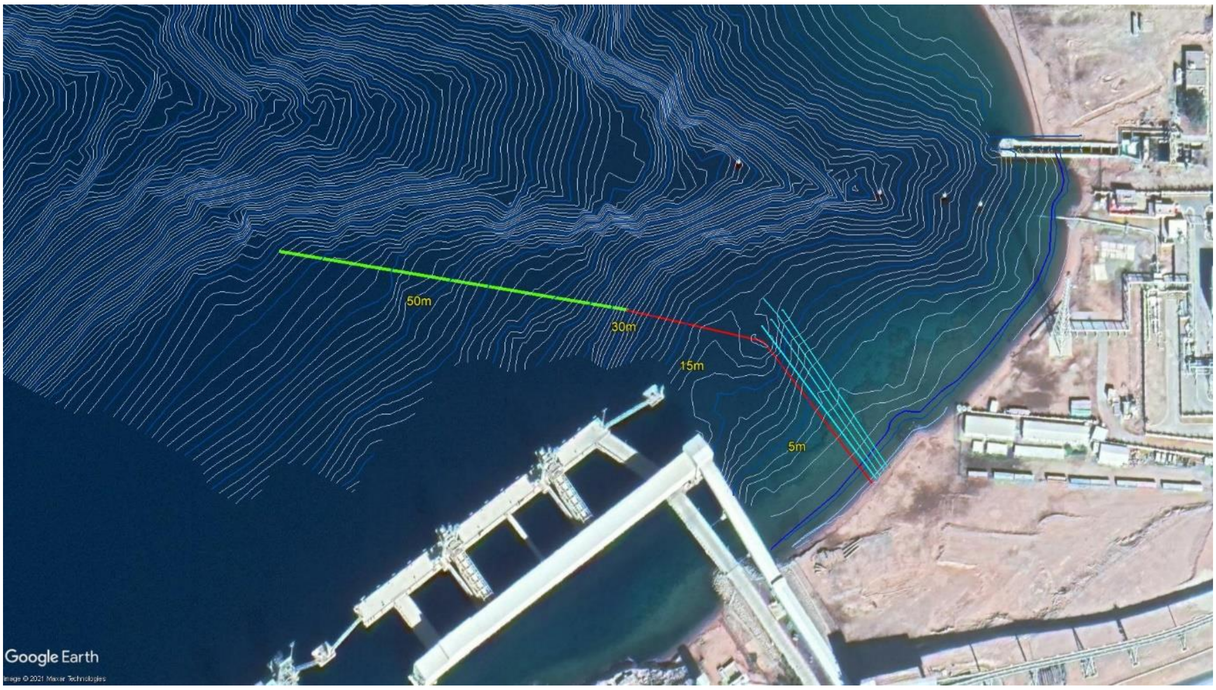

Figure 4. Intake and outfall location.

3.5. SEA WATER SALINITY AND TEMPERATURE

Ambient seawater temperatures were set to 28ºC and a seawater salinity of 40.8 psu was used for this study, according to the Near Field study. The excess salinity of the discharge as compared to the seawater would be 33.4 psu. The discharge value for salinity will be 70.34 psu for 42% recovery and 74.18 psu for 45% recovery.

There will be a discharged excess temperature as compared to the seawater of 1ºC, i.e., a temperature of 29ºC.

3.6. TIDES

The definition of the tide around the domain must be provided, indicating the tidal harmonic constants. Thus, MOHID simulates the tidal curve at each instant throughout the domain.

Harmonic constituents are the harmonic elements in a mathematical expression for the tide producing force and in the corresponding formula for the tidal curve. Each constituent represents a periodic change or variation in the relative positions of the earth, moon, and sun. The descriptions of the main harmonics are:

- 2N2: Lunar elliptic semidiurnal second order
- K1: Lunar diurnal
- K2: Lunisolar semidiurnal
- M2: Principal lunar semidiurnal
- M4: Shallow water overtides of principal lunar
- MN4: Shallow water quarter diurnal
- N2: Larger lunar elliptic semidiurnal
- O1: Lunar diurnal
- P1: Solar diurnal
- Q1: Larger lunar elliptic diurnal
- S2: Principal solar semidiurnal
- MM: Lunar monthly
- MF: Lunisolar fortnightly
- S1: Solar diurnal

For informational purposes, the main harmonic constituents are provided along the external domain, and the model reproduces the propagation of the tidal wave (see Table 1).

TIDAL HARMONICS		
Constituent	Amplitude (m)	Phase (º)
M2	0.267647	114.246
S2	0.0612594	150.149
K1	0.0516119	-159.563
K2	0.0116964	143.981
N2	0.0886161	85.482
2N2	0.00848642	74.5408
O1	0.0135232	137.004
Q1	0.0196409	-165.013
P1	0.00629927	31.4985
Mf	0.00549262	56.1286
Mm	0.00212409	30.0003
Mtm	0.00182196	69.5992
MSqm	0.000274458	73.154

Table 1. Tidal harmonics at the entrance of the Gulf of Aqaba.

The FES2014 database has been used, which facilitates with a resolution of 1/8ºx1/8º the main tidal harmonics throughout the world.

FES2014 was developed by Legos and CLS Space Oceanography Division and distributed by Notice, with the support of Cnes.

To correctly simulate the tidal wave, it is necessary to force the model from the limits of the outer mesh, using multiple points from where the model interpolates at each input node. In this case, the external domain includes the Egyptian and Saudi coasts and the full Gulf of Aqaba. As the Gulf is quite narrow, the location of these points is set on the entrance of the Gulf, where it is connected to the Red Sea.

The variation in the tidal surge along the Red Sea and the Gulf of Aqaba, produces several oscillations over the MSL among the year that are difficult to reproduce in a numerical model, therefore, only the astronomical tides obtained from FES2014 has been reproduced (see Figure 5).

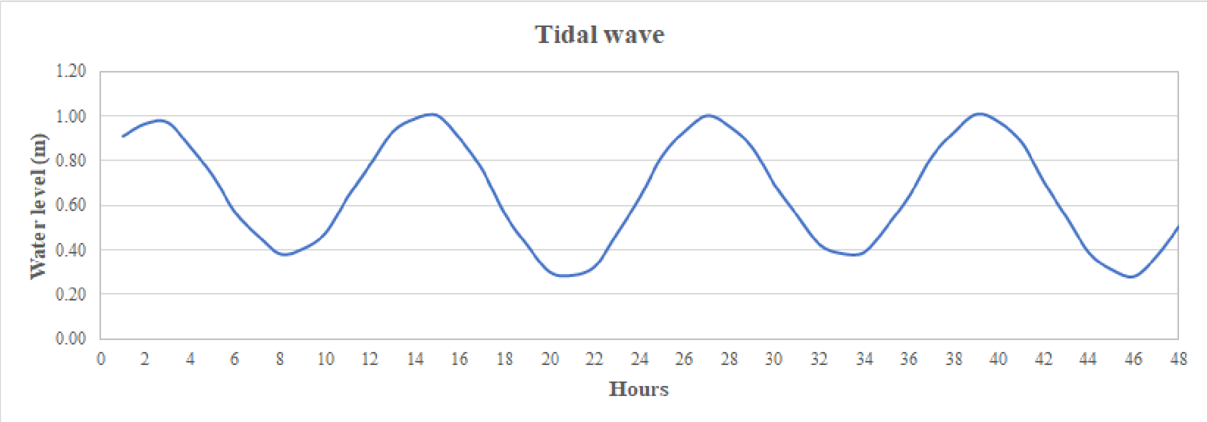

Figure 5. Tidal wave obtained from MOHID at the diffuser point.

3.7. WIND

Wind information and other transferred met-ocean dataset are provided by a CFSR node as hourly information at a Southwest location offshore Aqaba, on the Gulf of Aqaba (Lon=34.8ºE, Lat=29.2ºN).

CFRS is a third-generation reanalysis global product, which offers high accuracy wind dataset for the period from 1979 until at a spatial resolution of 0.2°. The metadata information contains hourly time series of offshore wind:

- W: wind at 10 metres height (m/s)
- Θ_{Wind}: Mean wind direction (degr., meteorological convention)

Wind speed roses are shown in Figure 6, in Figure 7 and in Figure 8 for the representative periods of summer and winter, and for the totality of data in an annual wind speed rose. There are no substantial differences between the winter and the summer rose, so no seasonality is considered for the study.

Finally, the scatter plot of wind speed and wind direction of the total annual data is shown in Figure 9.

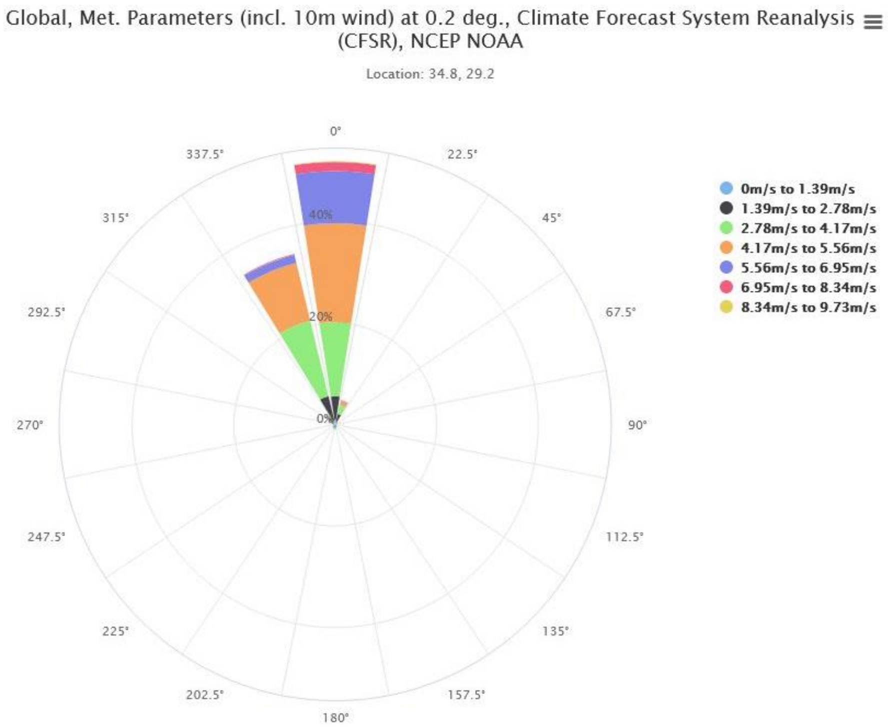

Figure 6. CFSR wind speed rose, representative summer simulation period.

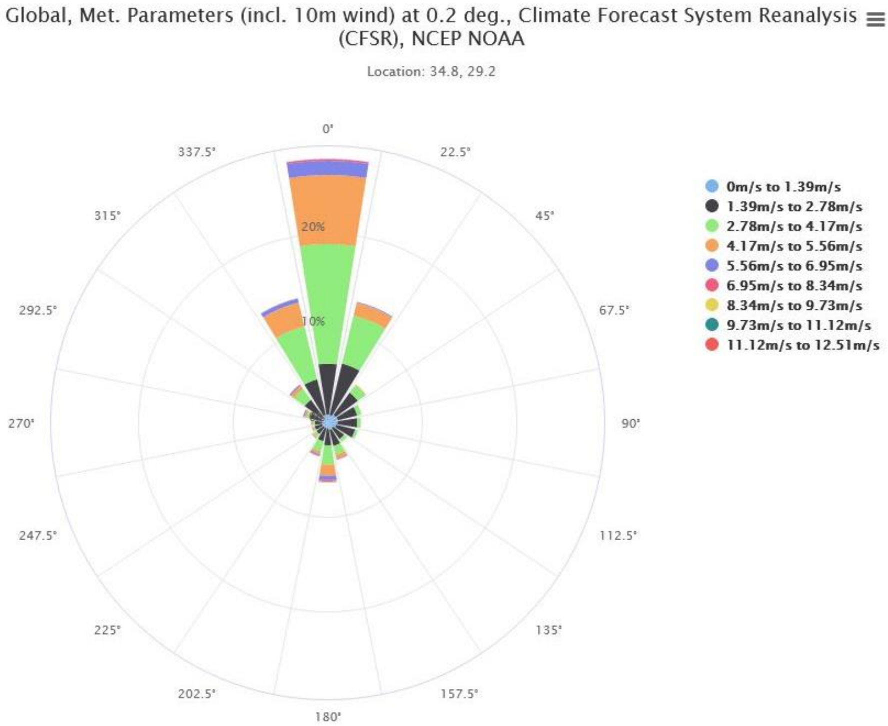

Figure 7. CFSR wind speed rose, representative winter simulation period.

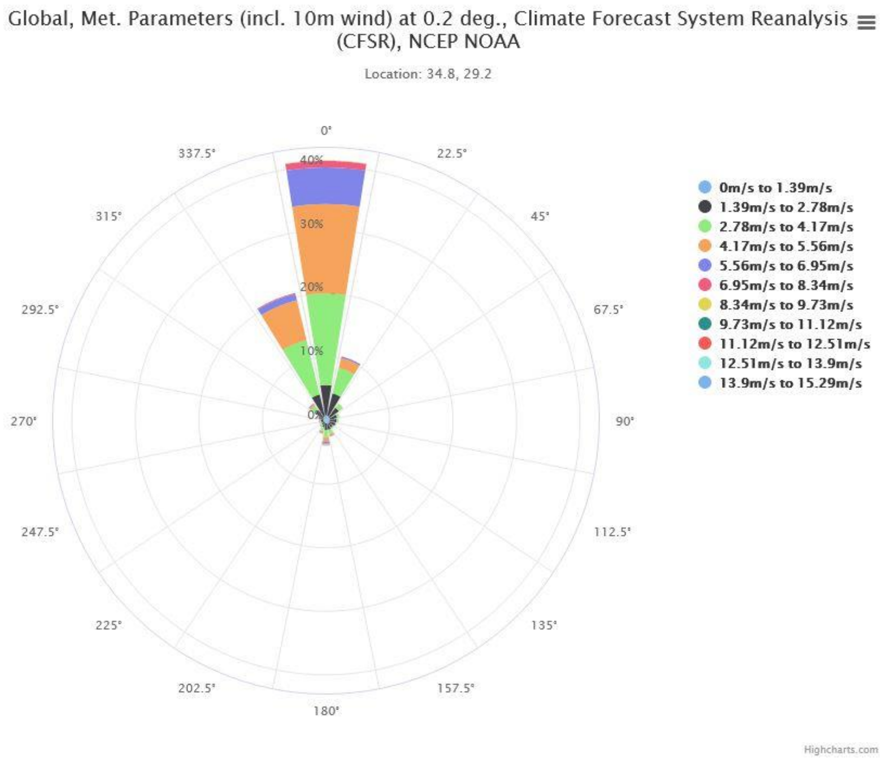

Figure 8. CFSR wind speed rose, annual.

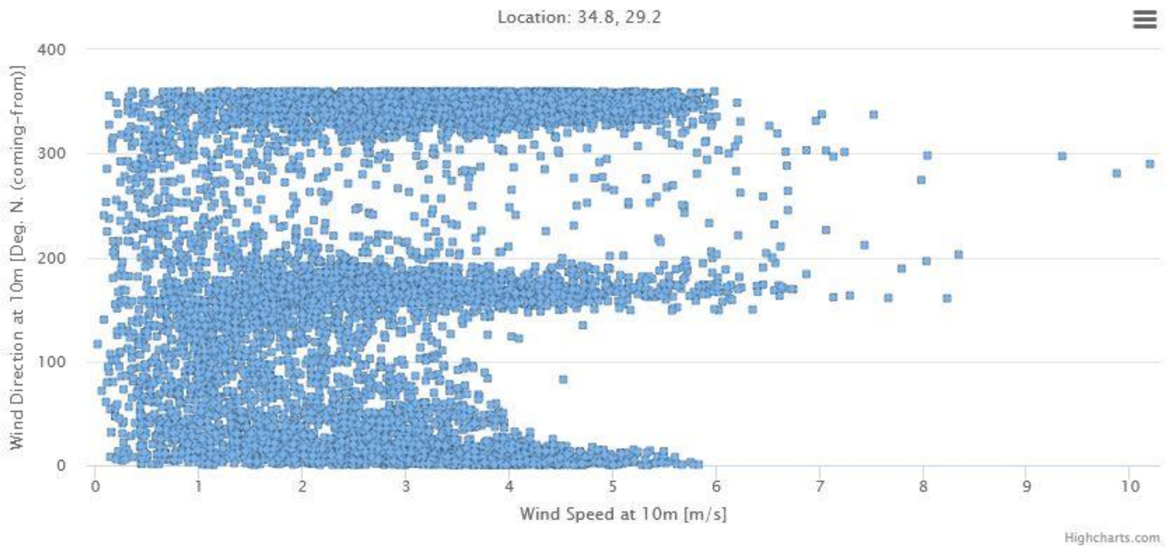

Figure 9. CFSR wind speed and direction scatter plot, annual.

It will be considered the hour-averaged daily wind for the simulations. Figure 10 to Figure 12 show the daily wind for the three different scenarios considered in the studio: mean wind from north, 90th percentile wind from north, and 90th percentile wind from south, respectively.

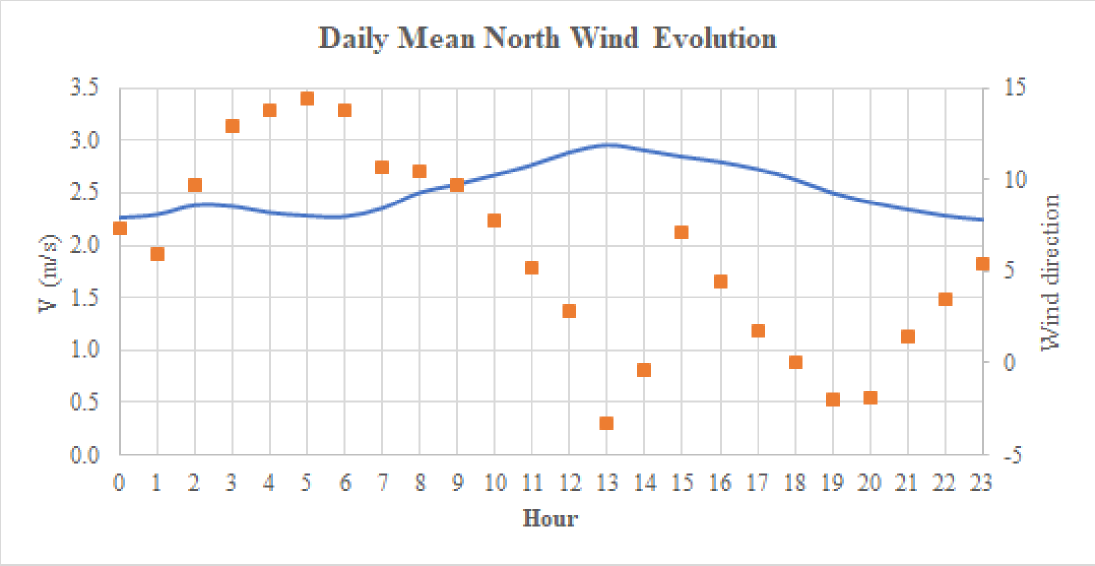

Figure 10. CFSR wind speed hourly series, representative mean wind from north scenario.

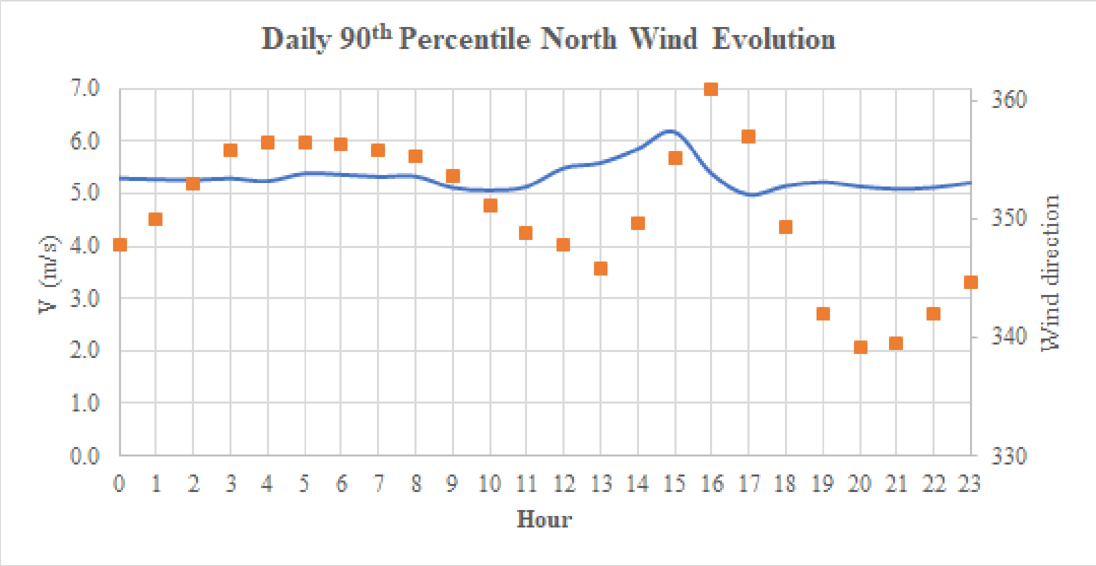

Figure 11. CFSR wind speed hourly series, representative 90th percentile wind from north scenario.

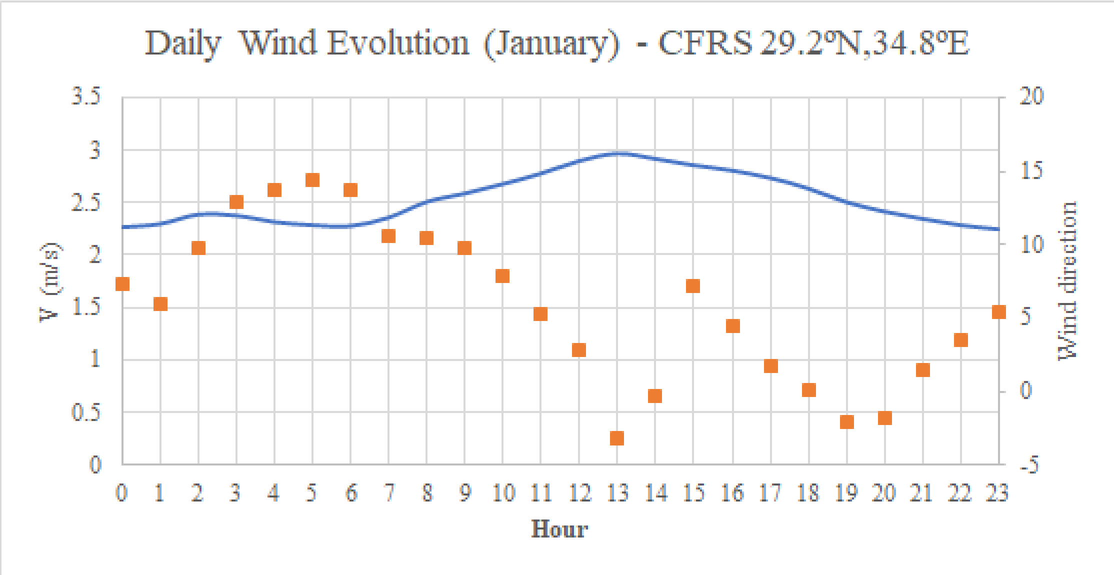

Figure 12. CFSR wind speed hourly series, representative 90th percentile wind from south scenario.

3.8. ENVIRONMENTAL REGULATIONS

Near Filed Study and diffuser design justify the compliment of the Environmental Regulations: the maximum admissible increase of salinity concerning ambient salinity (seawater) is 2% at 100 m from the discharge point.

4. FAR-FIELD DISPERTION AND RECIRCULATION

4.1. MODEL SET-UP

This section describes the calculation methodology used with the MOHID model in this study.

Four nested grids will be used.

A first grid will be used (the "external" domain), which covers the Gulf of Aqaba of some 68,400 m x 171,000 m with a resolution of 900x900m. This first model mesh is resolved in 2D given that it will be used to resolve the tide wave in an area that is extensive enough to consider the spatial variability thereof.

Later, a nested model ("intermediate" model) is defined with a 36 Km x 36 Km mesh, expanding the grid resolution by a ratio of 1:5, all the way to 180x180m. The domain is resolved in 2D. See Figure 13.

An additional nested model ("approximation" model) is defined with a 7.8 Km x 7.8 Km mesh, expanding the grid resolution by a ratio of 1:3, all the way to 60x60m. The domain is resolved in 3D using 5 vertical layers.

Finally, a "local" domain is added measuring approximately 2 Km x 2 Km which covers the outfall and intake area, with a certain margin to study the outfall in detail. The grid resolution is about 20x20 m, in 3D using 12 vertical layers. See Figure 13.

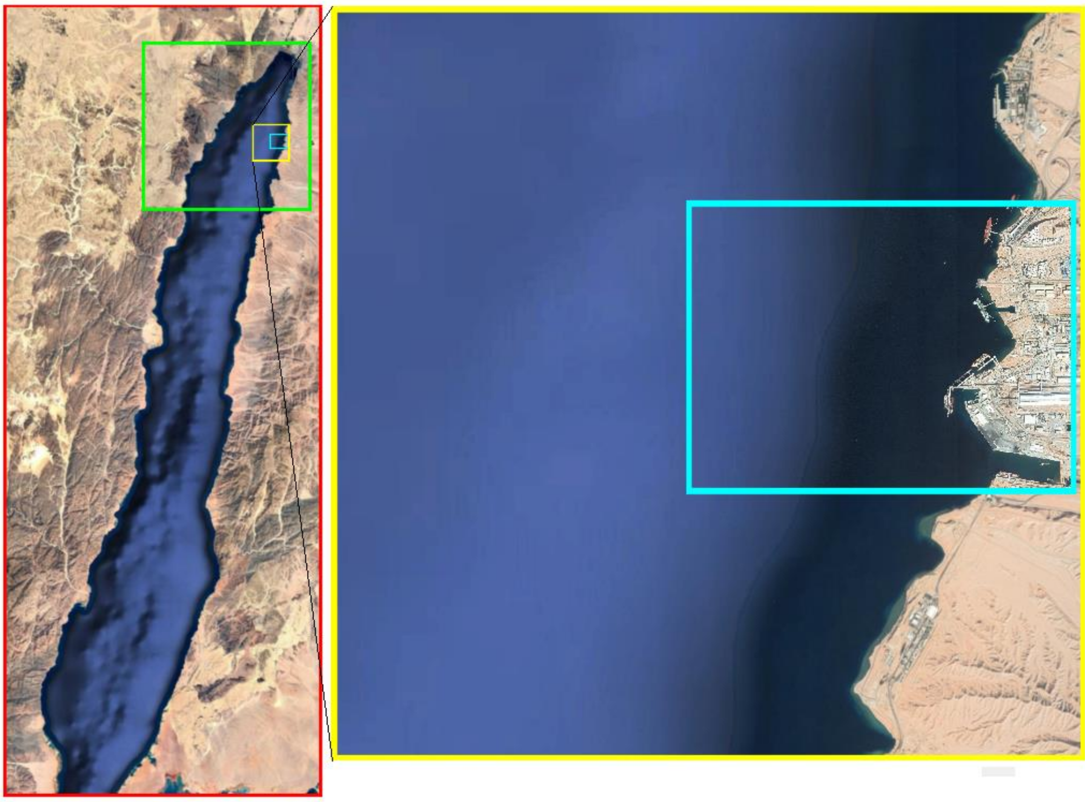

Figure 13. External, intermediate, approximation and local domains.

The vertical discretization of the MOHID Model is resolved with the Geometry Module which makes it possible to divide the water column into different types of vertical coordinates including the most common Cartesian and Sigma ones. In this case, the "sigma" discretization was chosen (see Figure 14).

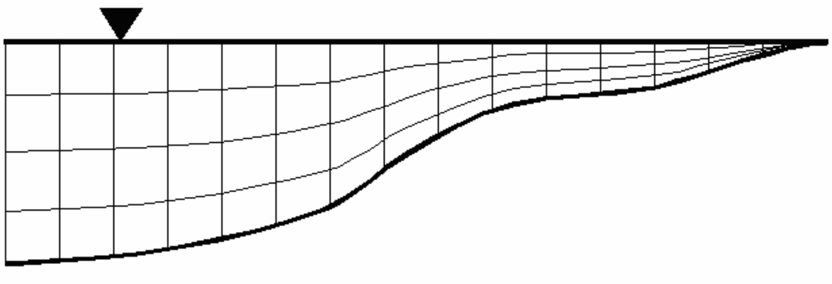

Figure 14. Scheme of sigma coordinates.

The size of each one of the 12 layers is taken from the following total percentage of the water depth:

- Local model: 4.5% 5.5% 5.5% 6.5% 6.5% 7.5% 8.5% 9.5% 10.5% 12.5% 13.5%.

The reason for nesting four domains is that a fine discretization makes no sense in major areas where the bathymetric resolution is weak (nautical chart) and where it is also not necessary to refine the hydrodynamic resolution.

For this reason, a thicker grid is used outside of the area of interest where only GEBCO data are available as opposed to where the outfall and intake are located and where more accurate bathymetric data are available. Moreover, it significantly reduces the calculation time.

Once the grids are defined and the bathymetry for the area is available, the depth of each mesh node is calculated via interpolation. Thus, the bathymetry value is obtained for each point of the grid and this is known as "grid data".

As an example, what follows is an image with this terrain model for the “local” domain used.

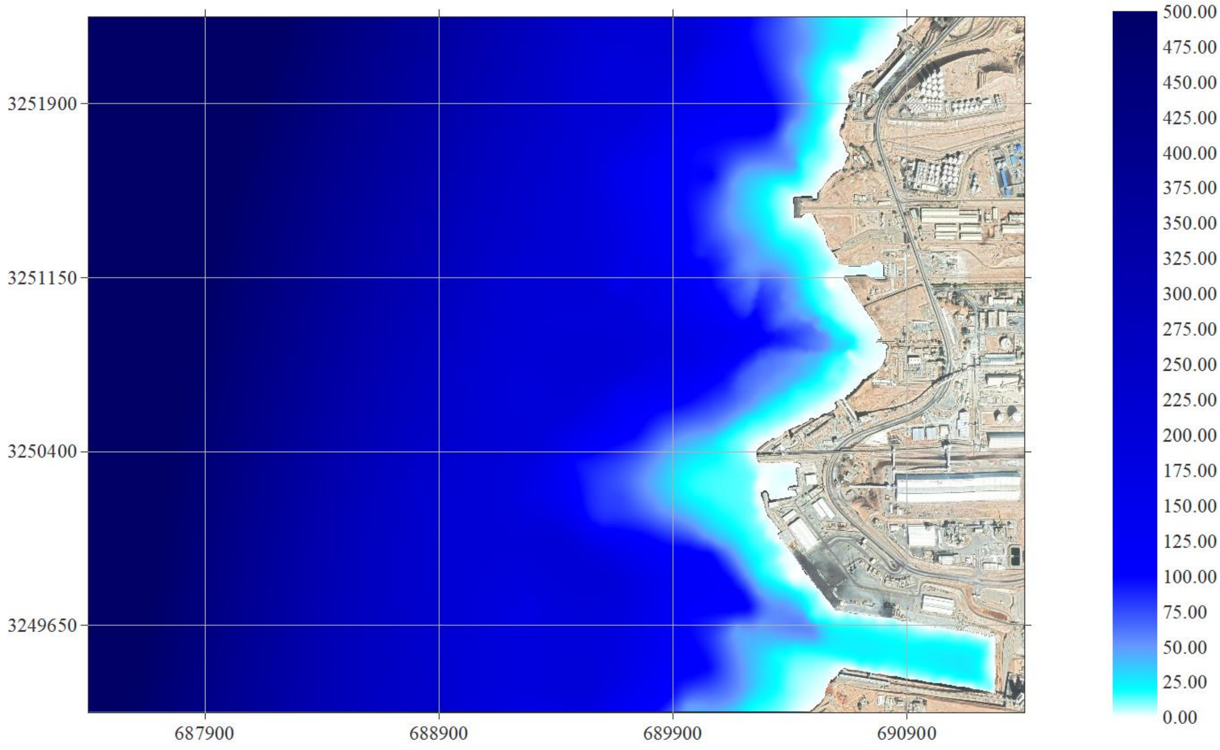

Figure 15. Local domain used in the study.

After the bathymetry is available for the area, the model must be configured by defining the hydrodynamic conditions for the study. Once they are defined, the brine discharge is added to the domain in the plan detail.

The study philosophy is to simulate the most significant hydrodynamic conditions for the tide and wind.

The simulations will be done over 2 days in each scenario, which is considered adequate time to stabilize the simulation. Mean conditions for a North wind will be simulated since it has the highest frequency, along with two more combinations of intense winds from the North and from the South belonging to the 90th percentile. This will be done for the two cases of recovery proposed.

4.2. HYDRODYNAMICS IN THE AREA

The hydrodynamics in the area is conditioned by the existing wind and tide as there is no other important agent that affects the current.

The velocity and direction of currents are variable throughout the day due to the flood tide and ebb tide times vary over the course of the simulation and do not always coincide with the same wind. The wind-induced current can be rather important in the layers closest to the surface, especially in periods of strong wind intensity. An example of the MOHID results considering strong winds is shown in Figure 16, where the hydrodynamics on the surface layer are clearly governed by the south wind induced forcing.

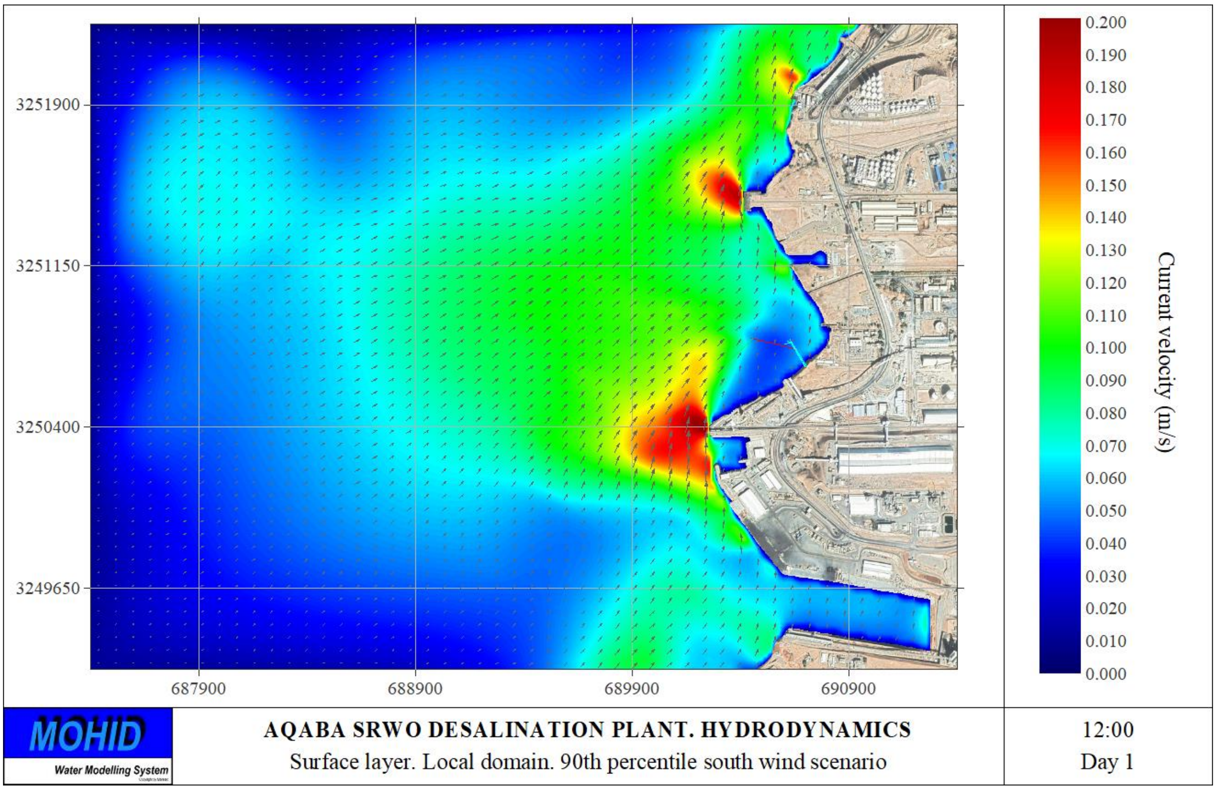

Figure 16. Hydrodynamics at the surface, induced by strong south winds.

Due to the Coriolis effect, this current deviates with respect to the wind speed on the surface. According to Ekman's Theory, the current turns toward the bottom, forming a spiral.

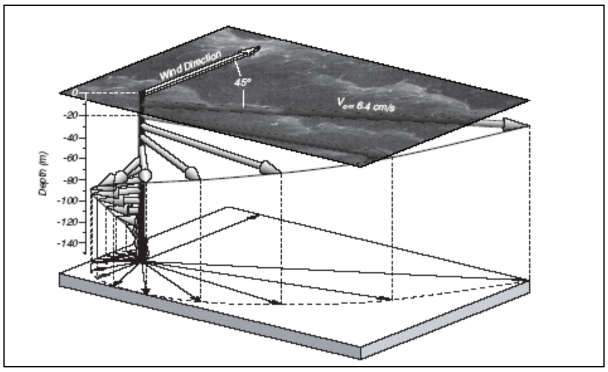

Figure 17. Typical structure of the wind speed profile (Ekman's Theory)

The wind-induced current speeds in the lower layer (desalination plan outfall area) are very low and almost unnoticeable due to the fact that the values get lower, the deeper down. The wave-induced current at these depths is null since there is no break process. Again, the tide-induced current at these depths is quite weak or almost null.

Since the currents on the bottom are so low, the typical behavior occurs once the brine discharge outcomes the diffuser. This behavior is described in the laboratory studies carried out by several organizations, including the Spanish CEDEX. A baroclinic current arises due to the greater density of the water discharged, forming a bottom current that runs along the maximum slope on the bottom. As will be seen bellow, in the next figure, the discharge “ends up forming a layer that is generally hyperdense which flows and spreads along the bottom, tending to go downwards in the direction of the maximum slopes”. In this case, the currents are baroclinic, caused by the hypersaline discharge with a direction towards the deepest area (see Figure 18). Other hydrodynamic results are summarized at the Addendum 1.

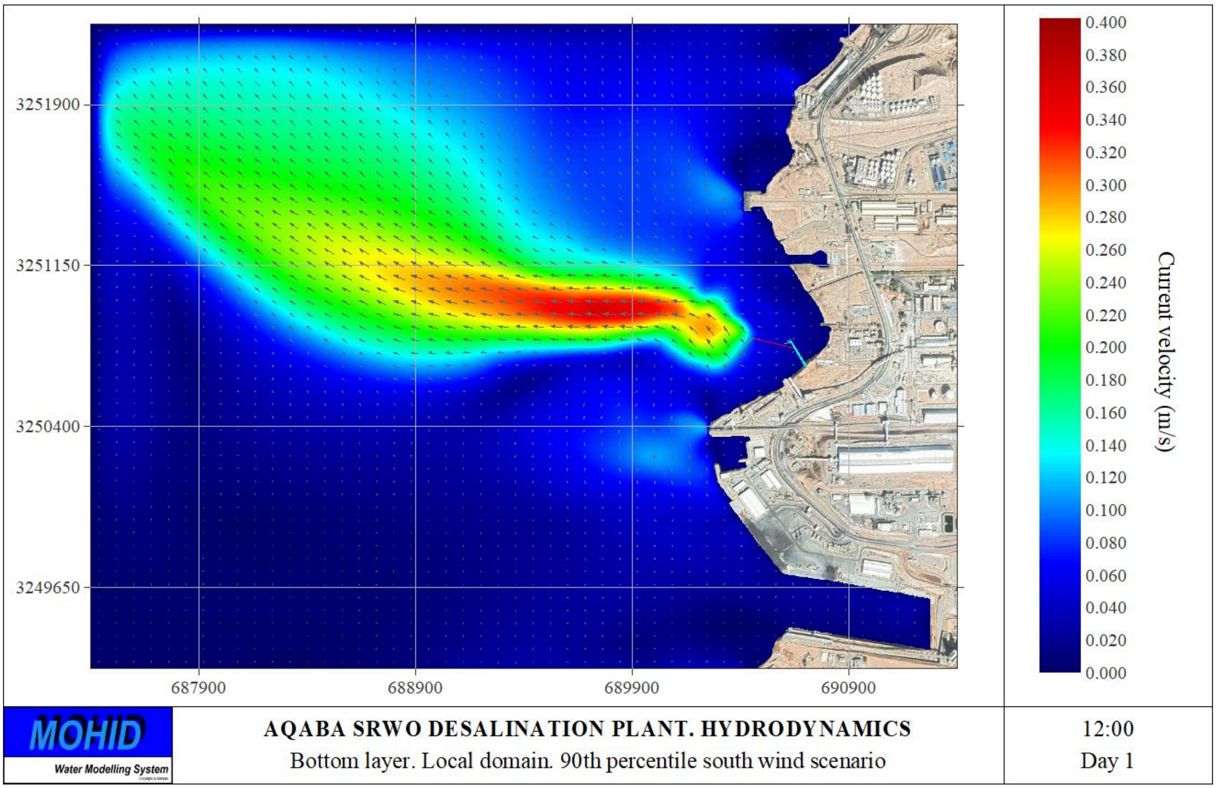

Figure 18. Hydrodynamics at the bottom, considering strong south winds but dominated by baroclinic processes.

4.3. DISPERSION & RECIRCULATION: DISCUSSION OF THE RESULTS

This section studies the dispersion of the brine discharged by the desalination plant for the two cases.

4.3.1. Recovery 42%

Considering the three hydrodynamic scenarios simulated with the recovery of 42%, in Figure 19 the maximum salinity "footprint" can be appreciated, with the brine dispersion on the bottom layer, for the hydrodynamic simulation of a mean North wind. In the same way, the maximum salinity footprint for the 90th percentile for a North wind is shown in Figure 20, and the maximum salinity footprint for the 90th percentile for a South wind is shown in Figure 21.

Salinity at different distances has been obtained too.

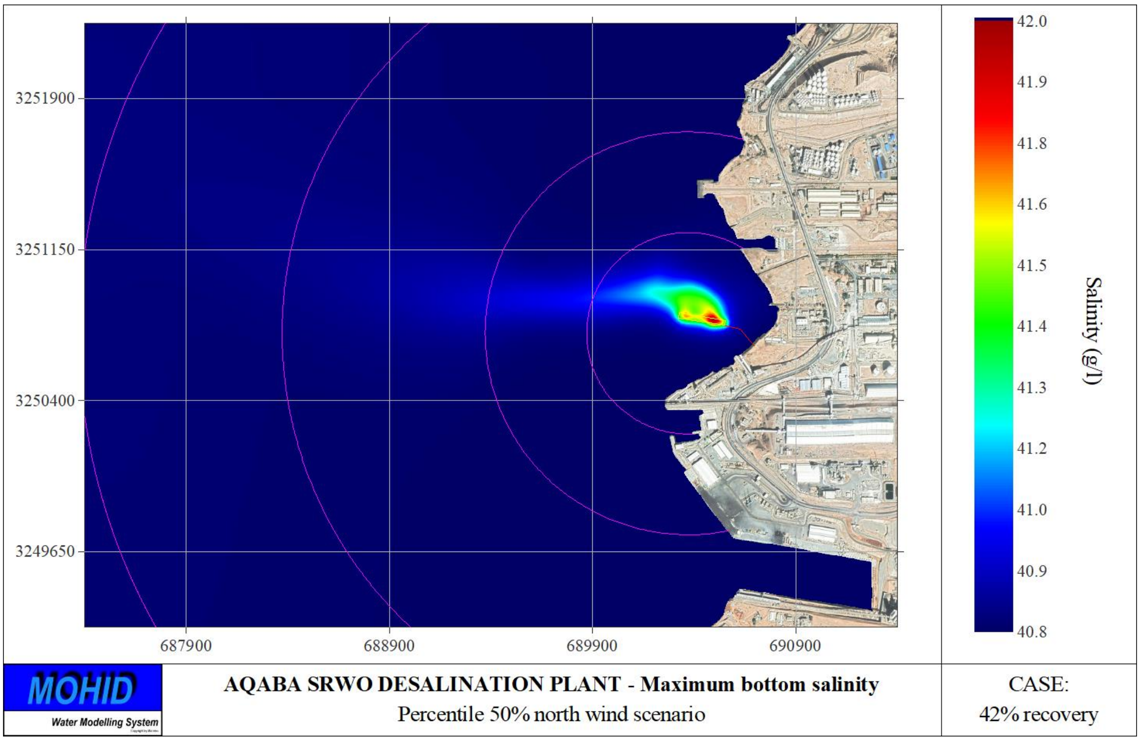

Figure 19. Maximum salinity at the bottom layer in the mean North scenario with 42% of recovery.

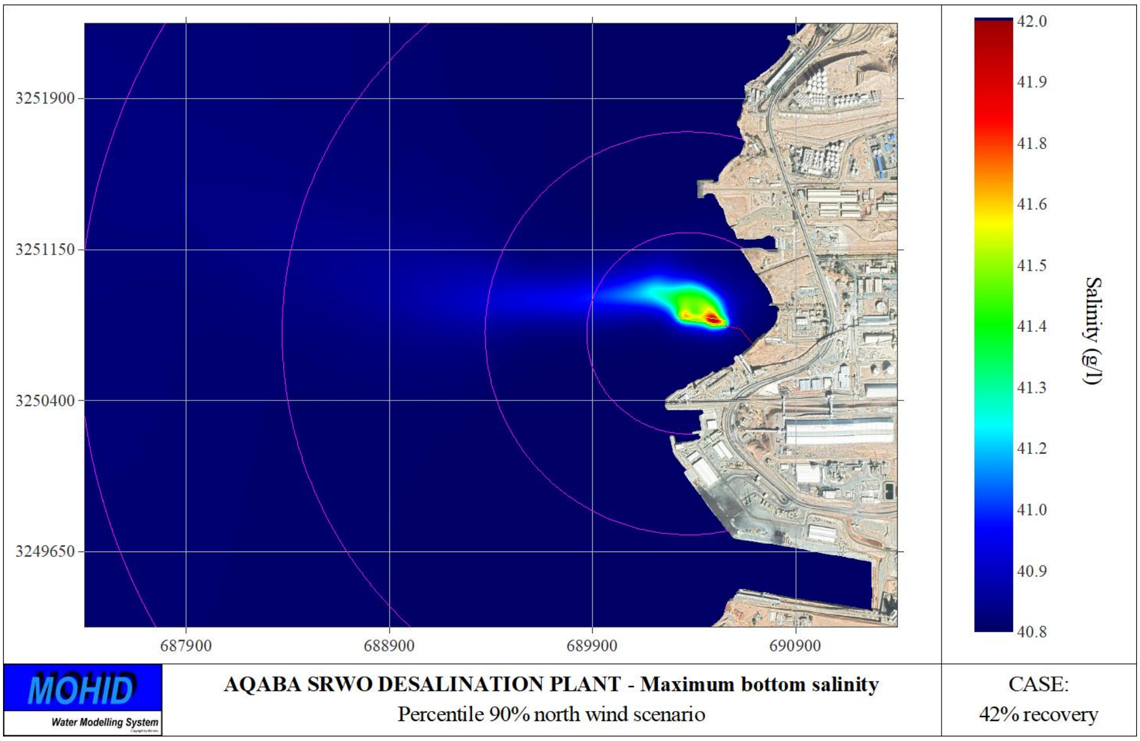

Figure 20. Maximum salinity at the bottom layer in the 90th percentile North scenario with 42% of recovery.

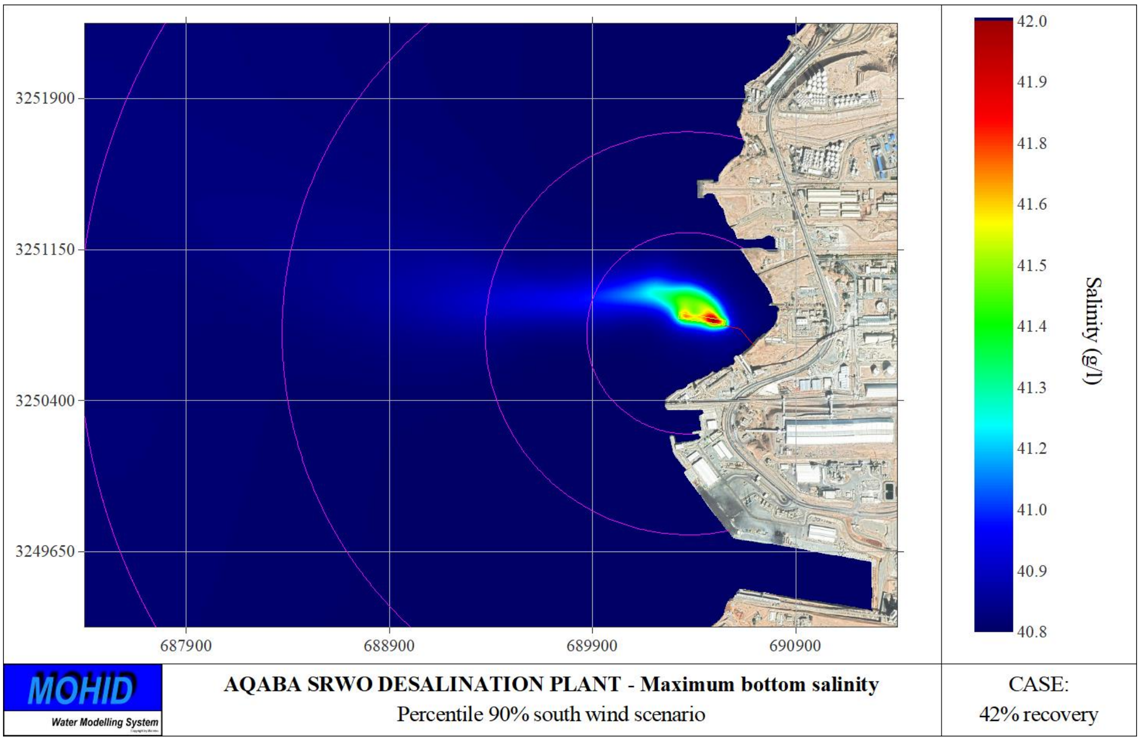

Figure 21. Maximum salinity at the bottom layer in the 90th percentile South scenario with 42% of recovery.

The figures for the three simulations are remarkably similar as the greatest conditioning factor is the baroclinic current generated by the discharge itself and not winds or tides. Thus, changing wind direction or intensity will not substantially affect the discharge dispersion and the three simulations represent all possible combinations of winds and tides. Brine plume will flow, then, following the bathymetry down slope, which, in this case, is really pronounced, letting the plume get dissolved with these high depths.

In Table 2, the value of the salinity for the end of near field, at 500 m away from the diffusers, at 1000 m, at 2000 m, and at 3000 m from the diffusers, can be found for the three scenarios simulated.

Scenario	Maximum salinty (psu) from the diffusers			
	500m	1000m	2000m	3000m
Mean Wind North	41.04	40.95	40.86	40.85
90^{th} Percentil Wind North	41.04	40.95	40.85	40.85
90^{th} Percentil Wind South	41.05	40.94	40.85	40.84

Table 2. Salinity at different distances from the diffusers with 42% of recovery.

Attending to the results at different distances from the diffusers, it can be observed that the wind conditions no affected to those results, and the maximum excess salinities above the ambient are generally small, getting less than 0.25 psu at 500 m, 0.15 psu at 1000 m, and 0.06 psu (or less) at major distances (2000 m and 3000 m)

Figure 22 shows the salinity evolution during the 2 days simulations for mean north wind scenario for the Intakes 1, 2, and 3. This is the scenario that causes the lowest mixing processes, but anyway, the excess salinity values at the intake positions are small (around 0.01 psu), so there will not be any recirculation. Other figures at the Addendum.

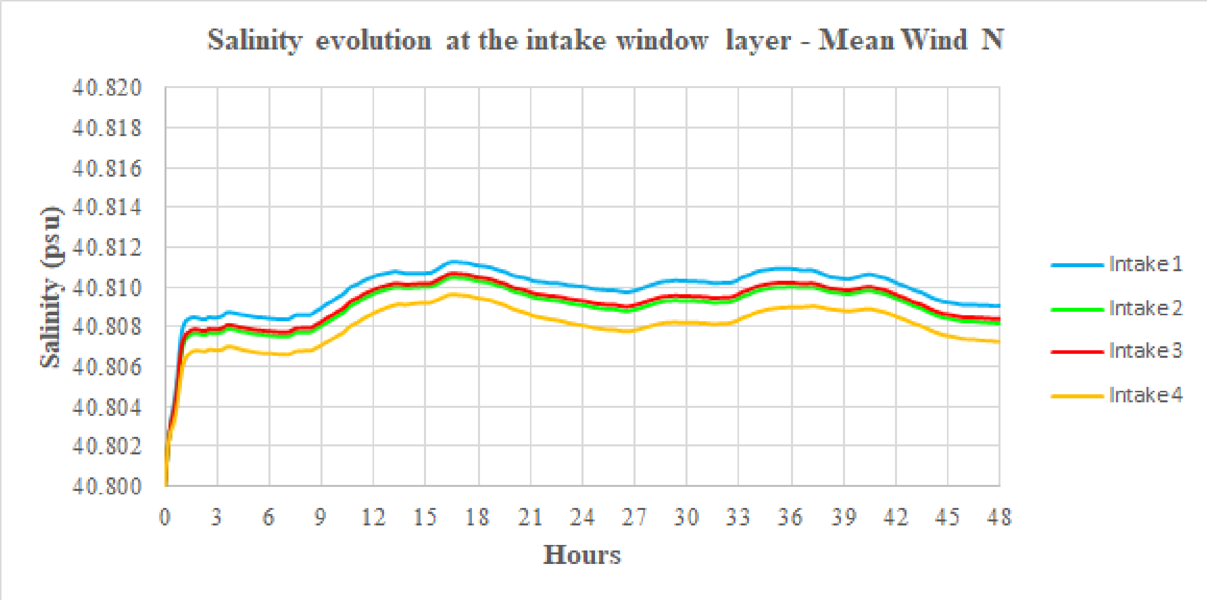

Figure 22. Salinity evolution at intake window with 42% of recovery.

4.3.2. Recovery 45%

In the other side, for the three scenarios simulated with the recovery of 45%, in Figure 23 the maximum salinity footprint for the mean North wind can be appreciated. In the same way, the maximum salinity footprint for the 90th percentile for a North wind is shown in Figure 24, and the maximum salinity footprint for the 90th percentile for a South wind is shown in Figure 25.

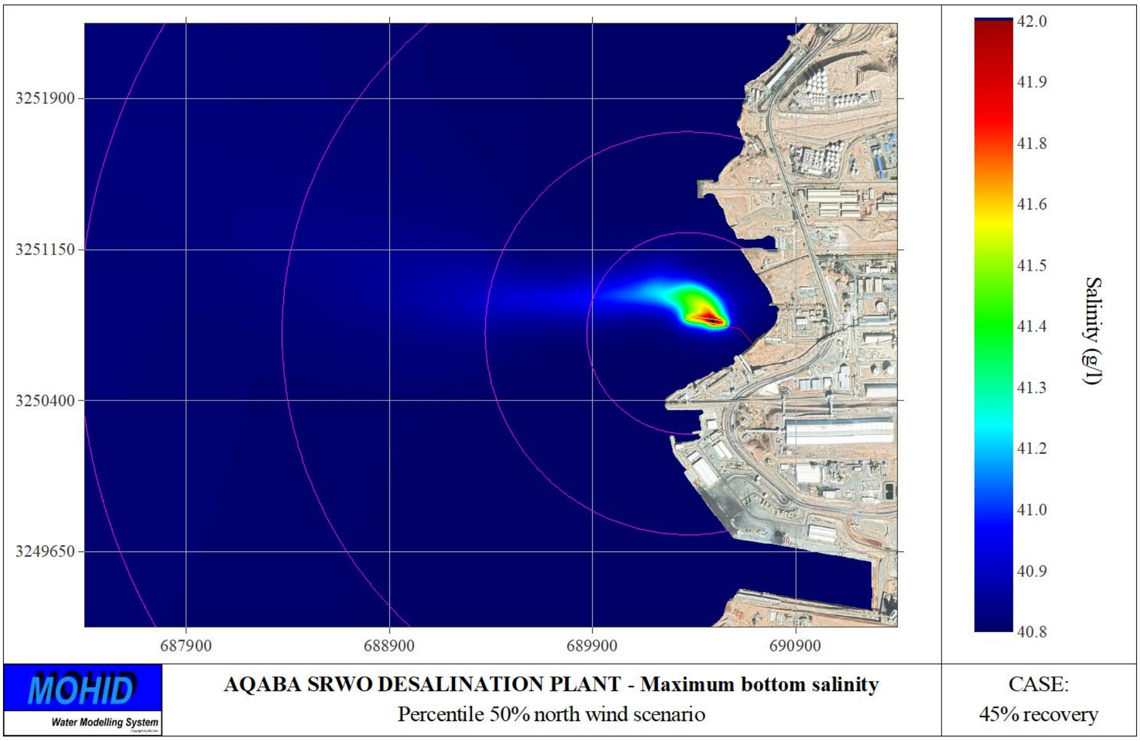

Figure 23. Maximum salinity at the bottom layer in the mean North scenario with 45% of recovery.

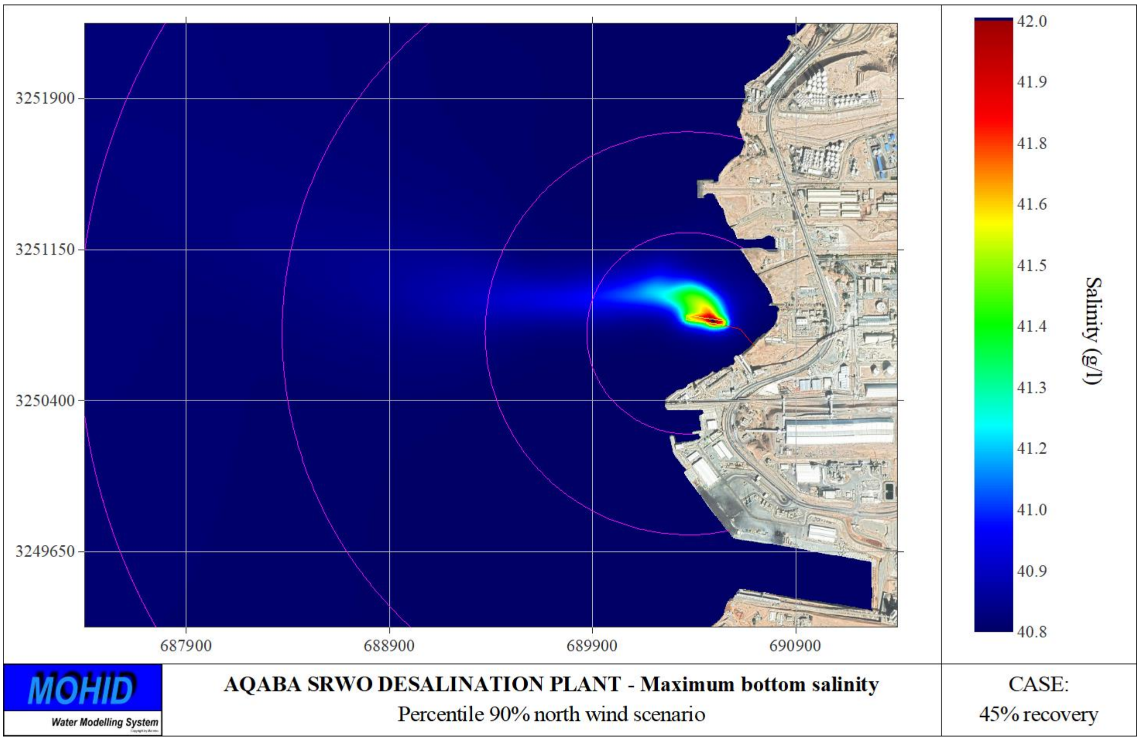

Figure 24. Maximum salinity at the bottom layer in the 90th percentile North scenario with 45% of recovery.

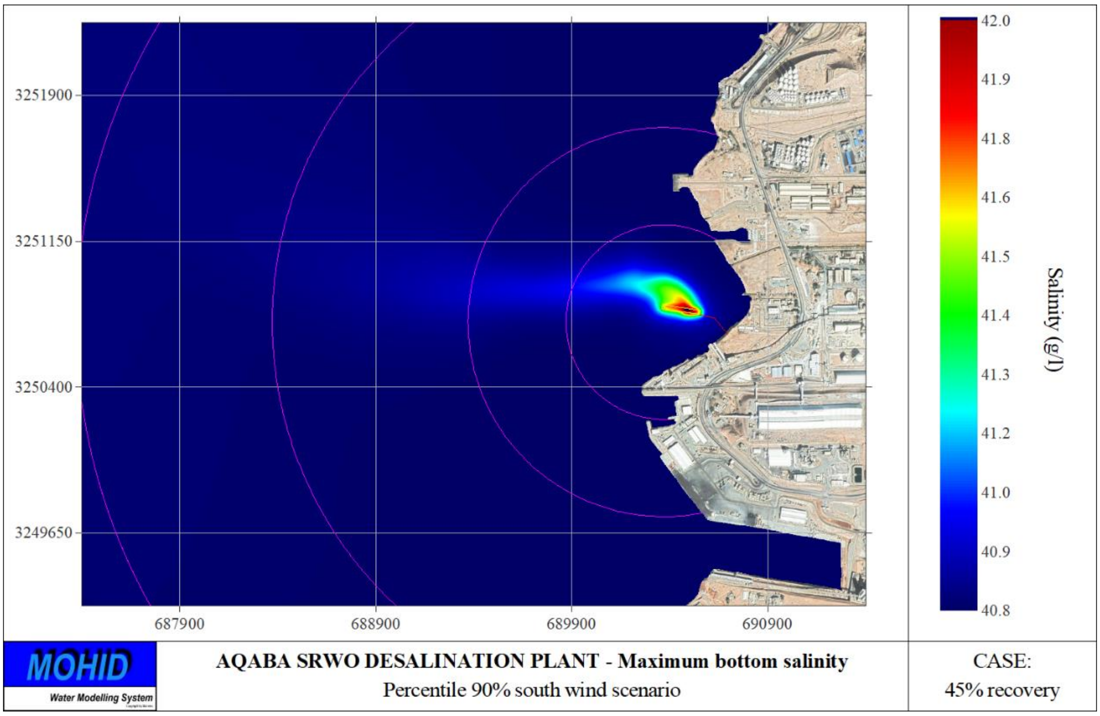

Figure 25. Maximum salinity at the bottom layer in the 90th percentile South scenario with 45% of recovery.

In Table 3, the value of the salinity for the end of near field, at 500 m away from the diffusers, at 1000 m, at 2000 m, and at 3000 m from the diffusers, can be found for the three scenarios simulated.

Scenario	Maximum salinty (psu) from the diffusers			
	500m	1000m	2000m	3000m
Mean Wind North	41.02	40.94	40.85	40.84
90th Percentil Wind North	41.02	40.93	40.85	40.84
90th Percentil Wind South	41.02	40.93	40.85	40.84

Table 3. Salinity at different distances from the diffusers with 45% of recovery.

Attending to the results at different distances from the diffusers, it can be observed that the wind conditions no affected to those results, and the maximum excess salinities above the ambient are generally small, getting around 0.22 psu at 500 m, 0.14 psu at 1000 m, and 0.05 psu (or less) at major distances (2000 m and 3000 m)

Figure 26 shows the salinity evolution during the 2 days simulations for mean north wind scenario for the Intakes 1, 2, and 3. This is the scenario that causes the lowest mixing processes, but anyway, the excess salinity values at the intake positions are around 0.01 psu, so there will not be any recirculation. Other figures at the Addendum.

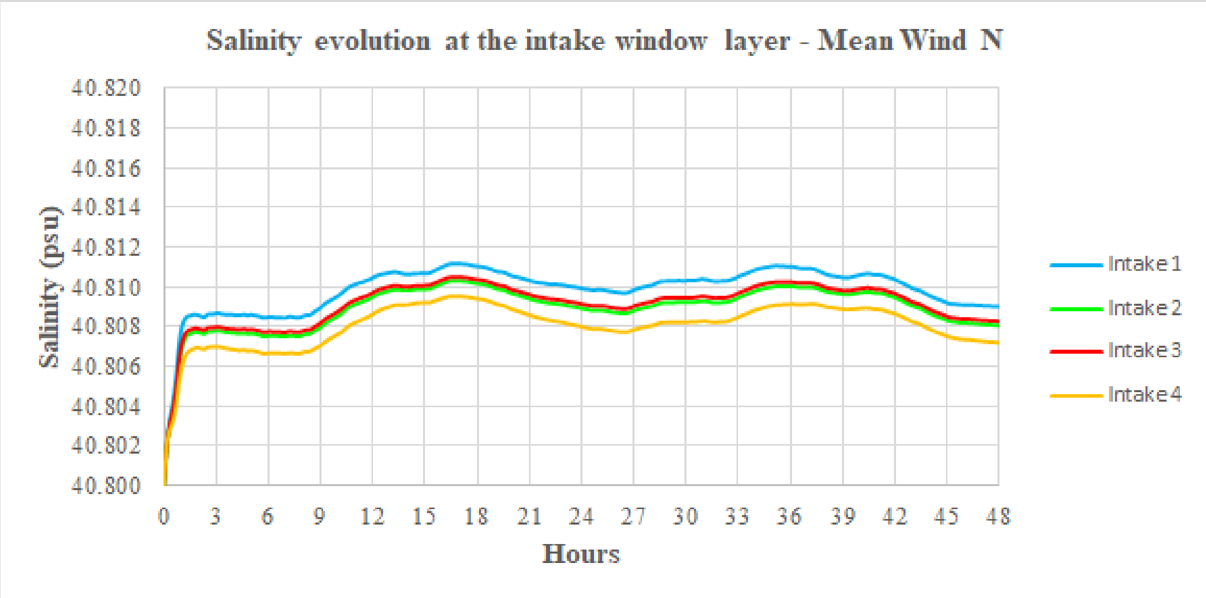

Figure 26. Salinity evolution at intake window with 45% of recovery.

5. CONCLUSIONS

This study offers a complete dispersion and recirculation study to design the new desalination plant in Aqaba, Jordan.

Two cases are proposed with different recovery rates: 42% y 45%.

The diffuser was previously designed using the BrIHne model and guarantees that the increase in salinity with respect to the seawater at the point of impact of the jet on the seabed complies with the Environmental Requirements.

Having designed the diffuser and the discharge plume in the near field, the MOHID model was used to calculate the dispersion and recirculation of the discharges for 3 hydrodynamic conditions: mean winds from the north, strong winds (90^{th} percentile) from the north and from the south.

As a main conclusion, diffusers pour brine in a depth far enough from the intake towers to avoid brine recirculation. The excess salinity values obtained at the Intake positions are very low, so it can be assured that it will not be recirculation in any case. In addition, attending to the results at different distances from the diffusers, it can be observed that the mixture of brine with seawater occurs in a short distance with a very reduced impact.

ADDENDUM 1:
HYDRODYNAMICS AND DISPERSION FIGURES