ADNOC PROJECT WAVE: COMPONENTS 1 & 2 – MIRFA SWTP AND DISTRIBUTION PIPELINE

HYDRODYNAMIC MODELING FOR SWTP DISCHARGE

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1 INTRODUCTION

1.1 Project Background

ADNOC Onshore is implementing Project Wave (the Project), which aims to utilize treated seawater as an alternative for the injection requirements on all ADNOC Onshore fields (BAB, Bu Hasa, NEB and Southeast). This Project Wave represents ADNOC ++ initiatives for ensuring an additional and more sustainable source of water for injection in ADNOC Onshore fields. The Project will include the following components (see Figure 1.1):

- Component-1: construction of a Seawater Treatment Plant (SWTP) at two locations (Mirfa and Nouf). Each consists of Seawater Intake, Outfall, Filtration and Sulphur Reduction Plant (SRP).
- Component-2: build a network of pipelines to transport treated, filtered, low-Sulphate seawater to all Onshore Fields (nine separate battery limits).
- Component-3: build a centralized pumping station and in-field distribution network to distribute treated water up to water injection wells.

The scope of the current Project is limited to Components 1 and 2 of the Mirfa SWTP (i.e., Component 3 is located within existing oilfields and is being implemented separately by ADNOC Onshore).

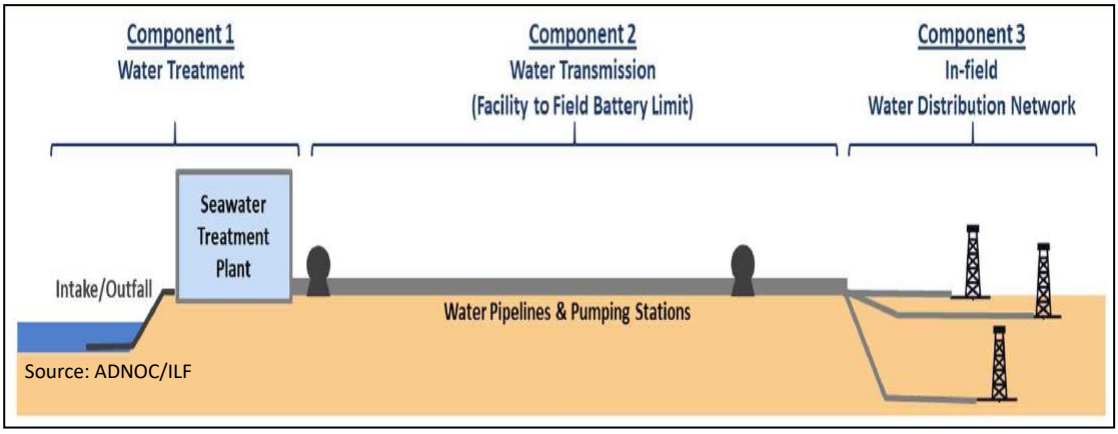


Figure 1.1 – Proposed Mirfa SWTP and Associated Facilities

Dome Oilfield Engineering & Services LLC (Dome) has been appointed by the Consortium of Metito Utilities Limited and Orascom Construction (the Client), to carry out the hydrodynamic modeling for the effluent discharge from the proposed Mirfa SWTP. The modeling was specifically undertaken as an update of the previous modeling study based on the proposed intake and outfall design specifications of the consortium, which has been selected as one of the preferred bidders for the Project. The modeling was undertaken in partnership with Global Energy and Environmental Engineering Services Ltd.

1.2 Study Scope and Objectives

The two main objectives of the effluent discharge modeling were to assess:

- The regulatory compliance of the brine discharged from the proposed SWTP in Mirfa with the EAD prescribed mixing zone; and
- The potential for recirculation of brine from the outfall to the seawater intake and define optimum location for the outfall.

Figure 1.2 provides the proposed design of intake channel and outfall pipeline of the SWTP. The effluent will be discharged through a pipeline that will run within the proposed intake channel. The proposed design by the consortium has adopted the Option 2 outfall of the FEED (i.e., approximately 900 m from the entrance point of the proposed intake channel).

The outfall discharge was assumed to have six (6) risers pipe OD 600 mm SDR26, with two outlet ports per riser (12 in total) OD 280 mm SDR26. Risers are spaced every 6 m. The total diffuser length is 30 m, and the discharge angle (respect the horizontal line) is 15 º. The existing Mirfa Independent Water and Power (MIWP) brine and cooling water shoreline discharges were included in the study, but they did not have any significant impact on the results due to the location and the dilution of the brine discharge by the much larger volume of the associated cooling water discharge.

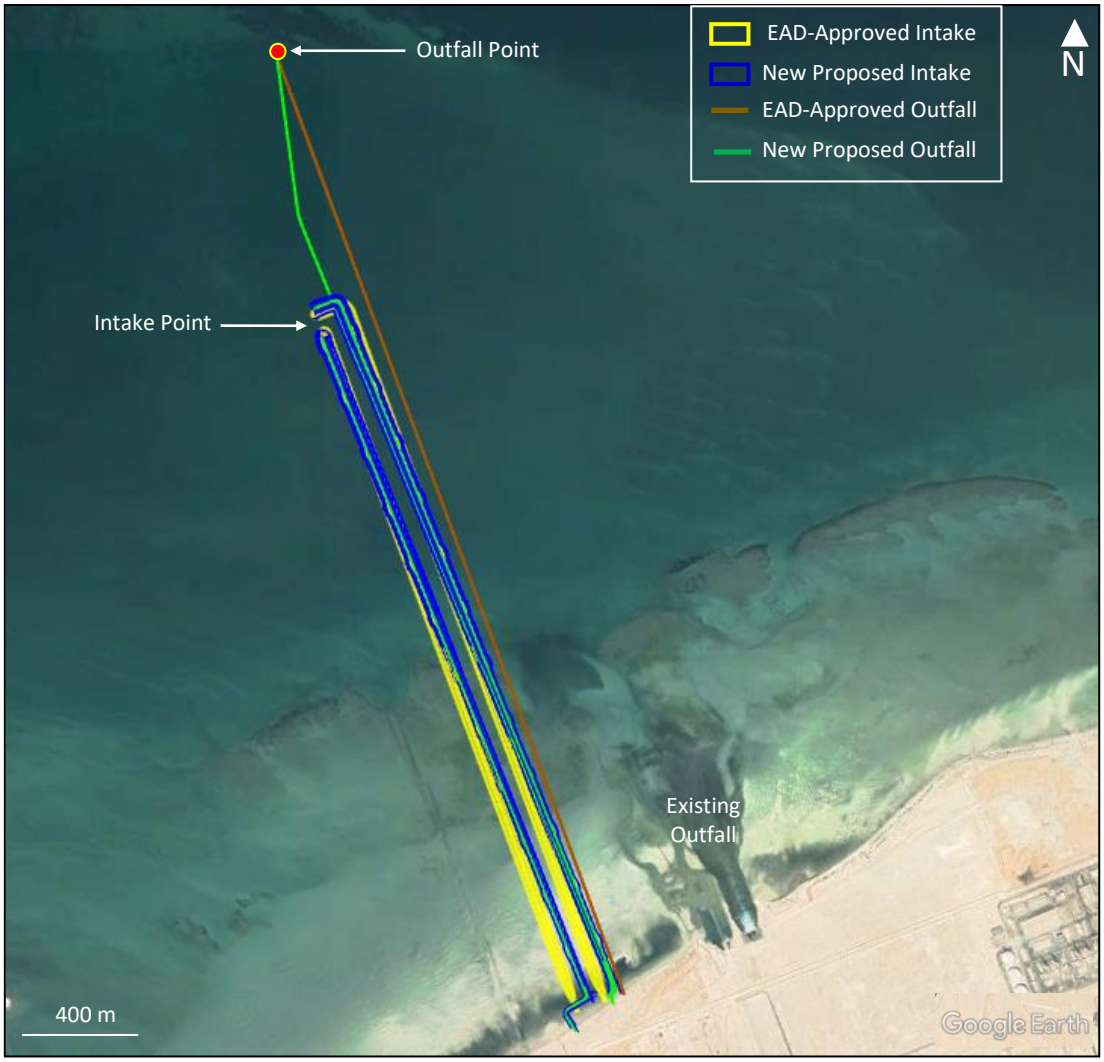


Figure 1.2 – Proposed Seawater Intake and Outfall Structures for the Mirfa SWTP

2 PARAMETERS AND REGULATORY REQUIREMENTS

2.1 Modeling Parameters

Table 2.1 provides the summary of changes in the design capacity of the proposed Mirfa SWTP. The new design data shows an increase in net capacity of about 16% from the original design. Nonetheless, it should be noted that the new design will have a lower intake flowrate (i.e., reduced by about 1,885 m^3/hr or about 6% from the original). This is similar for the return water or brine outfall flowrate, which has been reduced by about 3,565 m^3/hr or about 35% from the original. In terms of the plant design envelope, the new proposed design considered TDS background level of 42,000 mg/l.

Table 2.1 – Summary of Changes in Design Capacity

Parameter	EAD-Approved Design Details	New Proposed Design Details
Net Production Capacity	451,524 m^3/day	522,800 m^3/day
Minimum Production Capacity	255,336 m^3/day	125,500 m^3/day
Intake Flowrate (maximum)	32,385 m3/hr	30,500 m3/hr
Outfall Flowrate (maximum)	10,319 m3/hr	6,754 m3/hr

The new SWTP design also shows reduced concentrations of key pollutants associated with the seawater return (brine) that will be discharged into the marine environment (see Table 2.2. For instance, the temperature of the proposed discharge has been reduced by about 29% from the original value considered in the EAD-approved EIA Report. This is similar for the values of TDS, sulphate, and chloride, which have been reduced by about 4% to 18% from the original values considered in the EAD-approved EIA Report. In terms of the outfall diffuser design, the new design will include a higher number of ports (i.e., from 3 to 12) over a 30m diffuser stretch (see Table 2.2).

Table 2.2 – Properties of Seawater Return (Brine) Discharge

Design Aspects	EAD-Approved Design Details	New Proposed Design Details
Temperature of discharge waters	<42 degrees	30 degrees (from Annex 1 of B3.1 Document)
Salinity of brine discharge waters	< 75 ppt (parts per thousand)	65.50 psu (from Annex 1 of B3.1 Document)
TDS	75,000 mg/l	68.052 mg/l
Sulphate	14,500 mg/l	13,848 mg/l
Chloride	39,000 mg/l	31,821 mg/l
Outfall pipe diffuser configuration	3 diffusers at right angles to the outfall pipe, 10m apart, at 15 degrees to horizontal on alternate sides of the pipe (2 on opposite side to sea water intake).	Consist of 6 risers pipe OD 600 mm SDR26, with two outlet ports per riser (12 in total) OD 280 mm SDR26. Risers are spaced every 6 m. The total diffuser length is 30 m. The discharge angle (respect the horizontal line) is 15 º. [data from B3.1.1 Document)

2.2 Regulatory Requirements

The results of the plume dispersion modelling need to be assessed against the local regulatory requirements relating to any increased salinity due to discharges into the marine environment. Accordingly, the study was undertaken in line with the relevant requirements of EAD as defined in the Technical Guidance Document for Hydrodynamic Modelling (EAD-EQ-PR-TG-13). In the EAD's Marine Water Quality Regulation in the Emirate of Abu Dhabi (2021, Annex 5), the allowable increment must be <5% in comparison with the initial salinity, which is generally considered at the mixing zone boundary. As per the EAD guidelines, the mixing zone was set at 100 m from the discharge point.

The minimum dilutions required to satisfy the regulatory requirements can be calculated as follows:

- S1: maximum discharge salinity = 75 ppt
- S2: minimum ambient salinity = 42 ppt
- (Conservative value based on measurements off Ruwais by Atkins, 2009)
- n: minimum number of dilutions required.
- Then: (S1+n x S2) / (n+1) = 1.05 x S2
- Or: n = (S1 - 1.05 x S2) / (0.05 x S2)
- Therefore: n = 15

Note that:

- To obtain dilution to within 1 ppt of ambient requires a dilution of 32.
- To obtain dilution to within 0.5 ppt of ambient conditions requires a dilution of 65.
- If the requirement was to be within 3% of ambient conditions at the mixing zone boundary, a dilution of 25 would be required.

3 SITE ENVIRONMENTAL CONDITIONS

3.1 Tides and tidal currents

The tides are semi-diurnal with amplitude. The maximum spring tidal range is 2.15 m while minimum neap tidal range is 1 m as shown Figure 3.1.

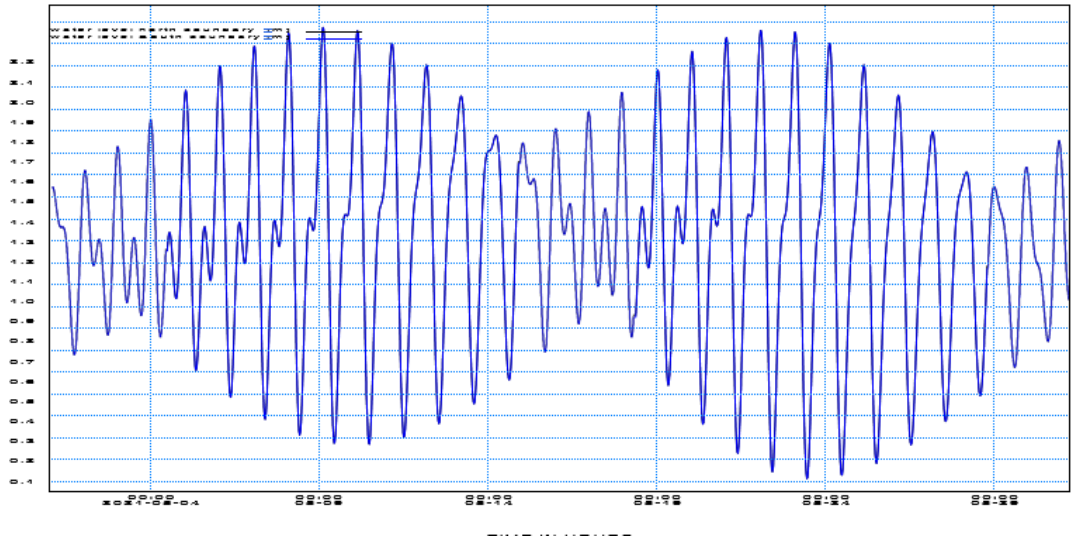


Figure 3.1 – Tidal Level at Halat Al Mubarraz location

3.2 Wind Speed and Direction

Figure 3.1 and Figure 3.3 show monthly mean wind rose diagram for the period April 2021 to June2021 near Mirfa location, in general, wind blows predominantly from North with a maximum intensity of 12.1 m/s and minimum intensity of 0.2 m/s. Wind with equal strength blows predominantly from North.

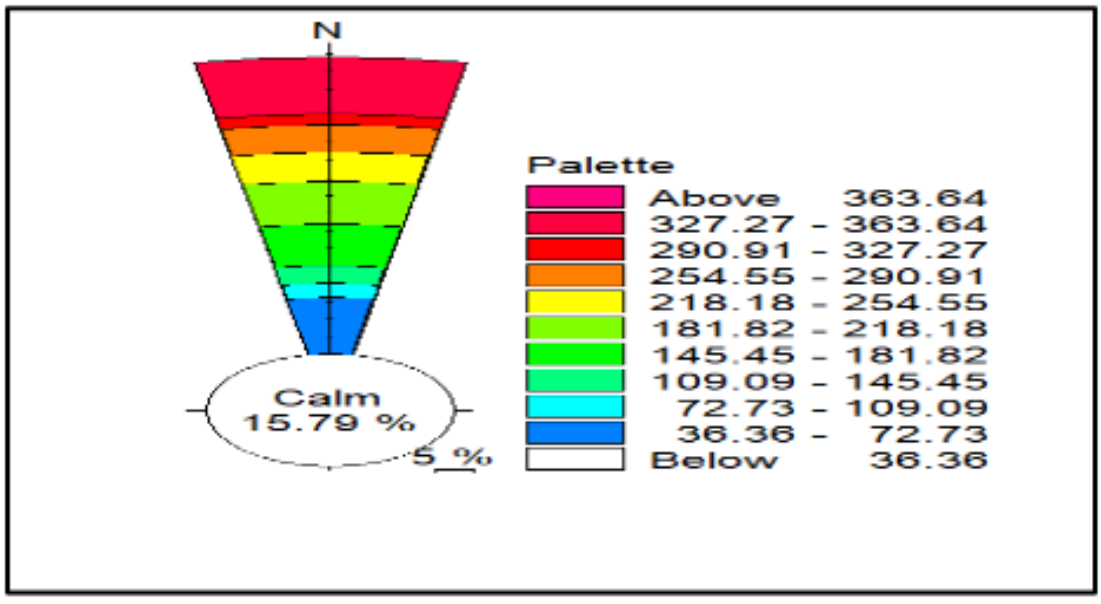


Figure 3.2 – Wind Rose Diagram at Survey Location

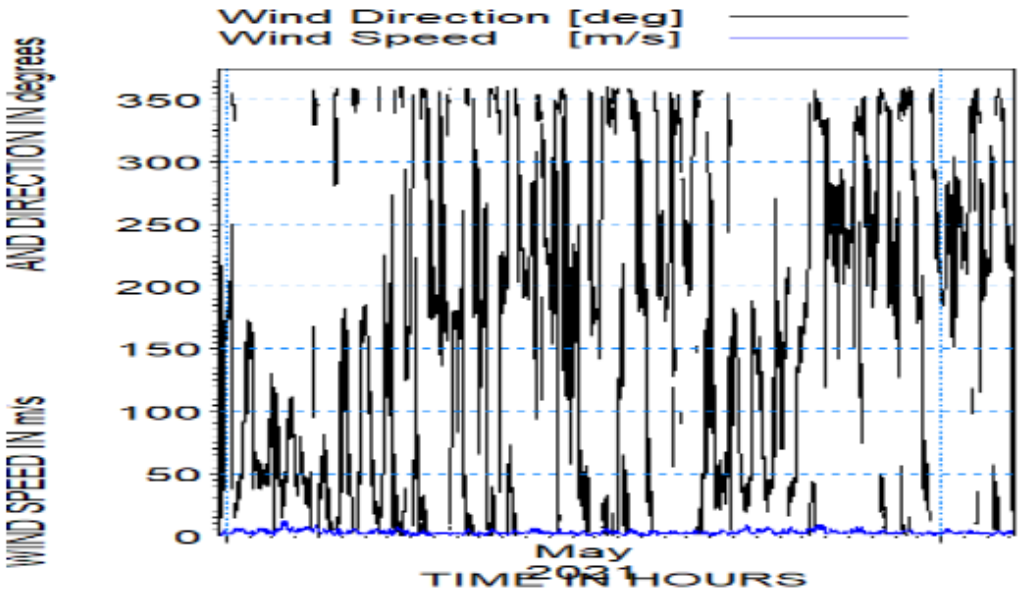


Figure 3.3 – Wind Speed and Direction at Survey Location

3.3 Salinity and other Chemicals Concentration.

The average sea water salinity was indicated by report to be 42 ppt and the effluent containing 65.5 ppt and the chemical concentrations such as TDS is 68052 mg/l, Sulphate 13848 mg/l and Chloride 31821 mg/l were recommended for the simulation studies by EAD Authority.

3.4 Temperature

The surface temperature distribution in the area exhibits the presence of warm water (temp 30.0 ^{0}C) towards the coast and relatively hot weather is about 34 0C during May and June of every year as shown in Figure 3.4.

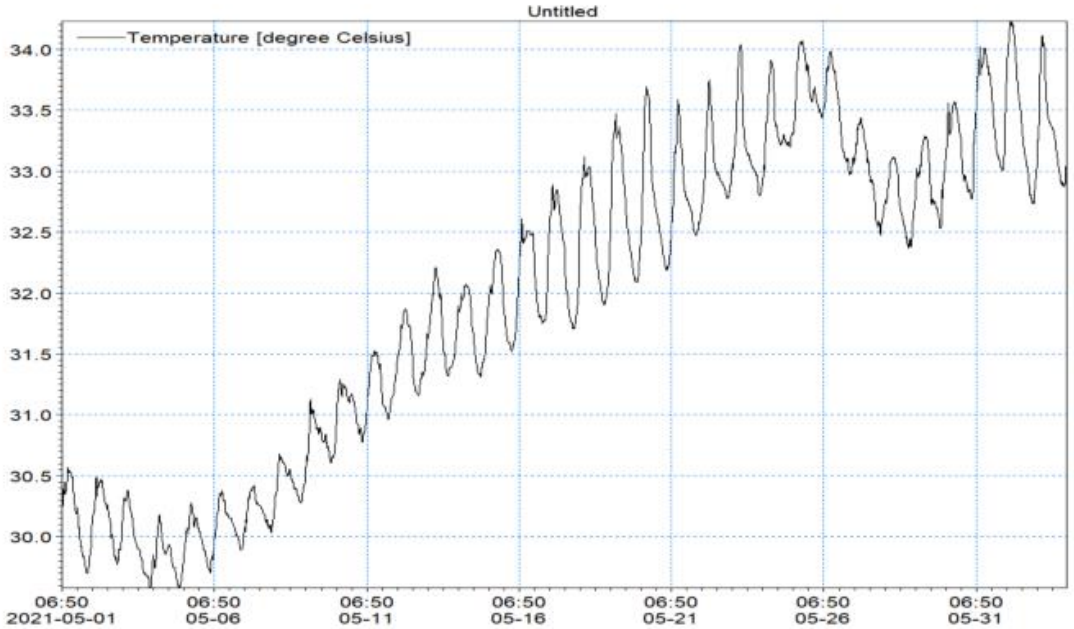


Figure 3.4 – Sea Surface Temperature at Survey Location

4 MODELLING TECHNIQUES IN FM MODEL FOR HD

This chapter describes the methodology adopted to carry out mathematical modelling studies. It includes the development of hydrodynamic, advection dispersion model to find out the dispersion of brine water discharge from an outfall at Mirfa SWTP, Abu Dhabi, UAE. As for all coastal projects in the UAE, the fate of ocean discharges is strongly affected by the complex phenomena of waves, current speed and direction and tides. It is therefore important to establish an ocean model capable of accurately simulating the Gulf oceanography to provide reliable predictions of water movements within the Arabian Gulf as well as simulating the flows in the region of interest.

4.1 Coastal Modelling

Coastal Hydrodynamics (HD) and advection and dispersion model (AD) is to be used for simulation of flow field and dispersion of brine discharges from the outfall. The above software developed by Danish Hydraulics Institute (DHI); Denmark is widely used commercial software for solving coastal engineering problems. A brief description of these models is given below.

4.2 The hydrodynamic Model Simulation in MIK21 (HD) FM

The hydrodynamic model MIKE 21 –HD (FM) (DHI, 2023) would be used for simulation of water levels and flows in coastal areas. It simulates unsteady two-dimensional flows in coastal areas and is based on the non-linear vertically integrated 2-D equations of conservation of mass and momentum. The Transport (AD) formulation is based on advection-dispersion calculations in the hydrodynamic module. MIKE (HD) FM (DHI, 2023) is the module of the MIKE 21 modelling system that calculates the rates of transport for both pure current and combined waves and current situations. Apart from the transport components, the initial rates of bed level change associated with the time-averaged - over the user-defined simulation period – transport field are also the output.

The MIKE 21 Flow Model is designed for 2-dimensional modelling by Danish Hydraulic Institute. The model is based on a cell centered finite volume approach generating linear triangular elements. The hydrodynamic model, MIKE-21 HD is used to simulate the unsteady flows such as the flow field in the existing and the proposed condition at the site under the given boundary conditions. To simulate transport of sediments, it is necessary to initially compute the hydrodynamics of water body in terms of velocity and water level fluctuations. The appropriate governing equations for hydrodynamics in desired areas are given by the shallow water wave equations. These shallow water equations are derived from the incompressible Reynolds averaged Navier Stokes equations of motion with the following simplified assumptions.

a) The flow is incompressible.

b) The flow is well mixed.

c) Vertical accelerations are negligible.

d) Bed stress can be modelled using a quadratic friction law.

These unsteady governing equations are solved using cell centered finite volume technique. The spatial discretization is done by subdivision of the continuum into non overlapping cells or elements. The elements can be arbitrarily shaped either triangular or quadrilateral. The time integration is done either in a low order method that uses low order explicit Euler's equation or higher order method which uses second order Rungakutta form.

The conservation of mass and momentum integrated over the vertical are used in the hydrodynamic model to describe the flow and water level variations.

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial y}=hS \quad (1)$$

$$\frac{\partial h\bar{u}}{\partial t}+\frac{\partial h\overline{u^2}}{\partial x}+\frac{\partial h\overline{vu}}{\partial y}=f\bar{v}h-gh\frac{\partial \eta}{\partial x}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial x}-$$
$$-\frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial x}+\frac{\lambda_{sx}}{\rho_0}-\frac{\lambda_{bx}}{\rho_0}-\frac{1}{\rho_0}\left(\frac{\partial s_{xx}}{\partial x}+\frac{\partial s_{xy}}{\partial y}\right)+\frac{\partial}{\partial x}\left(hT_{xx}\right)+\frac{\partial}{\partial x}\left(hT_{xy}\right)+hu_sS \quad (2)$$

$$\frac{\partial h\bar{v}}{\partial t}+\frac{\partial h\overline{v^2}}{\partial y}+\frac{\partial h\overline{uv}}{\partial x}=f\bar{u}h-gh\frac{\partial \eta}{\partial y}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial y}-$$
$$-\frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial y}+\frac{\lambda_{sy}}{\rho_0}-\frac{\lambda_{by}}{\rho_0}-\frac{1}{\rho_0}\left(\frac{\partial s_{yx}}{\partial x}+\frac{\partial s_{yy}}{\partial y}\right)+\frac{\partial}{\partial x}\left(hT_{xy}\right)+\frac{\partial}{\partial x}\left(hT_{yy}\right)+hv_sS \quad (3)$$

The following symbols are used in the equations:

h(x, y, t) :water depth(m) = still water depth(d) + surface elevation (η)
$\bar{u}, \bar{v}$: Depth averaged velocities
η : Surface Elevation
g : Acceleration due to gravity (m/s2)
f : Wind friction factor related to coriolis parameter
pa : Atmospheric pressure (kg/m-s2)
ρ_0 : Density of water (kg/m3)
x, y : Space coordinates (m)
t : Time(s)
Syy, Sxy, Sxx : Components of radiation stresses (N/m2)
Txx, Txy, Tyy : Viscous friction estimated using eddy viscosity formulation.
λ_{xx}, λ_{xy} λ_{yy} : Shear stress components
S : Magnitude of discharge due to point sources
us, vs : Velocities at point sources

5 MODELLING TECHNIQUES IN FM MODEL FOR AD MODELLING

The Advection-Dispersion model MIKE21-AD simulates dispersion of brine water in coastal waters. It is based on the following non-linear vertically integrated 2-D equation of conservation of heat which considers advection, dispersion, heat loss to atmosphere, brine water source and sink.

$$\frac{\partial \bar{c}}{\partial t}+u\frac{\partial \bar{c}}{\partial x}+v\frac{\partial \bar{c}}{\partial y}=\frac{1}{h}\frac{\partial}{\partial x}\left(hD_x\frac{\partial \bar{c}}{\partial x}\right)+\frac{1}{h}\frac{\partial}{\partial y}\left(hD_y\frac{\partial \bar{c}}{\partial y}\right)+Q_L C_L\frac{1}{h}-S \quad (4)$$

Where, c : Depth averaged concentration (g/m3),

Dx, Dy : Dispersion coefficients (m2 /s),

u, v : Depth averaged flow velocities (m/s),

h : Water depth (m), S : Temperature term,

QL : Source discharge per unit horizontal area (m3 /s/m2),

CL : Concentration of the source discharge (g/m3).

In the case of artificially warmed aquatic area, the loss of heat will increase due to long wave radiation, evaporation and convection. This increase in heat loss is included as a decay term FhT, in case of brine water the decay term used as conservation term.

$$F=0.2388/(\rho.C_p.H)(4.6-0.09(T_r+T)+4.06.W)\ \exp(0.033(T_r+T)) \quad (5)$$

where F is a heat decay coefficient.

The following expression is used for computing the decay coefficient.

F = .0 2388/(ρ p .. HC)(.06.4 09 r ++– .4) (06WTT .0exp(). 033 (r +TT)) ( )

ρ = density of water (kg/m3),

Cp = specific heat,

H = water depth (m),

Tr = reference temperature(0C),

T = excess temperature (0C),

W = wind speed (m/s).

2D models are depth averaged in which the variation of parameters over the vertical is not simulated. Rainfall and cyclonic conditions are not considered in this modelling. The model simulates the far field advection-dispersion of the brine water. In case of water, conduction is insignificant while advection/convection is important and is considered in the model.

6 PREPARATION OF BATHYMETRY

Figure 6.1 shows the 2D flexible mesh model region considered for this study. Bathymetry in the region was generated from the hydrographic survey commissioned by ADNOC. The region considered for the model is 40.949 km X 14.454 km., which extends up to –5.5 m contour towards offshore in north direction. The region is schematized by 2754 nodes and 5493 elements with grid size from 50 m in fine and 800 m in coarse grids as shown in Figure 6.2.

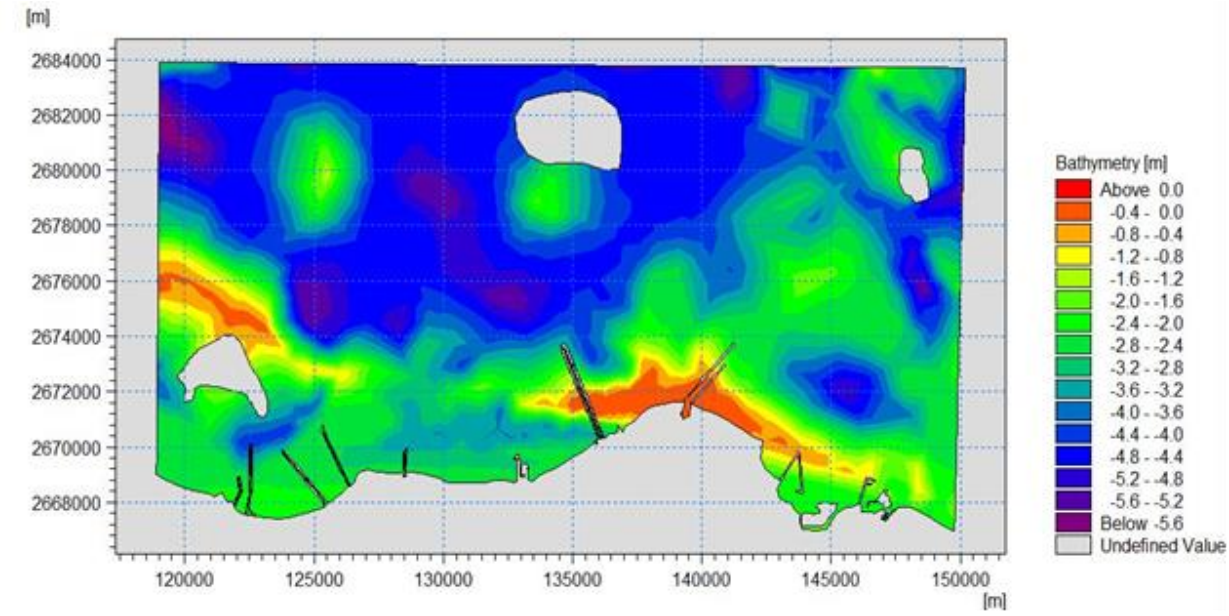


Figure 6.1 – Bathymetry at Mirfa SWTP location

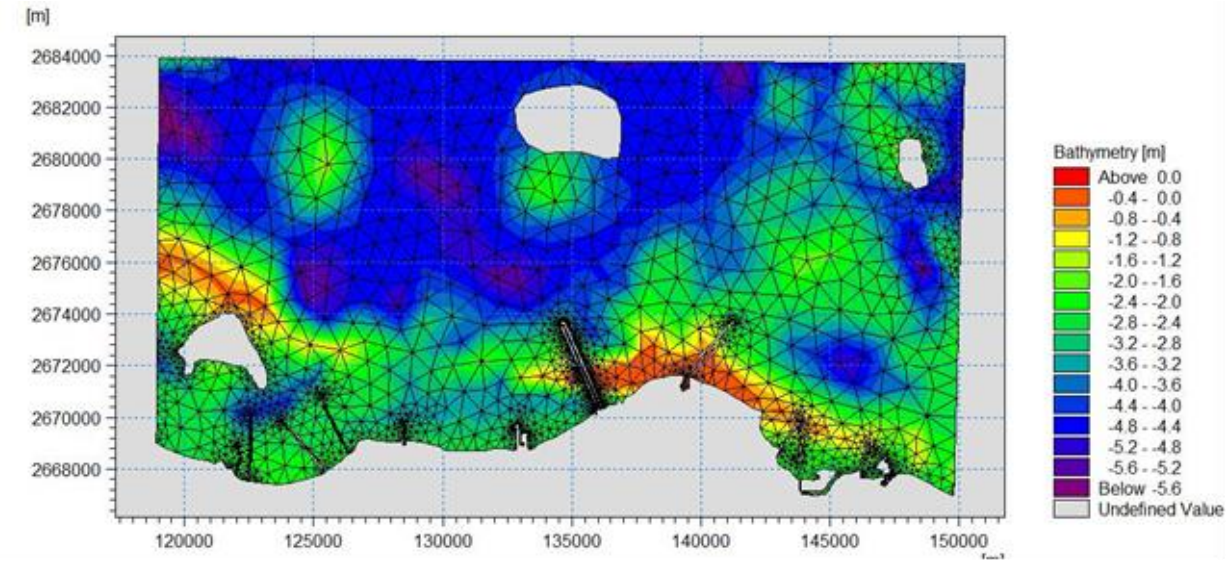


Figure 6.2 – Bathymetry of the Region with Element Mesh

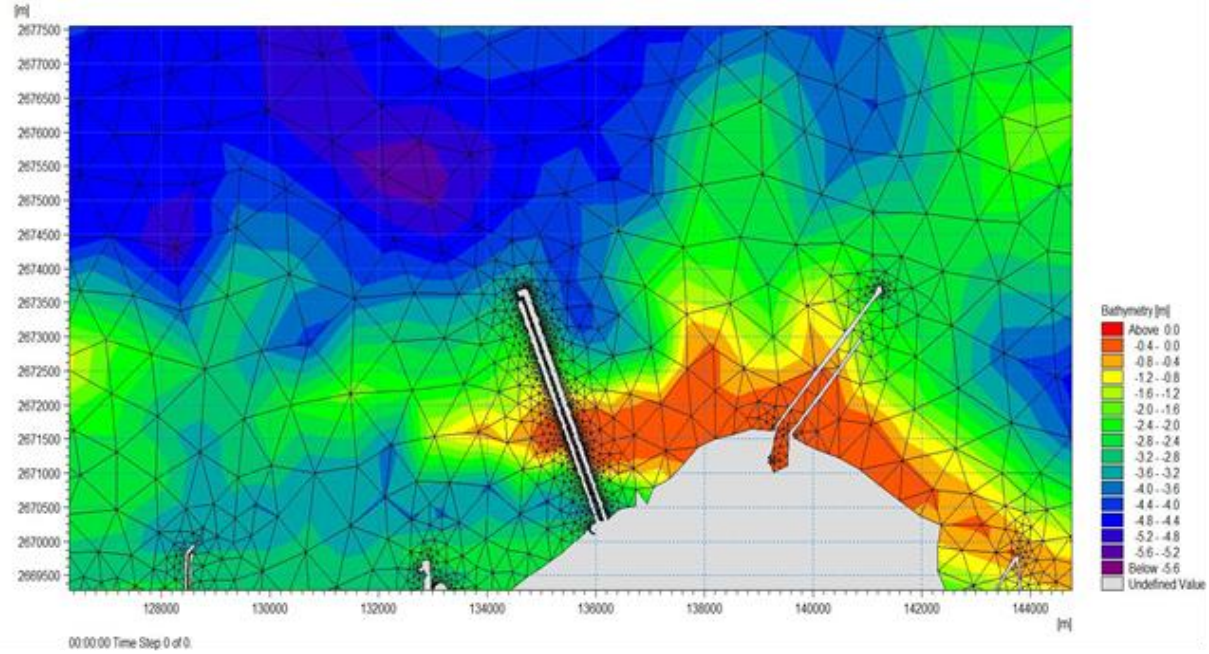


Figure 6.3 – Bathymetry of the Intake Channel with mesh

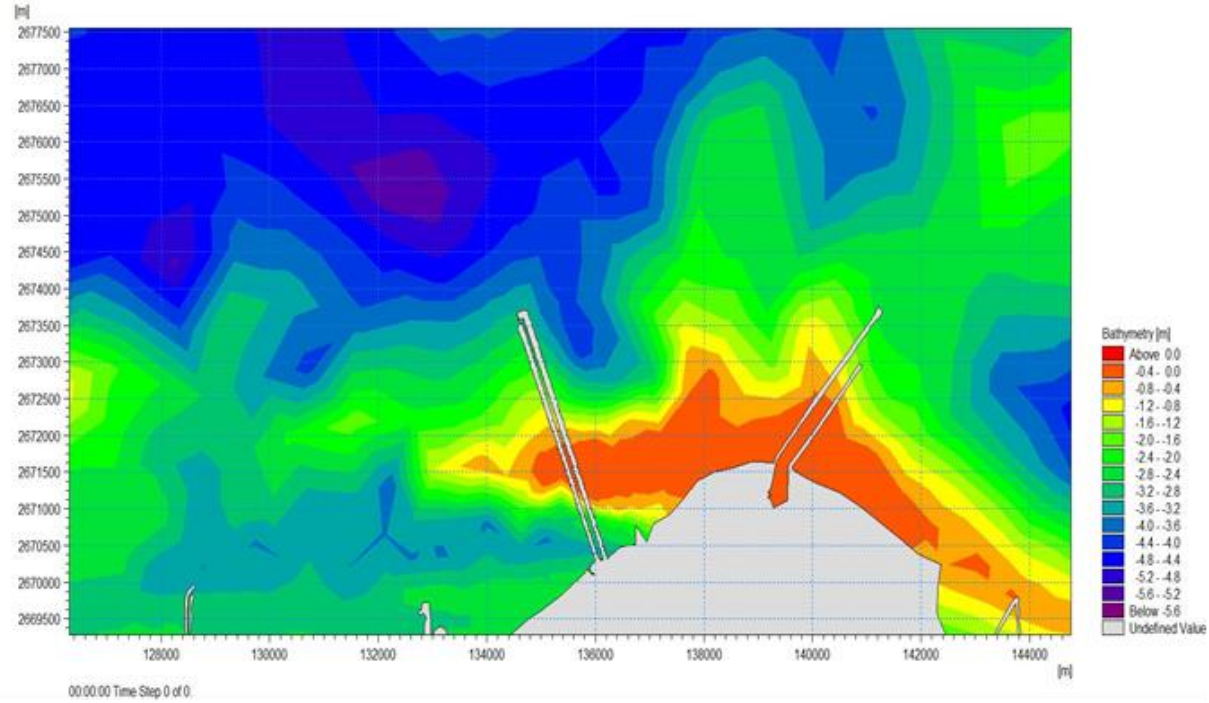


Figure 6.4 – Bathymetry of the Intake Channel

7 PREPARATION OF BOUNDARY CONDITIONS

Figure 7.1 show the boundary condition prepared for the simulation. The tidal level ranges from 0.1 to 2.2 m during the period of this simulation. The average tide is 1,2 m.

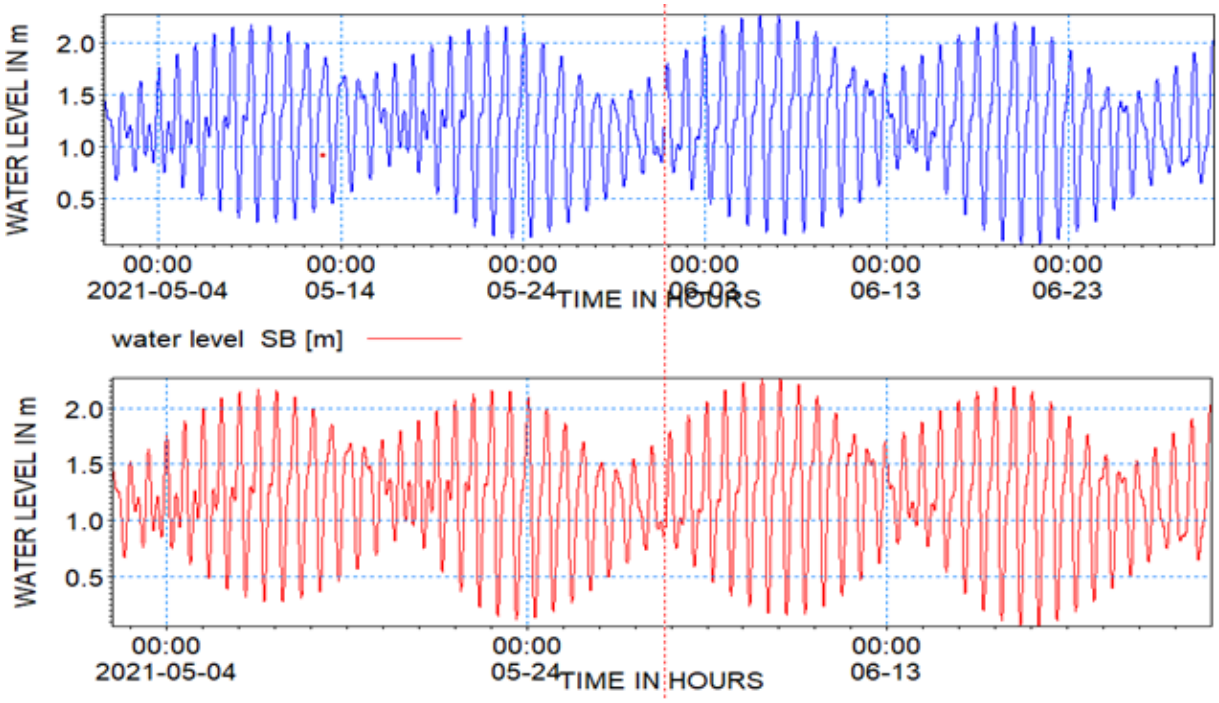


Figure 7.1 – Boundary Conditions used for Simulations.

In order to study hydrodynamics in the proposed project site, the mathematical model limits were selected based on available data and considering the outfall locations. The model limit extends up to 14 km in the offshore direction, similarly the model extends up to 40 km along the shoreline direction. Thus, the model limit includes possible outfall location and intake location suggested by Project Authority and EAD with sufficient margin to alleviate boundary effects. The intake is required to be considered outside the breaker zone. Also, considering that the intake is required to be placed about 1.2 m above the seabed to avoid the silt entering into the intake, and to maintain at least 3 m depth of water at the intake for sufficient water available for the plant, The outfall location also considered at -4.5 m depth for the quick dilution and dispersion of brine water.

8 MODEL CALIBRATION

As could be seen from the computational grid plan shown in Figures 6.1 and 6.2, 3 open boundary conditions are required to be provided for simulating the flow field in the project site. It could be seen from the velocity field that the flow is unidirectional in the north–south direction. Several trial runs of hydrodynamic model were made by varying Manning's bed roughness, and wind speed /direction to get the observed tide field in the model region (Figures 3.1 and 3.2). With Manning's bed roughness of 0.031, wind speed of 10 m/s and direction 900 N, the flow field corresponding to observed average northward current of the order of 0.2m/s was simulated in the model. The hydrodynamic model results are shown in Figure 8.1, Figure 8.2, Figure 8.3, Figure 8.4, Figure 8.5, Figure 8.6, Figure 8.7, and Figure 8.8. Figure 8.1 indicated that the flow field of high water with a spring tide shows the current speed is in the order of 0.15 m/s. The **Error! Reference source not found.** indicated the flow field of water with a spring tide and shows the current speed is in the order of 0.13 m/s.

Figure 8.3 indicates the flow field of flooding with a spring tide and shows the current speed is in the order of 0.14 m/s. Figure 8.4 indicated the flow field of ebbing with a spring tide and shows the current speed is in the order of 0.11 m/s. Figure 8.5 indicated the flow field of high water with the neap tide and shows the current speed is in the order of 0.19 m/s. Figure 8.6 indicated the flow field of low water with a spring tide and shows the average current speed is in the order of 0.11 m/s. Figure 8.7 indicated the flow field of flooding water with the neap tide and shows the average current speed is in the order of 0.12 m/s. Figure 8.8 indicated the flow field of ebbing water with the neap tide and shows the average current speed is in the order of 0.17 m/s. The observed and computed tidal levels are shown in Figure 8.9. The simulated current speed is shown in Figure 8.10. It seems to be a very good match of the observed and computed tidal level in the field survey location. The model seems to be ready to make predictive simulations with source and sink as an intake and outfall with design criteria.

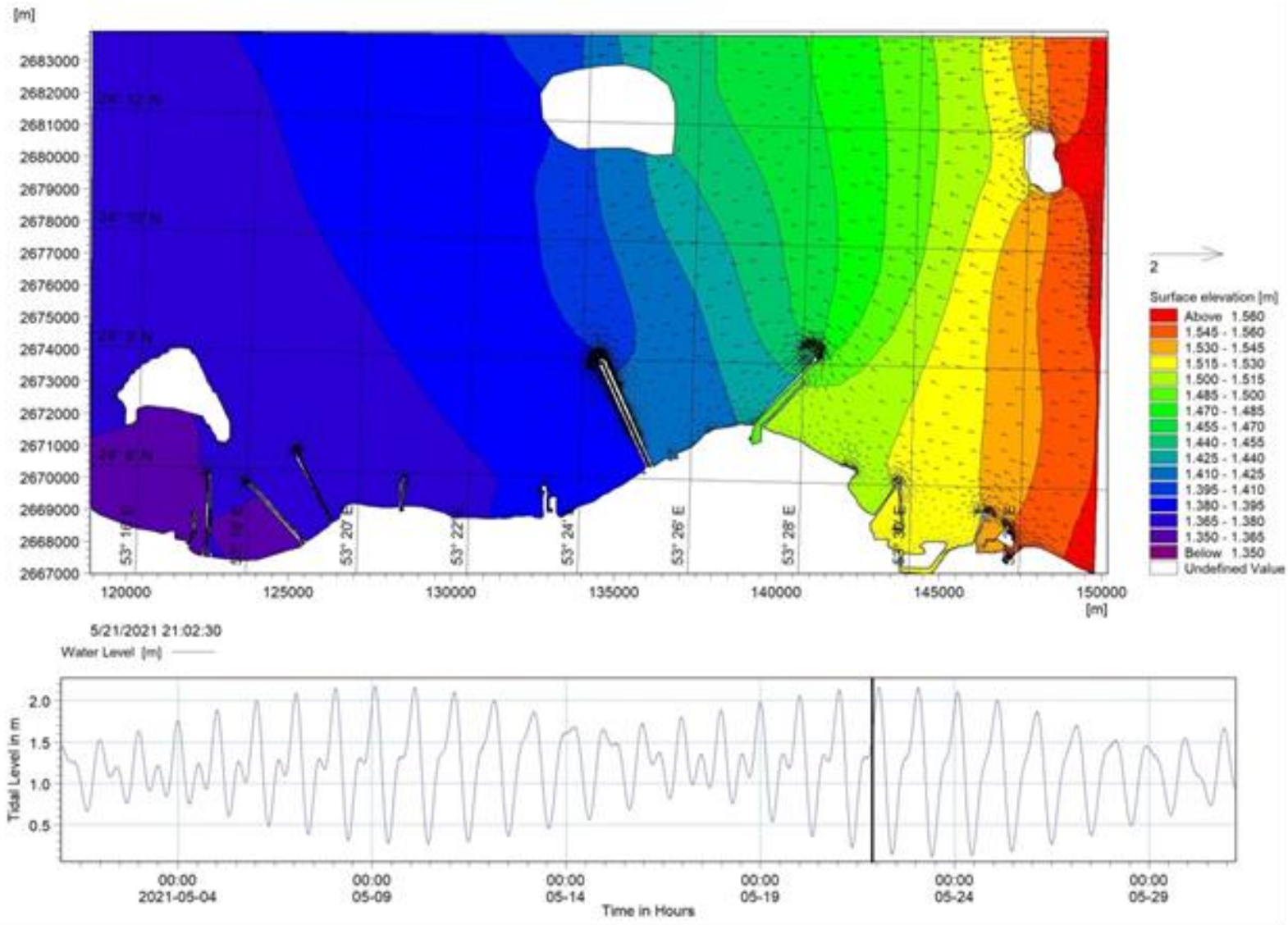


Figure 8.1 – Flow Field During High water (Spring Tide)

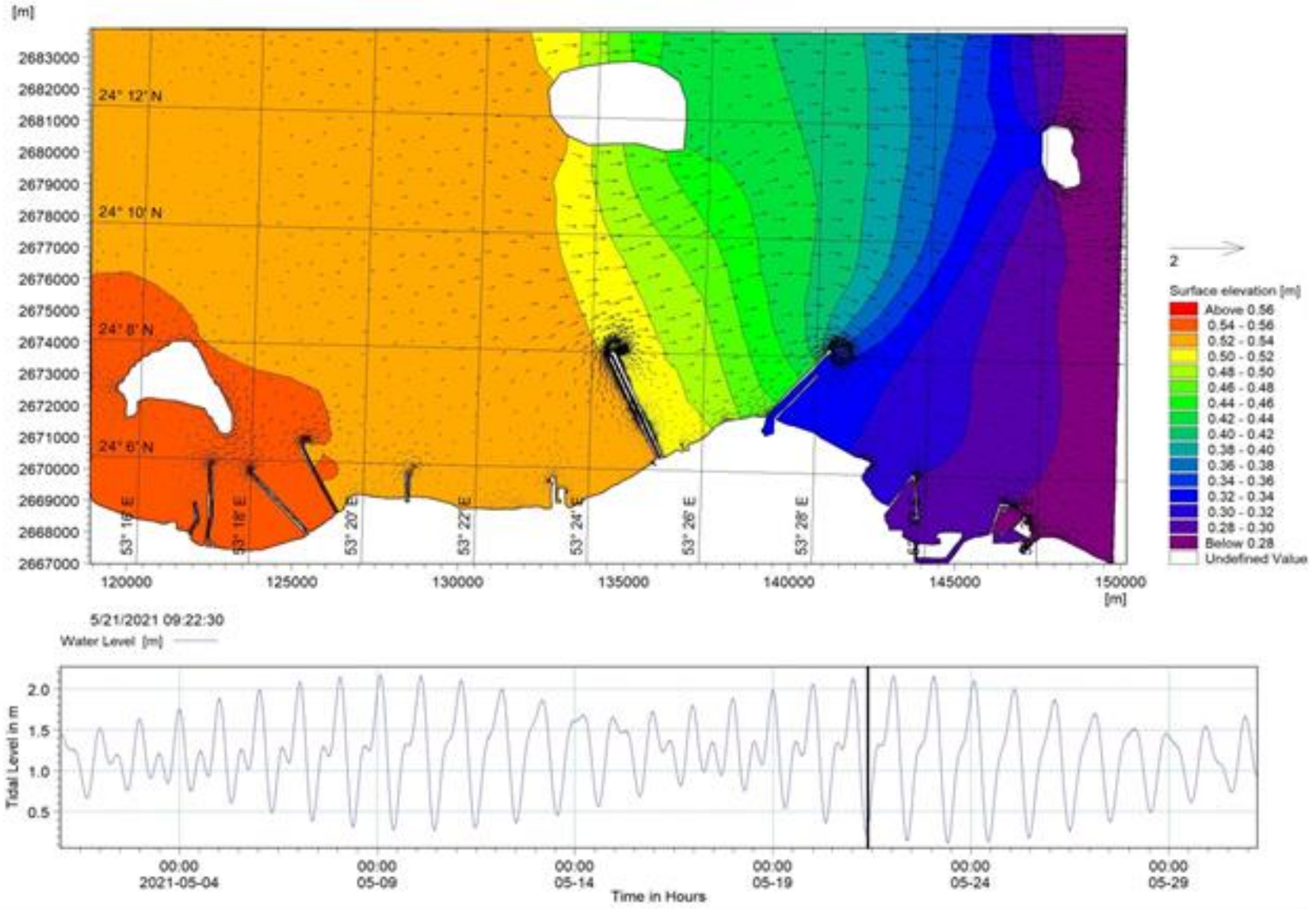


Figure 8.2 – Flow Field During Low Water (Spring Tide)

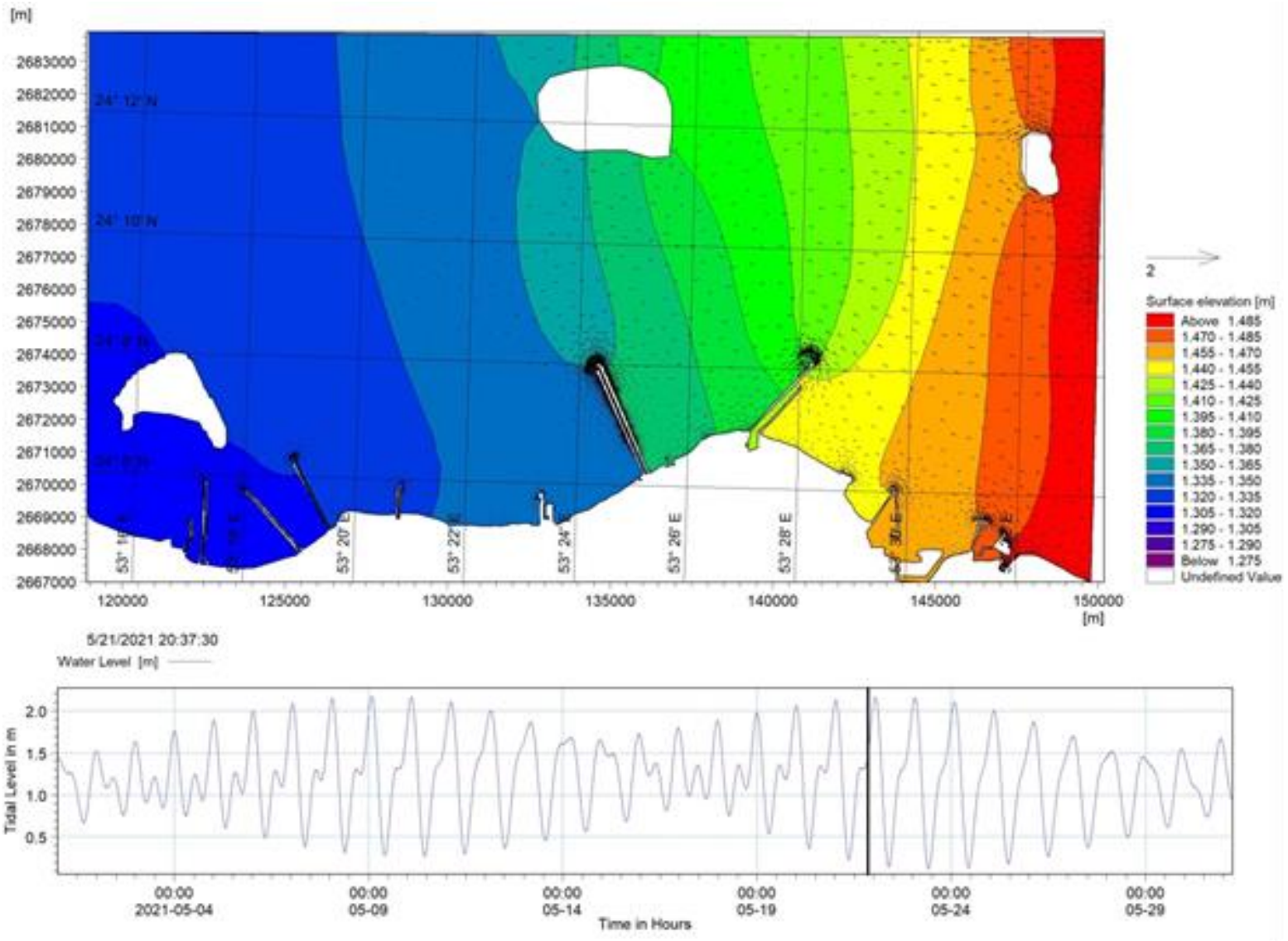


Figure 8.3 – Flow Field During Flooding (Spring Tide)

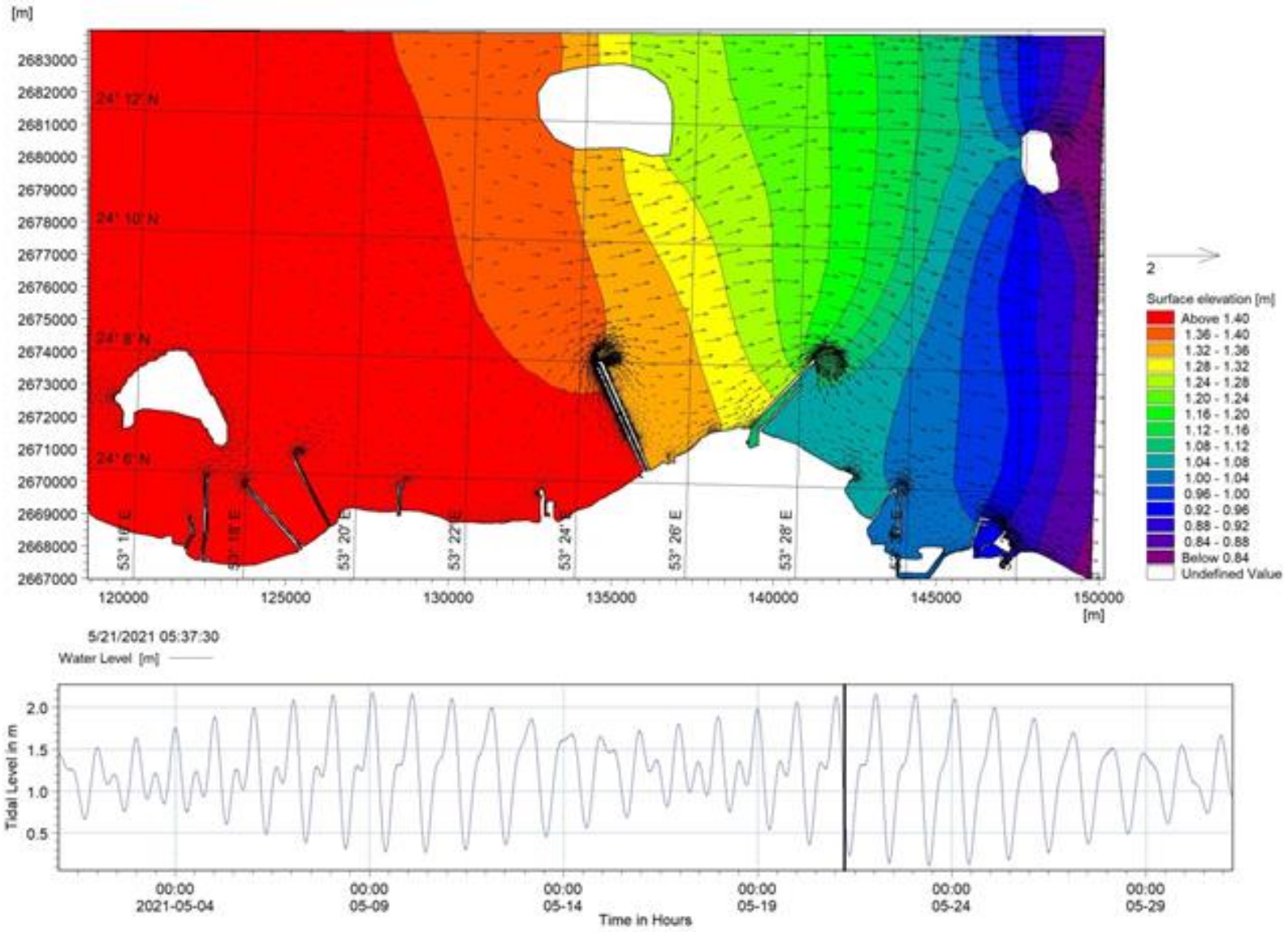


Figure 8.4 – Flow Field During Ebbing (Spring Tide)

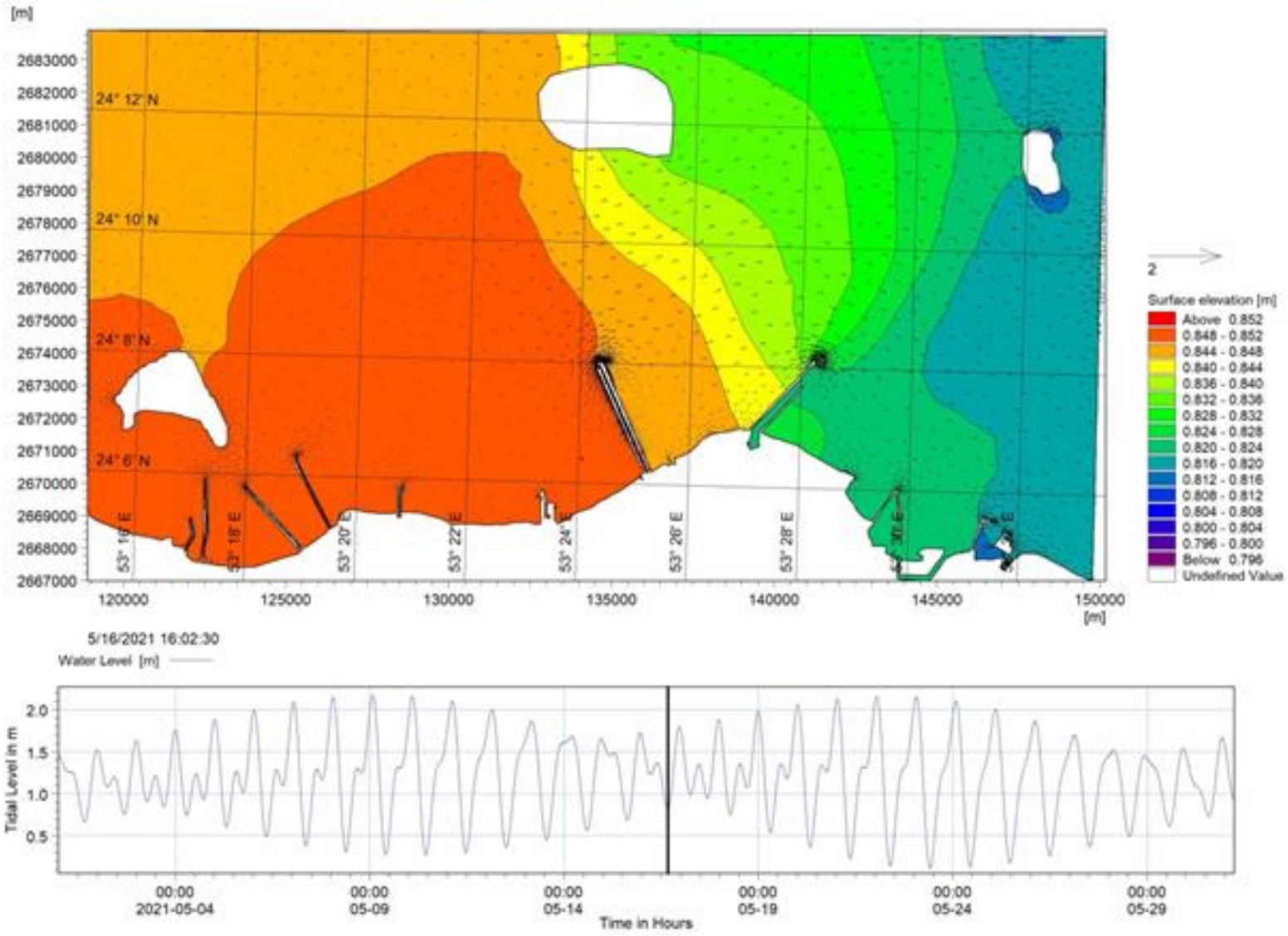


Figure 8.5 – Flow Field during Low Water (Neap Tide)

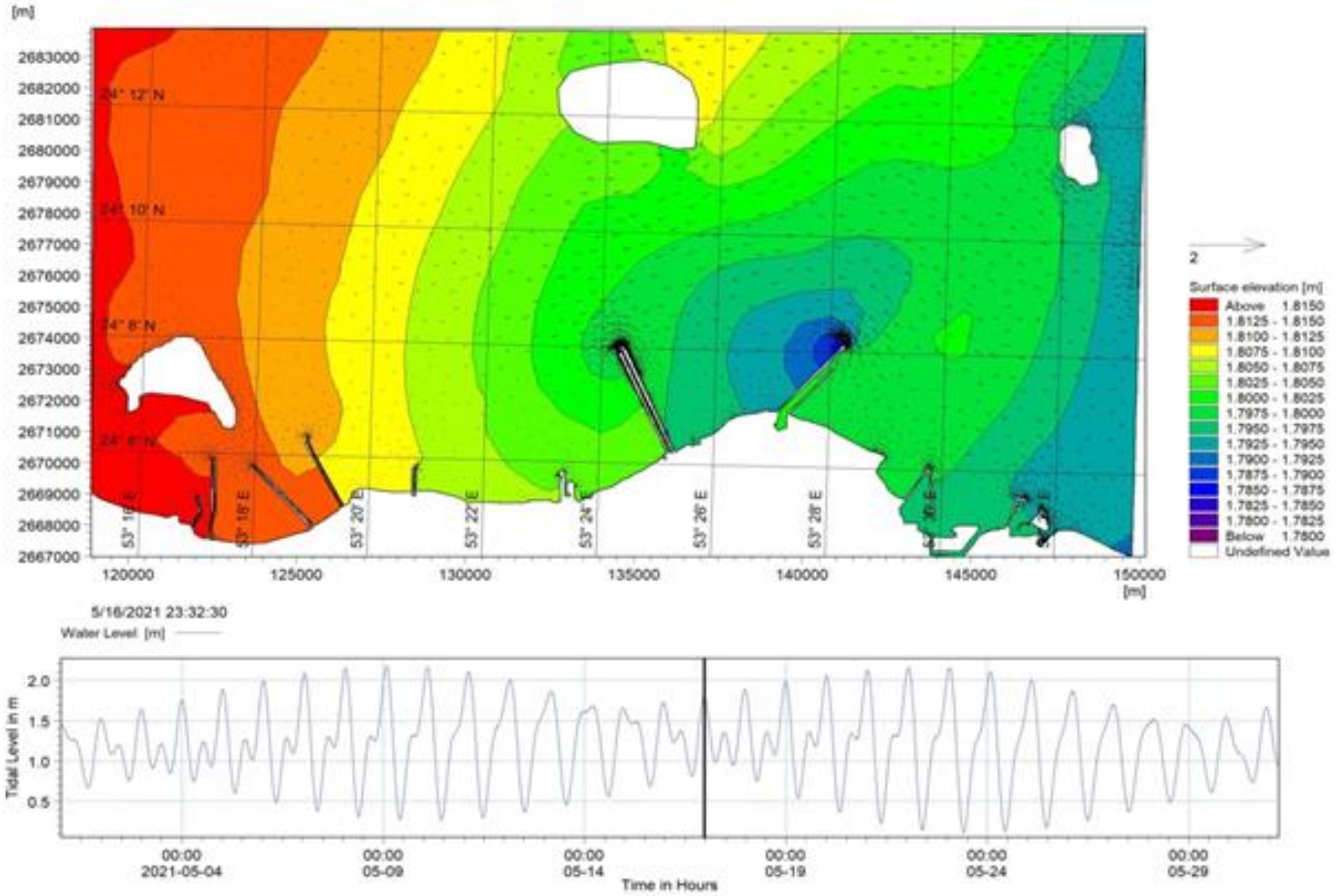


Figure 8.6 – Flow Field during High Water (Neap Tide)

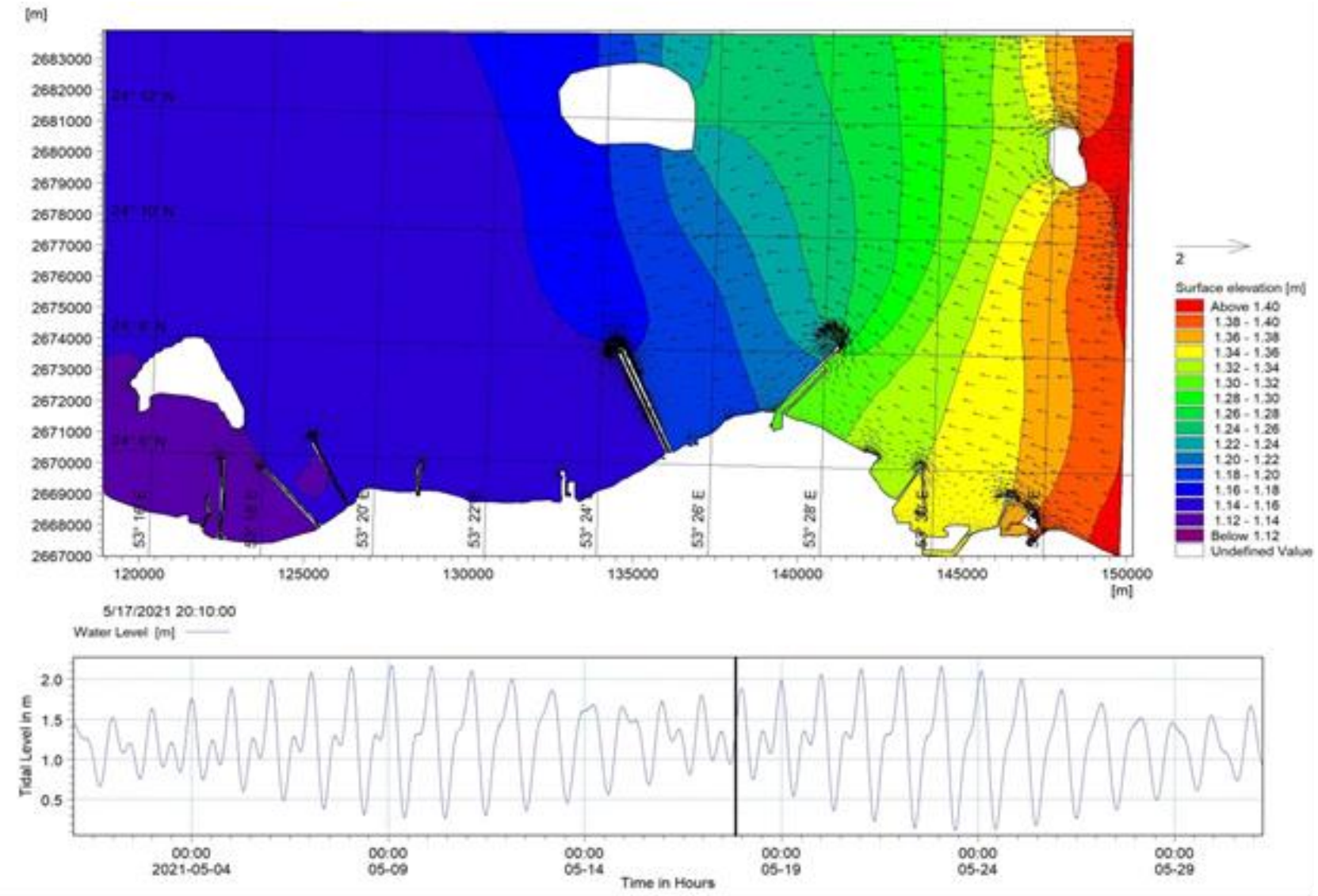


Figure 8.7 – Flow Field during Flooding (Neap Tide)

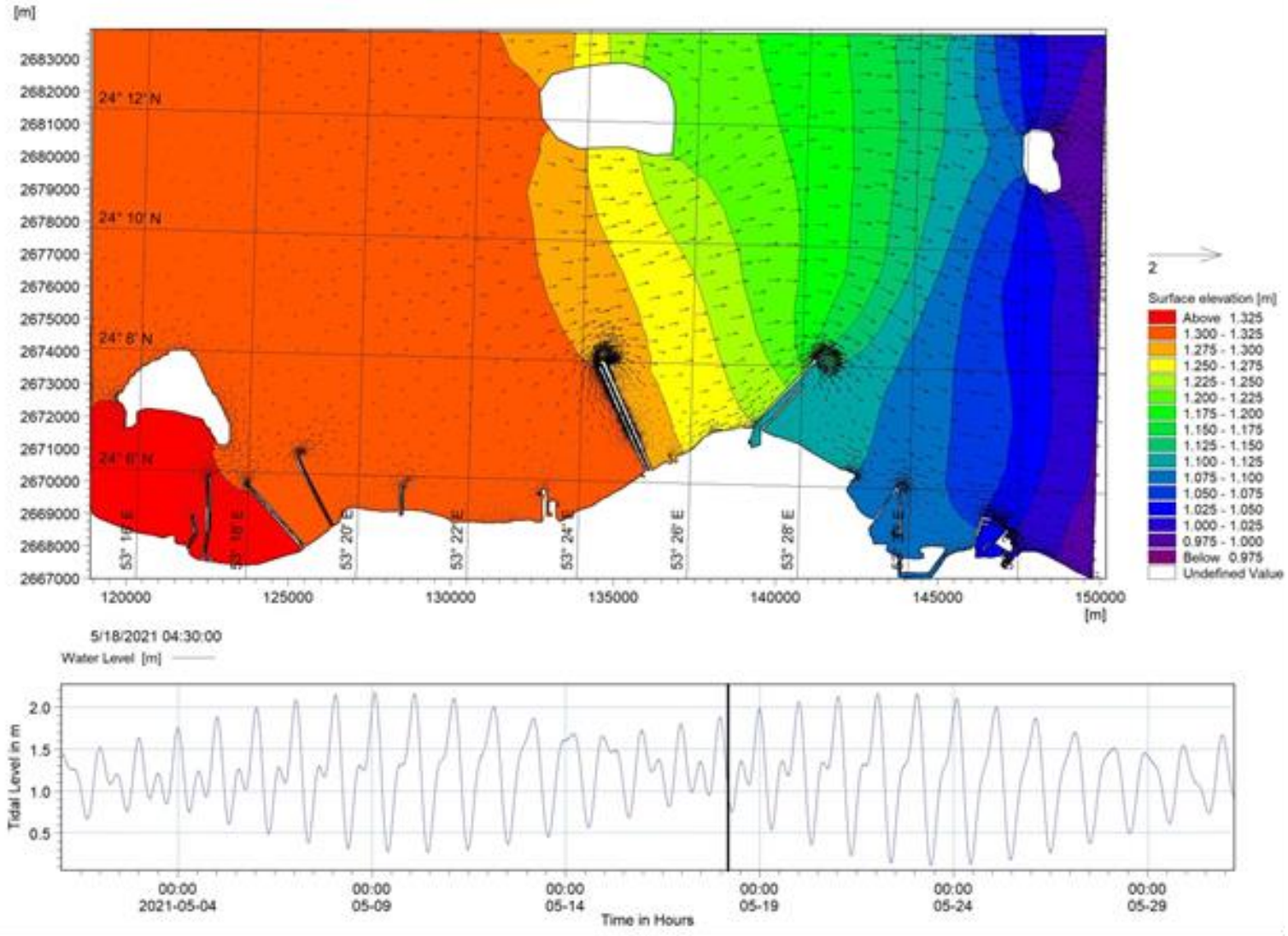


Figure 8.8 – Flow Field during Ebbing (Neap Tide)

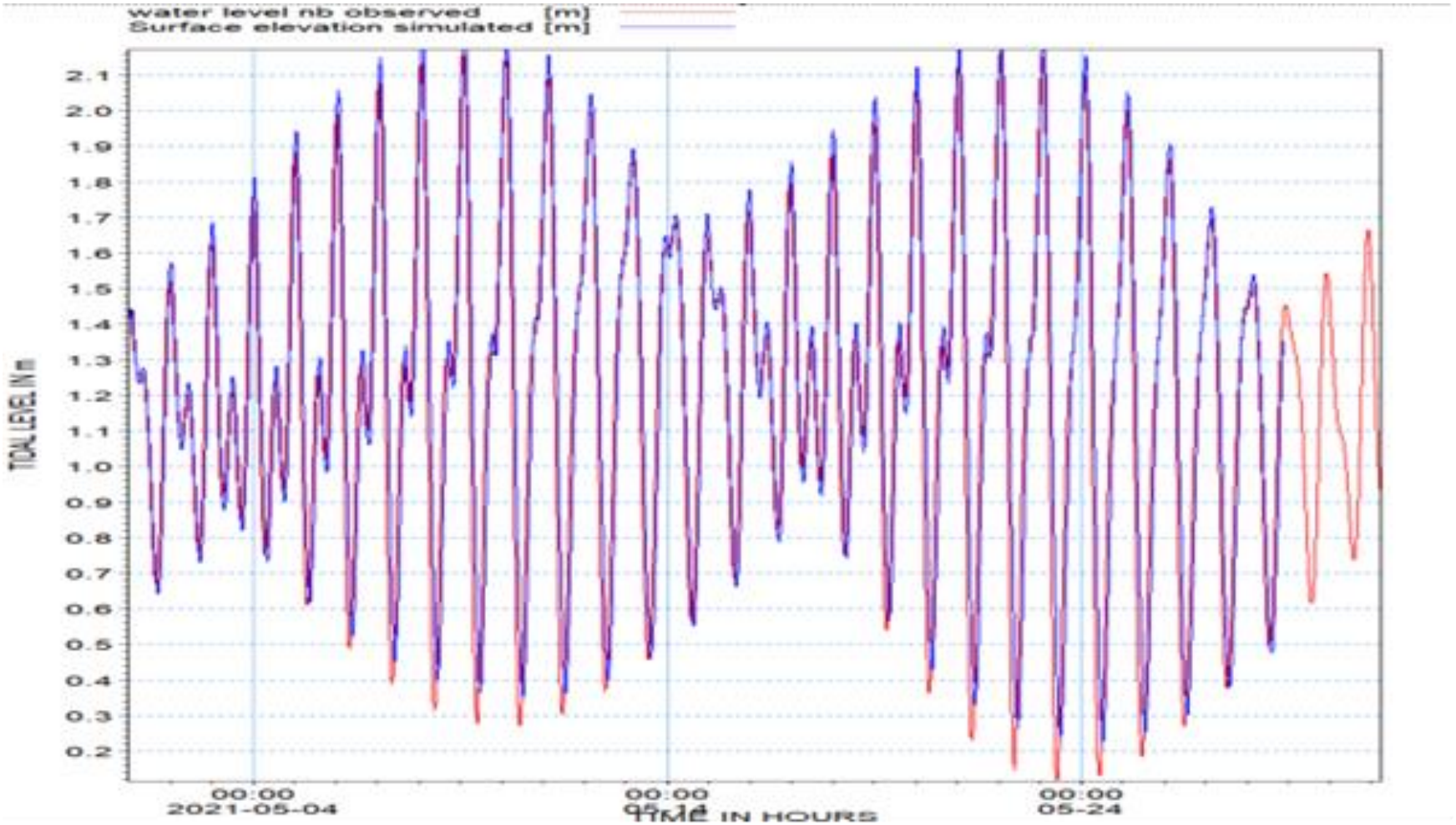


Figure 8.9 – Comparison of Tidal Level (Observed and Simulated)

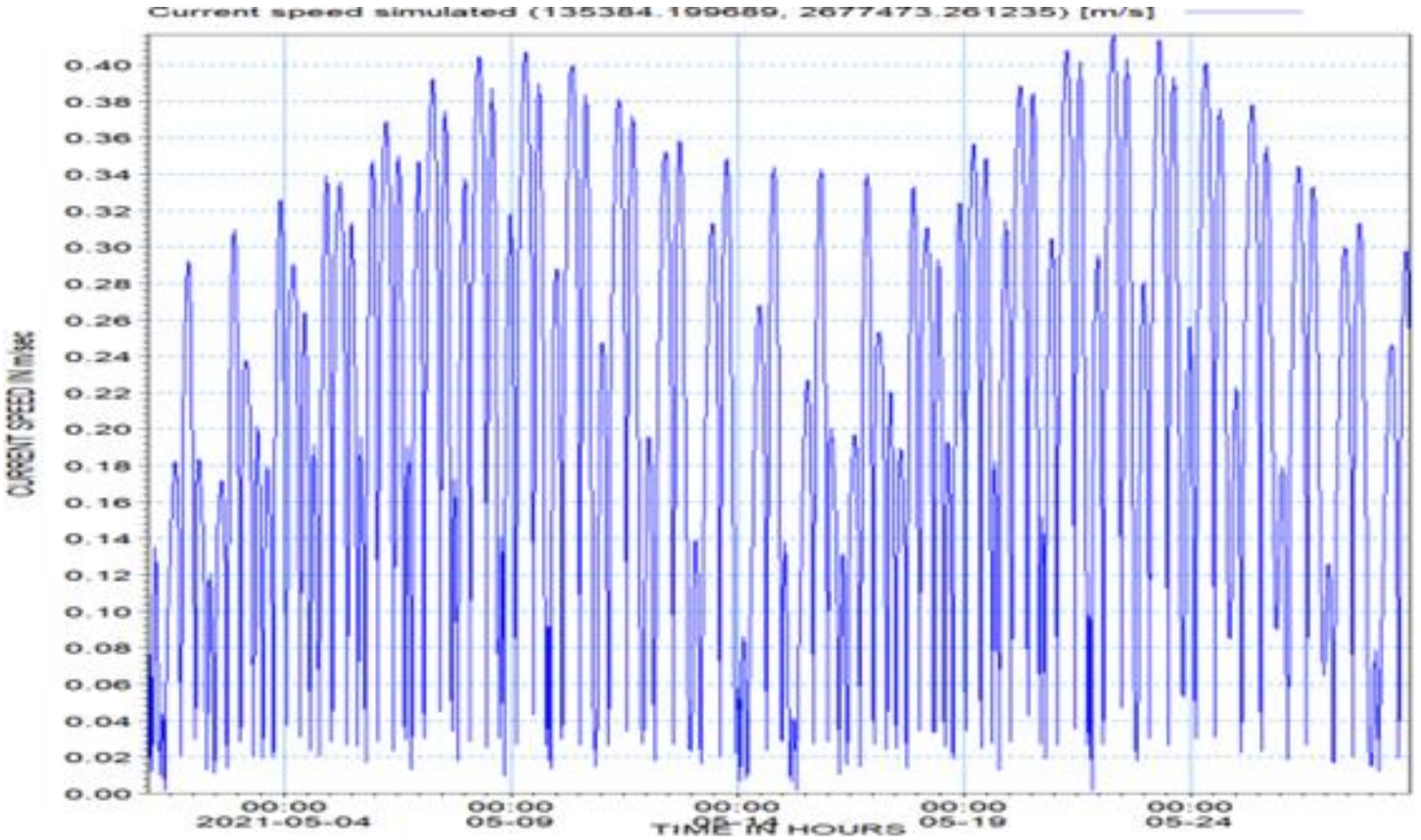


Figure 8.10 – Current Speed (Simulated)

9 SALINITY DISPERSION STUDIES – MIKE21 AD

To achieve efficient functioning of the intake, with an unhindered supply of water free from salinity and chemicals recirculation and to obtain quick dilution and dispersion of brine solution discharge from the outfall, the mixing and dilution of reject waters from a marine outfall can be considered in two distinct spatial zones, near-field dispersion and far-field dispersion. The initial, near-field dispersion of the reject waters is a function of several parameters including:

- The volume and properties of the discharge like concentration of the brines and chemicals.
- The momentum flux of the discharge velocity, which induces entrainment of the surrounding ambient fluid.
- The current speed and direction of the marine waters at the location of outfall; and
- The design and number of the diffusers would be installed based on the position of diffusers vertically and horizontally. The vertical position of the diffusers will work more efficiently compared to a horizontal position.

The volume of brine water discharged in the outfall plays a very vital role in the dispersion, for example, the volume of discharge is less dilution and dispersion is maximum at the near field and far field with considerable current speed and direction. The chemical properties of the reject water particularly salinity is 65.5 ppt with an average current speed is about 0.25 m/sec with a depth of the outfall is around 3.5 m is well mixed and the brine concentration immediately mixed with ambient water and getting diluted to get the ambient condition i.e. 42 ppt.

Far-field horizontal and vertical mixing and dilution rely on the ambient conditions of the receiving waters (tidal and wind-driven currents, wave-induced turbulence and density gradients). Some plumes are positively buoyant and will rise to the surface (e.g. oil) whilst negatively buoyant plumes (e.g. brine) will sink to the bottom of the water column. In both cases, similar near-field mixing processes of entrainment induced by momentum flux occur, but buoyant plumes experience more mixing in the far-field than dense plumes, as buoyant plumes ultimately reside near the surface where turbulent mixing due to winds and waves is more pronounced. The present study is brine water dilution and dispersion of an SWTP at Mirfa location and the plume travels near bed level of the sea and below the sea surface due to density difference. The brine water discharge to the marine environment travels near the bottom of the sea due to being negatively buoyant with density differences.

In the far-field, dense plumes tend to move in the lower part of the water column where mixing occurs predominantly due to bed velocities, baroclinic flows and turbulent mixing down from the surface, which are typically less energetic, depending on the depth of the water, than the processes closer to the surface. Simulation of these processes can be carried out in three ways:

The use of near-field dilution algorithms which define the near-field dilution achieved by different discharge/diffuser configurations. The use of specific near-field CFD (computational fluid dynamics) sub-models such as the MIKE21 Ad model to define the behaviour of the reject flow in the first few meters from the outlet.

As could be seen from the computational grid plan shown in Figure 6.1 and Figure 6.2, 3 open boundary conditions are required to be provided for simulating flow field in the project site. These open boundary conditions have been considered as no flow of brine from the boundary or inside the domain. It could be seen from the salinity dispersion distribution that the dispersion is unidirectional in east and west directions.

Several trial runs of the advection-dispersion model were made by varying dispersion coefficients. The advection and dispersion model results are shown in Figure 9.1, Figure 9.2, Figure 9.3, Figure 9.4, Figure 9.5, Figure 9.6, Figure 9.7, Figure 9.10, and Figure 9.11, The Figure 9.1 indicated that the dispersion of brine water with spring tide during high water and shows the distribution of concentration is in the order of .0.024 ppt. Figure 9.2 indicates the dispersion of brine water with spring tide during low water and shows the distribution of concentration is in the order of 0.024 ppt. Figure**Error! Reference source not found.** 9.3 indicated the dispersion of brine water with spring tide during flooding and shows the distribution of concentration is in the order of 0.020 ppt. Figure 9.4 indicated the dispersion of brine water with spring tide during ebbing and shows the distribution of concentration is in the order of 0.028 ppt. Figure 9.5 indicated the dispersion of brine water with the neap tide during high water and shows the distribution of concentration is in the order of 0.024 ppt. Figure 9.6 indicates the dispersion of brine water with the neap tide during low water and shows the distribution of concentration is in the order of 0.0.028 ppt. Figure 9.7 indicated the dispersion of brine water with the neap tide during flooding and shows the distribution of concentration is in the order of 0.025 ppt. Figure 9.8 indicated the dispersion of brine water with neap tide during ebbing and shows the distribution of concentration is in the order of 0.022 ppt. Figure 9.9 indicated the dispersion of brine water at end of the simulation i.e. 60 days and shows the distribution of concentration is in the order of 0.024 ppt. Figure 9.10 indicated that the distribution of concentration of salinity at the intake is from 0.001 ppt to 0.021 ppt.

The volume of brine water discharged in the outfall plays a very vital role in the dispersion, for example, the volume of discharge is less dilution and dispersion are maximum at the near field and far field with considerable current speed and direction. The chemical properties of the reject water particularly salinity is 65.5 ppt with an average current speed is about 0.25 m/sec with a depth of the outfall is around 3.5 m is well mixed and the brine concentration immediately mixed with ambient water and getting diluted to get the ambient condition i.e. 42 ppt.

Based on the mathematical modelling studies for the salinity dispersion in the marine environment using MIKE21 HD and AD, it is observed that the negligible amount of salinity concentration in the near field and far field in the marine environment from the outfall location. The recirculation of salinity concentration at intake is a very minimal or negligible amount interacting with ambient water. The EAD criteria i.e. salinity concentration in the marine environment should be well below 1 ppt at the intake structure to avoid recirculation of brine discharge at outfall are well with the prescribed level.

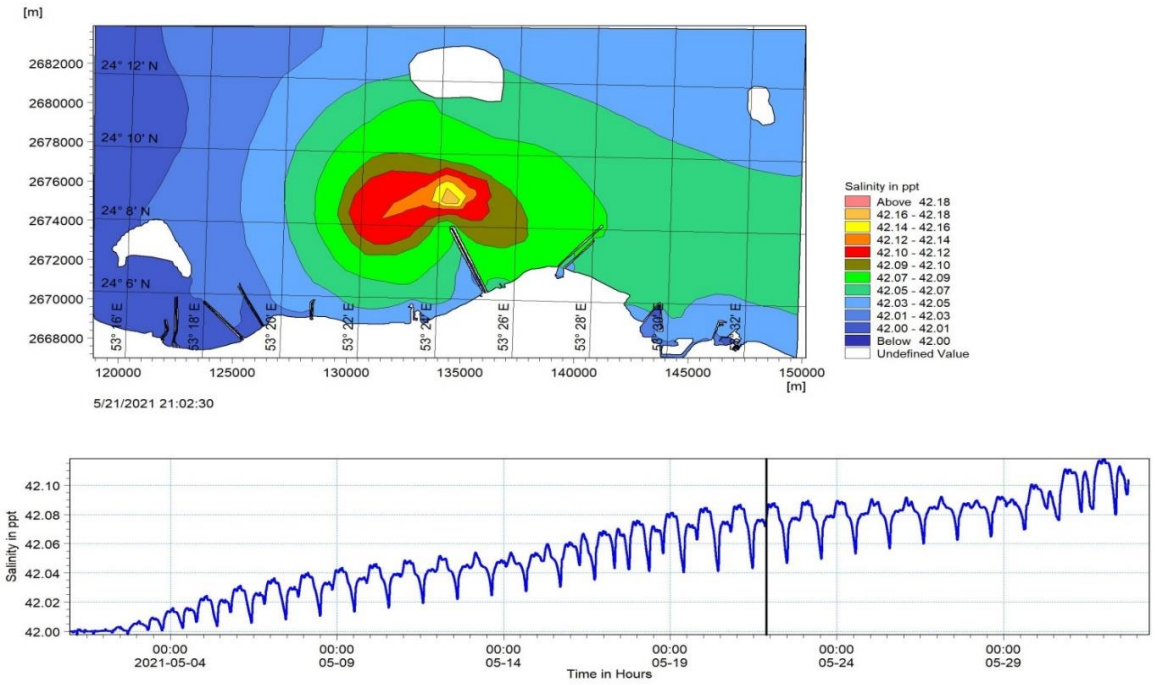


Figure 9.1 – Salinity Dispersion During High water (Spring Tide)

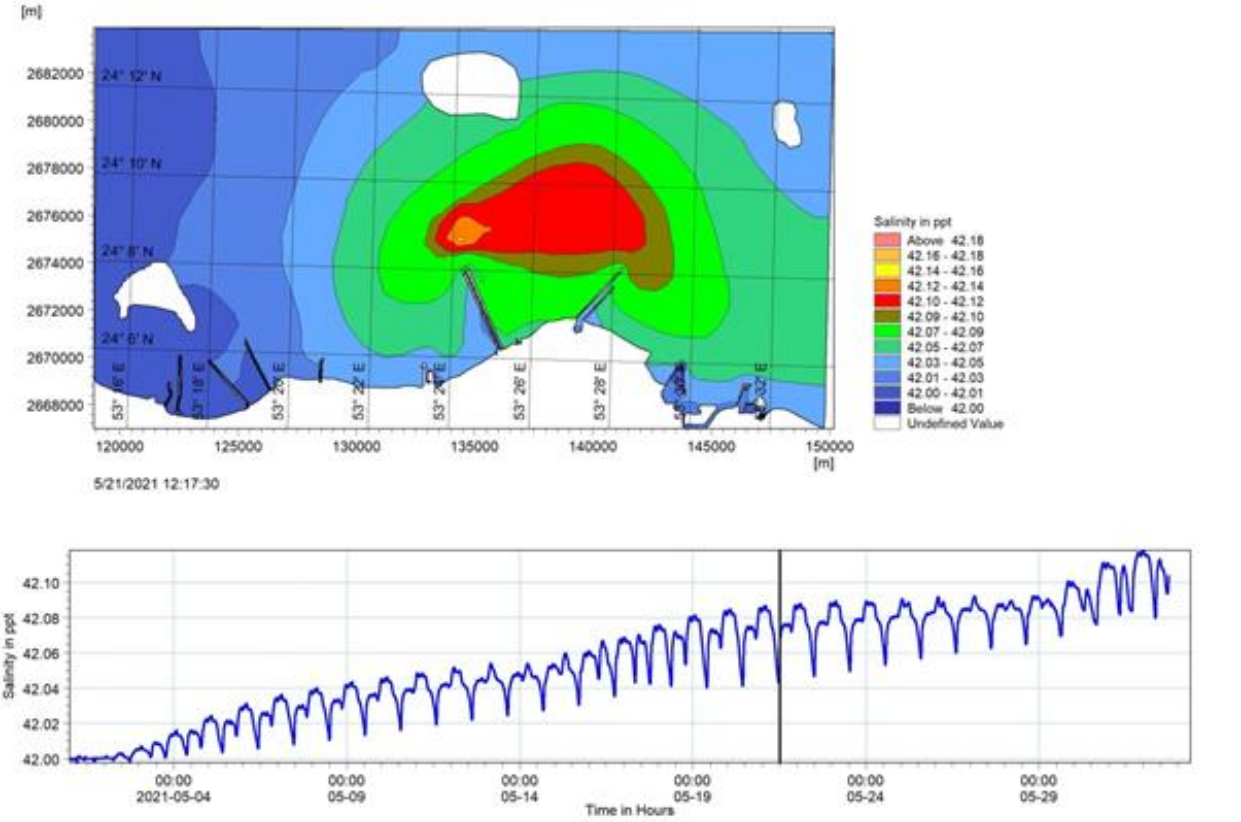


Figure 9.2 – Salinity Dispersion During Low water (Spring Tide)

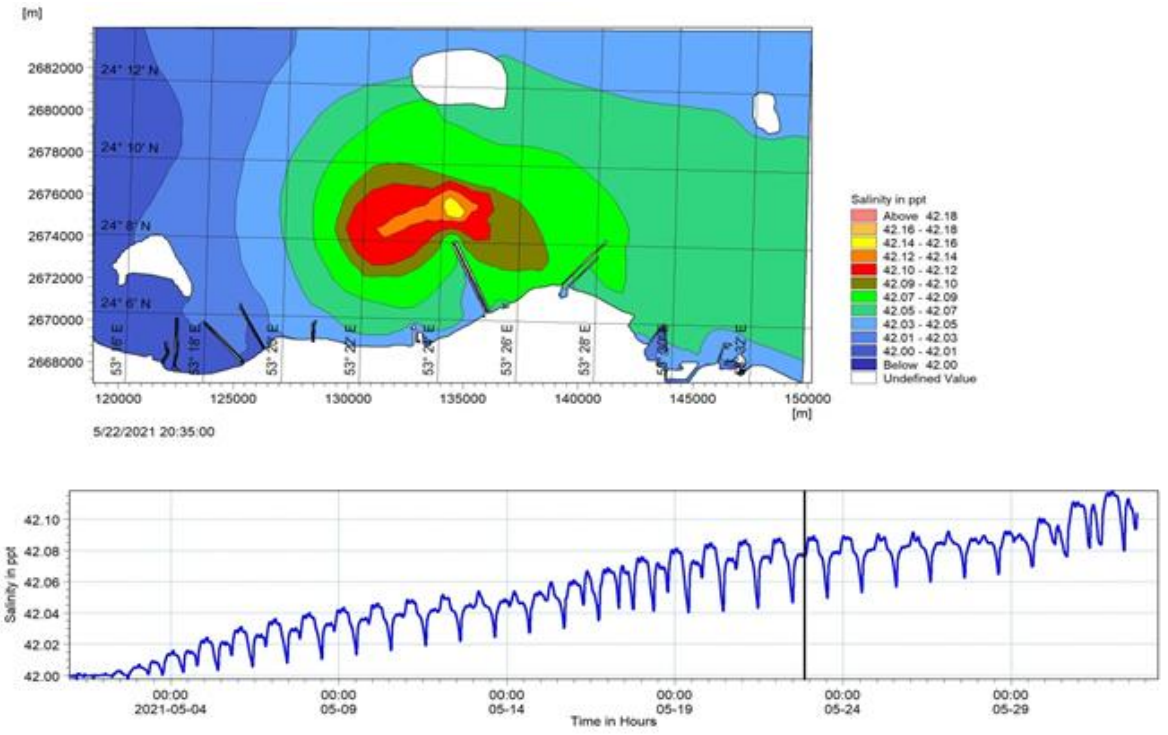


Figure 9.3 – Salinity Dispersion During Flooding (Spring Tide)

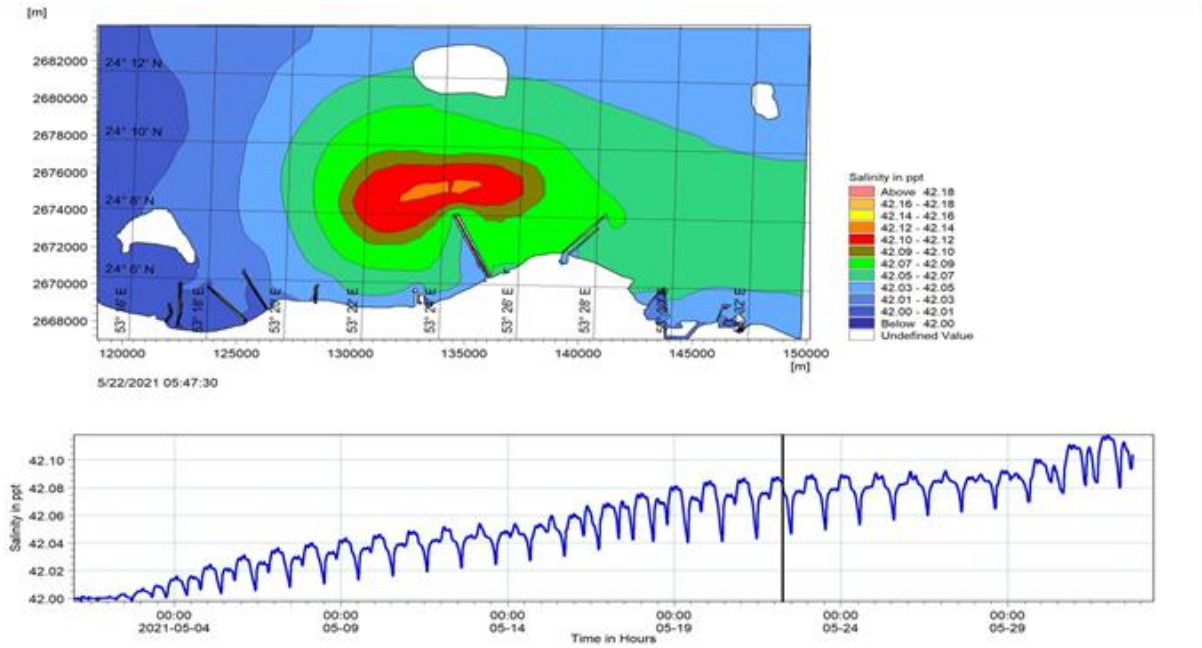


Figure 9.4 – Salinity Dispersion During Ebbing (Spring Tide)

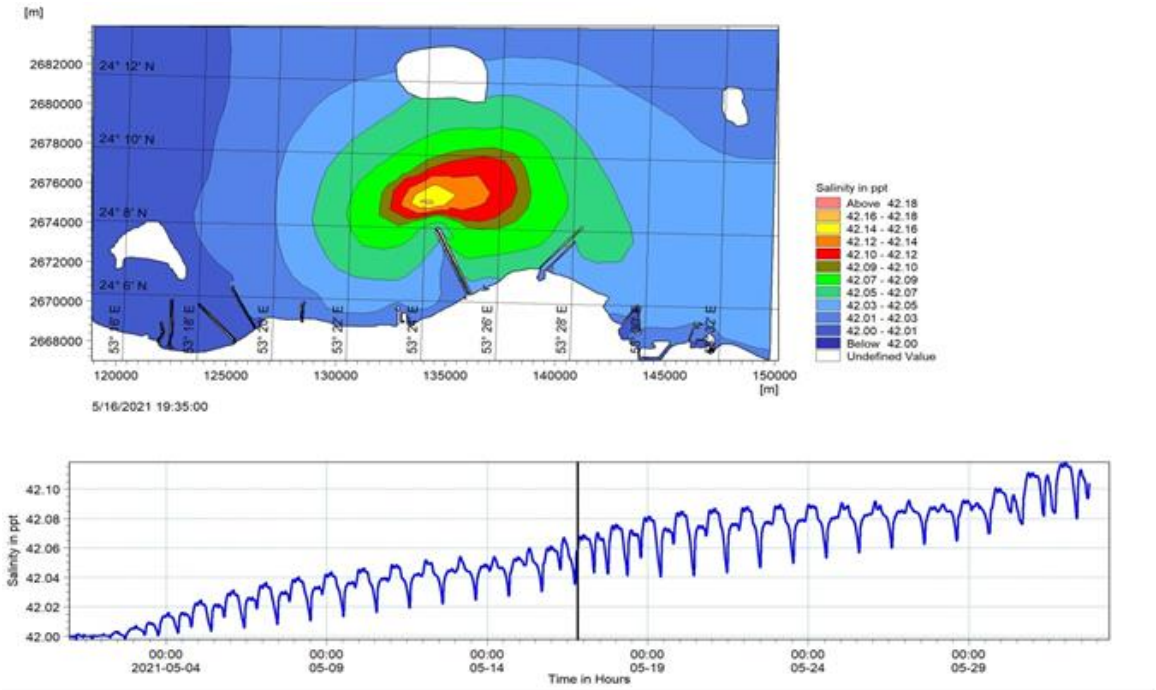


Figure 9.5 – Salinity Dispersion During High Water (Neap Tide)

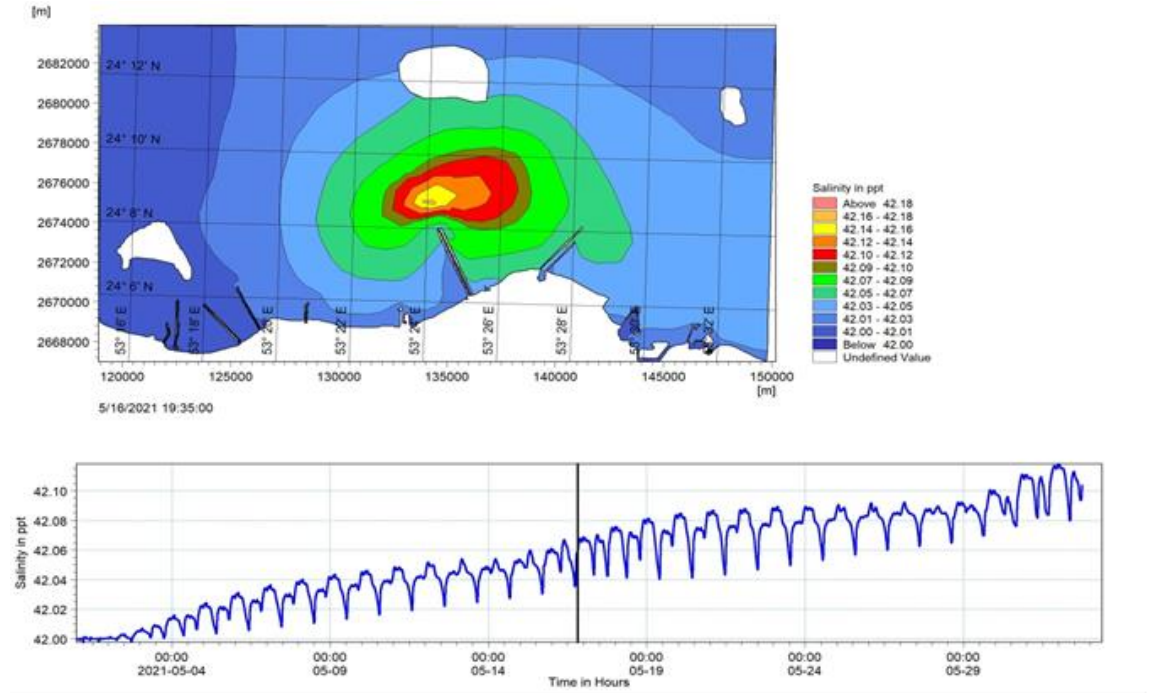


Figure 9.6 – Salinity Dispersion During Low Water (Neap Tide)

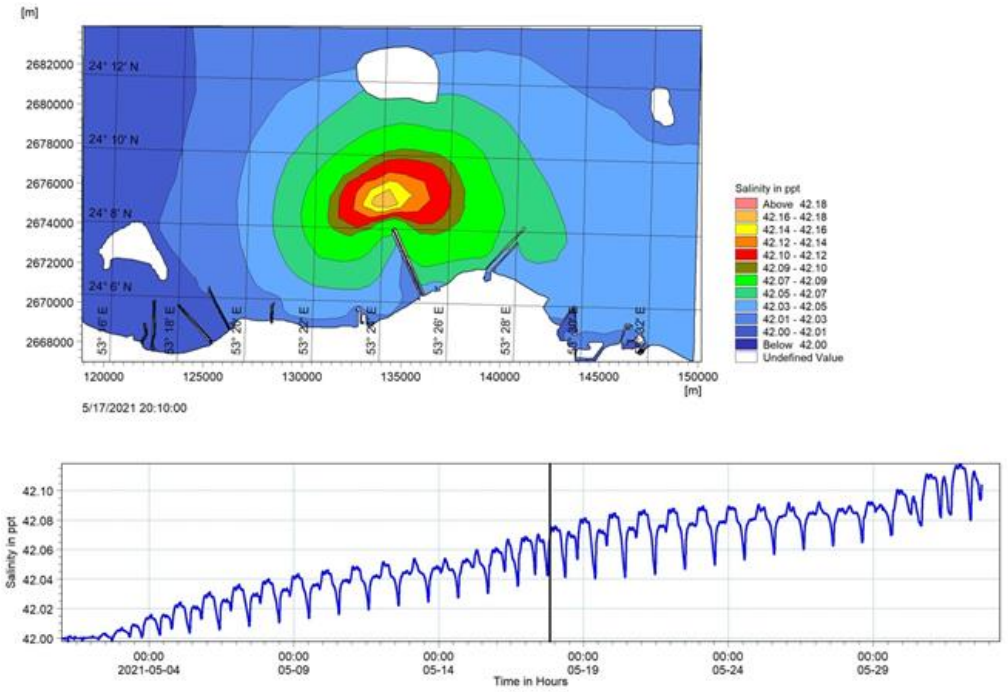


Figure 9.7 – Salinity Dispersion During Flooding (Neap Tide)

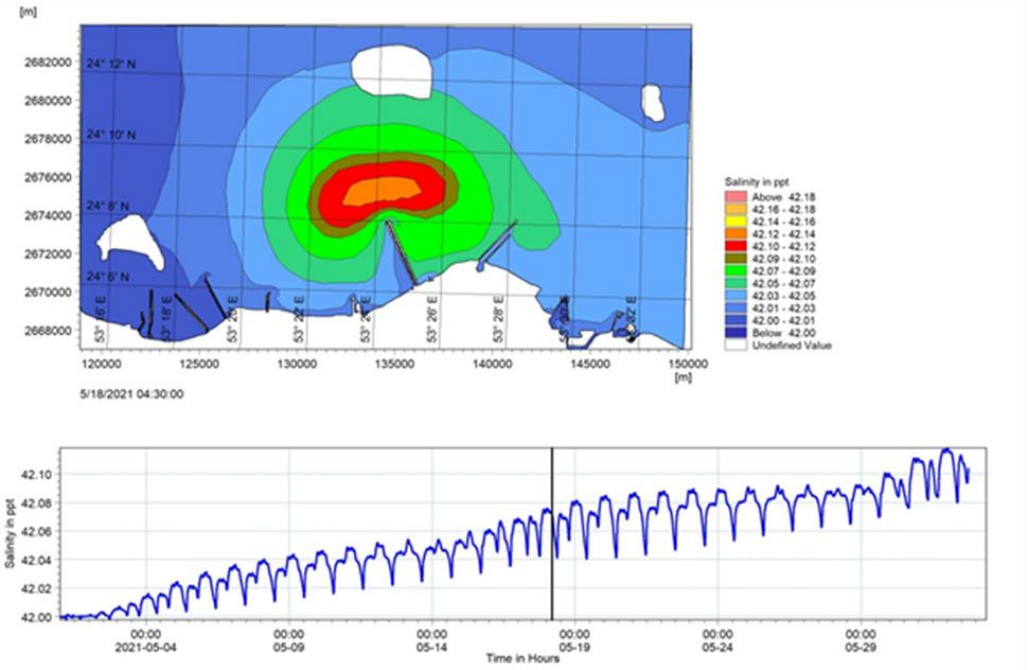


Figure 9.8 – Salinity Dispersion During Ebbing (Neap Tide)

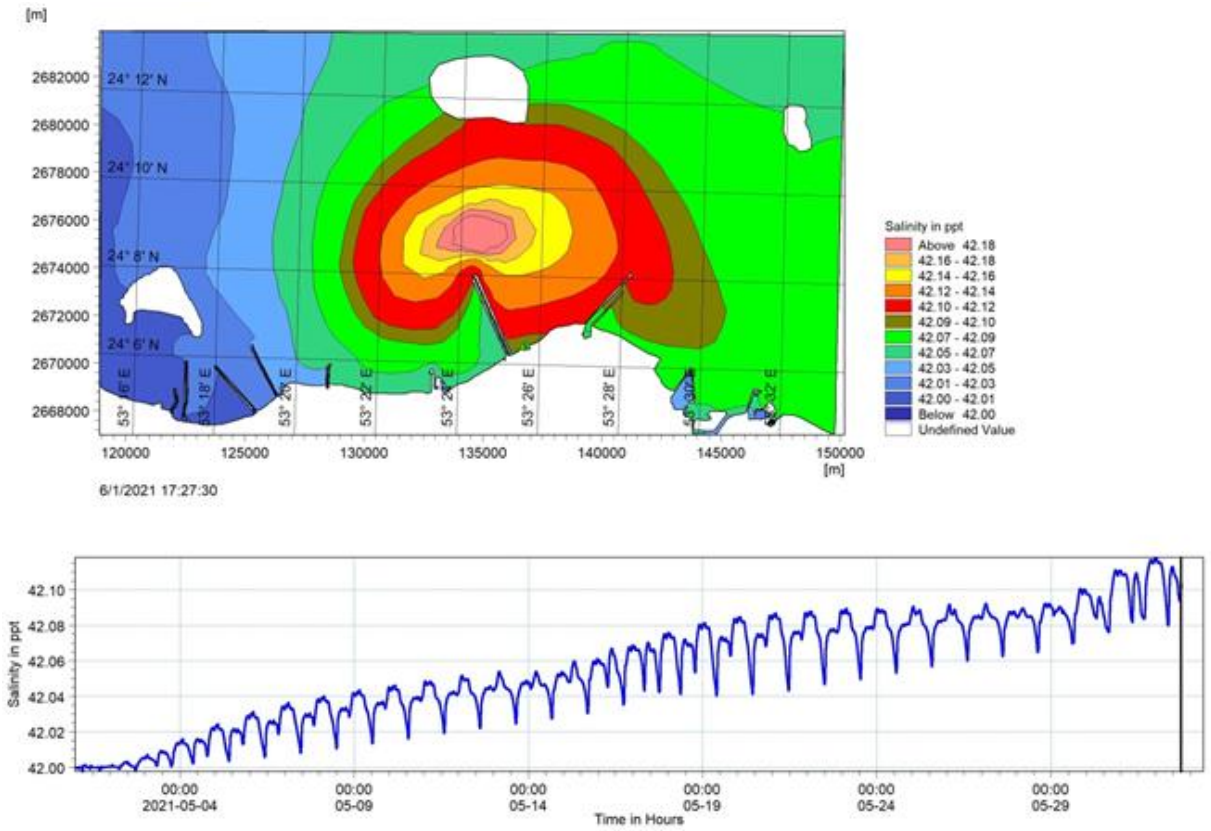


Figure 9.9 – Salinity Dispersion End of Simulation

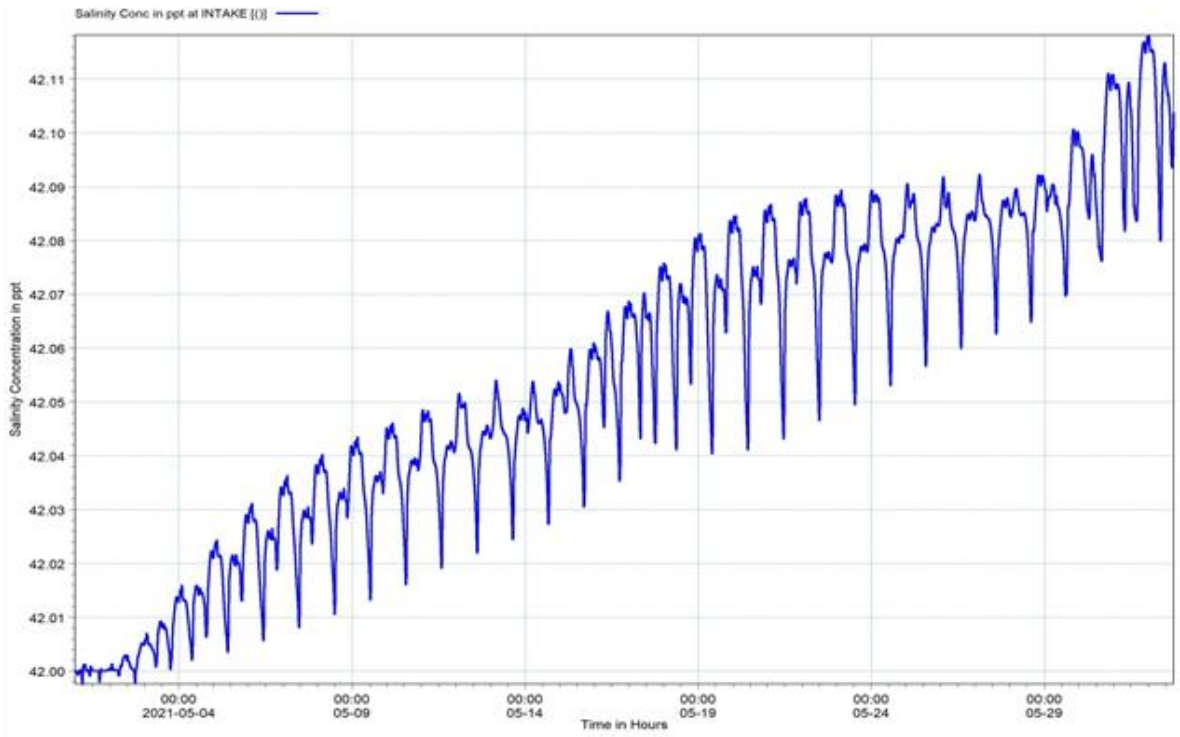


Figure 9.10 – Salinity Concentration at the Intake

$$\% \text{ of the dilution} = \frac{\text{The volume of Brine (Solute)}}{\text{(Volume of Brine + Volume of Water (Solvent) in a Time Step)}} \times 100$$

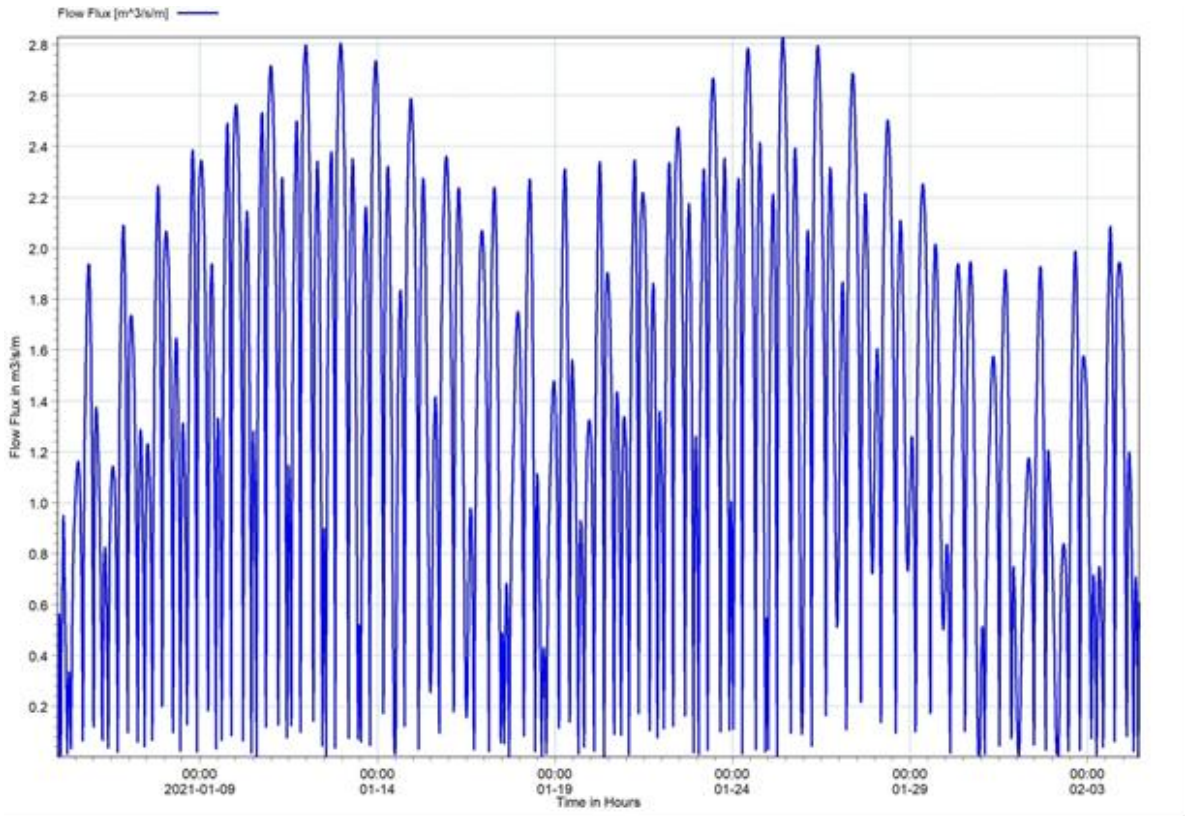


Figure 9.11 – Volume of Water Available at the Outfall in Time step

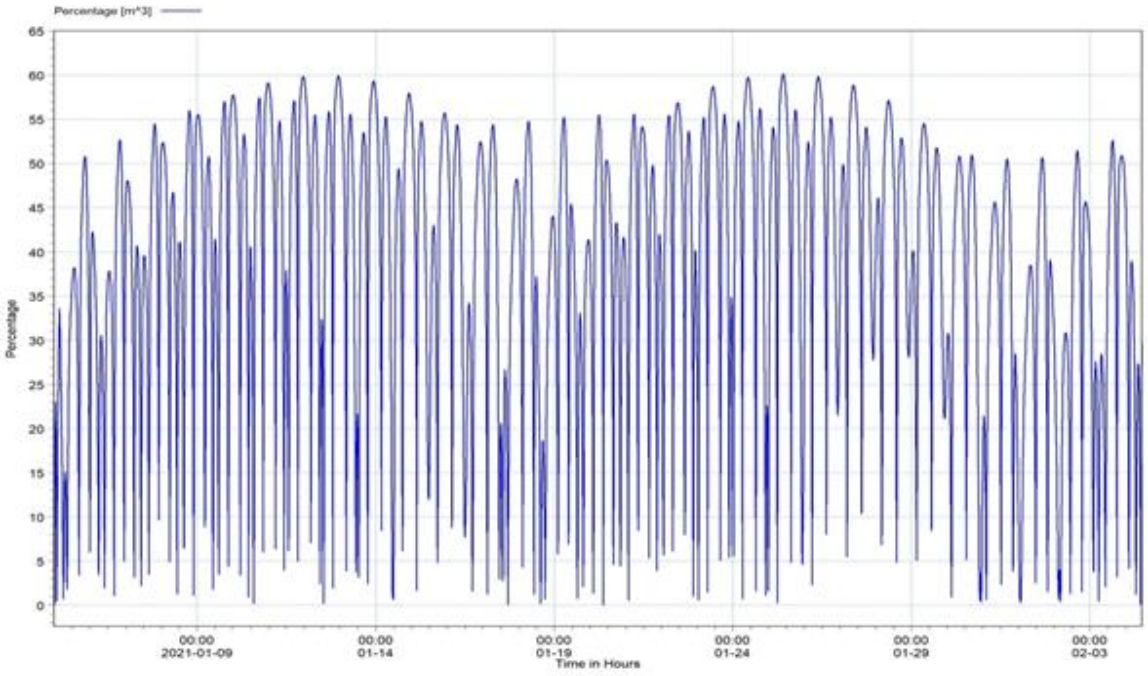


Figure 9.12 – Volume of Water Available at the Outfall in Time step

EAD regulation

The minimum dilutions required to satisfy the regulatory requirements can be calculated as follows:

If: S1: maximum discharge salinity = 68.052 ppt

S2: minimum ambient salinity = 42 ppt

(Conservative value based on measurements off Ruwais by Atkins, 2009)

n: minimum number of dilutions required.

Then: (S1+n x S2) / (n+1) = 1.05 x S2

Or: n = (S1 - 1.05 x S2) / (0.05 x S2)

n= (65.50-1.05x42)/0.05x42)

Therefore: n = 10.1905

Note that:

- To obtain dilution to within 1 ppt of ambient requires a dilution of 32
- To obtain dilution to within 0.5 ppt of ambient conditions requires a dilution of 65
- If the requirement was to be within 3% of ambient conditions at the mixing zone boundary, a dilution of 25 would be required

The average dilution percentage for the present study calculated as per the formula is 39.05618 percentage. Figure 9.13 and Figure 9.14 show the Close up view of the simulated results with the outfall has a concentration of 42.18 ppt. it means that 0.18 ppt is increased from the ambient salinity.

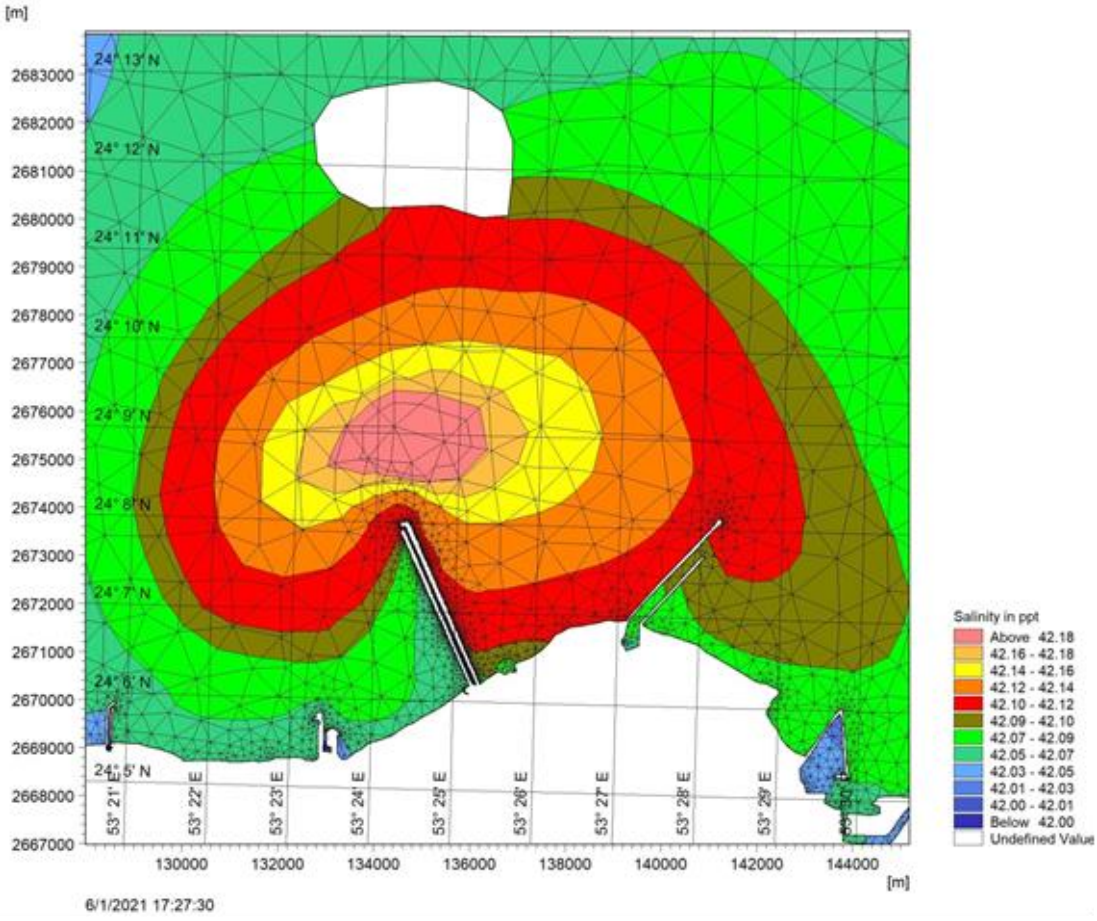


Figure 9.13 – Close-up View of the end of the Simulation

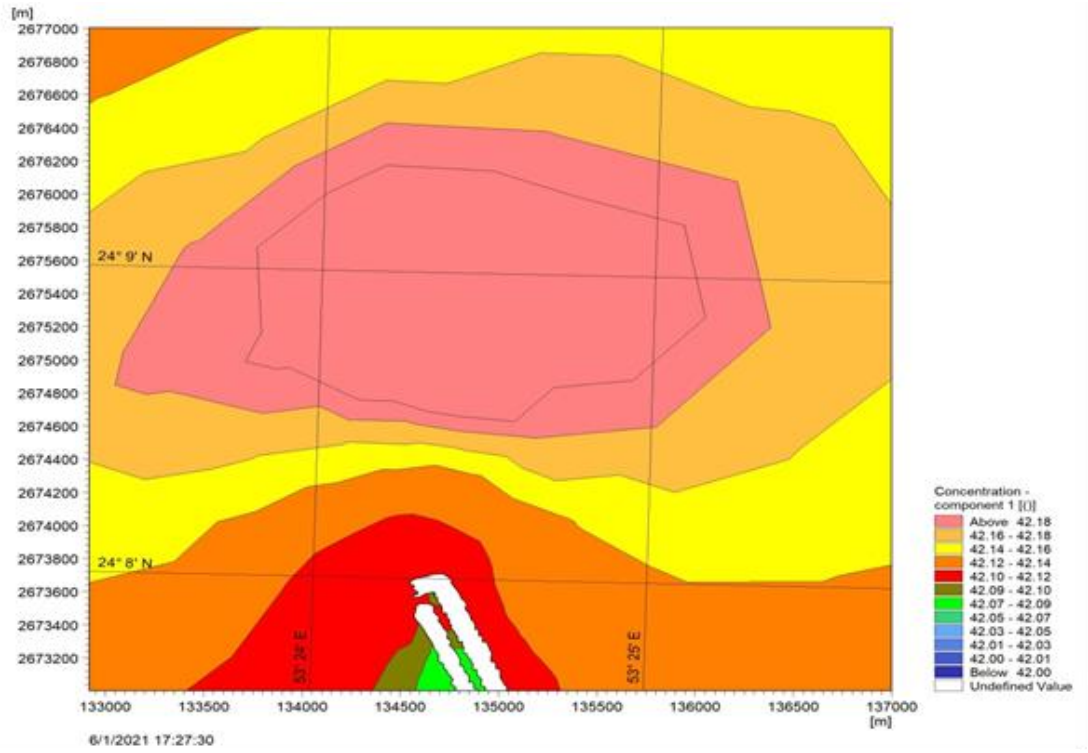


Figure 9.14 – Close-up view of the outfall for the dispersion at end of the simulation

10 CONCLUSIONS

The volume of brine water discharged in the outfall plays a very vital role in the dispersion, for example, the volume of discharge is less dilution and dispersion is maximum at the nearfield and far-field with considerable current speed and direction. The chemical properties of the reject water particularly salinity is 65.5 ppt with an average current speed is about 0.25 m/sec with a depth of the outfall is around 3.5 m is well mixed and the brine concentration immediately mixed with ambient water and getting diluted to get the ambient condition i.e. 42 ppt.

Results of the study show that under the worst-case scenario, the hydrodynamic model results are shown as the tide and current speed are parallel to the coastline. The circulation and vertices of the velocities are not observed in the selected domain area. The tidal level varies from 0.1 m to 2.2 m including spring tide and neap tide for the 60 days velocities are not seen. The velocity of the domain is from 0.01 to 0.4 m/s.

Based on the mathematical modelling studies for the salinity dispersion in the marine environment using MIKE21 HD and AD, it is observed that the negligible amount of salinity concentration in the near field and far field in the marine environment from the outfall location. The recirculation of salinity concentration at the intake is a very minimal or negligible amount interacting with the ambient water. The EAD criteria ie salinity concentration in the marine environment should be well below 1 PPT at the intake structure to avoid recirculation of brine discharge at outfall are well within the prescribed level. It can be concluded that the salinity concentration at the intake, a minimum amount of salinity concentration enters in to the intake water for the recirculation of the plant and the damage to the environment is also very less.

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