ΕΡΓΟΔΟΤΗΣ

Αρχή Λιμένων Κύπρου

ΕΡΓΟ

ΕΠΙΚΑΙΡΟΠΟΙΗΜΕΝΗ ΜΕΛΕΤΗ ΕΚΤΙΜΗΣΗΣ ΕΠΙΠΤΩΣΕΩΝ ΣΤΟ ΠΕΡΙΒΑΛΛΟΝ (ΜΕΕΠ) ΓΙΑ ΤΗΝ ΕΠΕΚΤΑΣΗ ΤΟΥ ΛΙΜΕΝΑ ΛΕΜΕΣΟΥ – ΤΕΡΜΑΤΙΚΟ 2 (ΒΑΣΙΛΙΚΟ)

ΤΙΤΛΟΣ ΕΓΓΡΑΦΟΥ

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Έκδοση	Ημερ.	Περιγραφή	Ετοιμασία	Έλεγχος

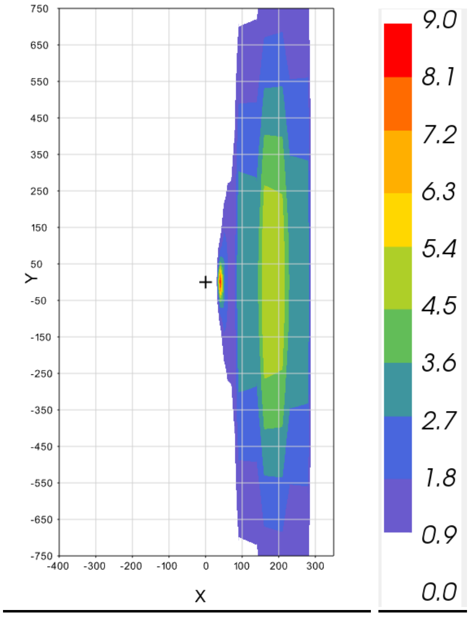
ΕΠΙΤΕΛΙΚΗ ΣΥΝΟΨΗ

Η Αρχή Λιμένων Κύπρου προγραμματίζει την επέκταση του λιμένα Λεμεσού – Τερματικό 2 (Βασιλικό) προς τα ανατολικά.

Για την υλοποίηση της επέκτασης αυτής απαιτούνται σημαντικές βυθοκορήσεις, οι οποίες θα γίνουν με την χρήση ειδικού εξοπλισμού βυθοκόρησης για εκτιμωμένη ποσότητα 2,690,000 m^3 . Για την απόρριψη των βυθοκορημάτων προτείνεται σημείο απόρριψης, με συντεταγμένες 34^o 39.210'N, 33^o 18.928'E. Η περιοχή των βυθοκορήσεων χωρίστηκε σε τρεις ζώνες βάση τη Γεωτεχνική Μελέτη, η οποία καθόρισε χαρακτηρίστηκα ιζήματος για την κάθε ζώνη. Το σημείο απόθεσης των βυθοκορημάτων πληροί τις προϋποθέσεις βάθους (200 m), έχει απόσταση περίπου 7200 m από την ακτή και εμφανίζει πολύ μικρές ταχύτητες ρευμάτων (0,075 m/s). Η διάταξη της εκροής θεωρείται ότι γίνεται στα 185 m από τον πυθμένα με διαχυτήρα διατομής 1 m, σε κατακόρυφη γωνιά -90 και οριζόντια 0 μοίρες, με δυνατότητα διάθεσης από μέρος των Βυθοκόρων (Dredgers) 5000 m^3 σε 1.5 ώρες (0,926 m^3/s) με συγκέντρωση στερέων 200 Kg/m^3.

Από τα αποτελέσματα της μελέτης διαπιστώνεται ότι η αρχική απόθεση λαμβάνει χώρα αρκετά πλησίον της πηγής εκπομπής (~50 m), ενώ μόνο το 0,02 % της ροής απομένει σε απόσταση μεγαλύτερη από τα 290 m κατάντη, στο δυσμενέστερο σενάριο. Και για τις τρεις ζώνες με μεταβλητά χαρακτηριστικά τα αποτελέσματα είναι παρόμοια, καθώς οι ισορυπαντικές καμπύλες συγκέντρωσης των 0.5% δεν υπερβαίνουν τα 21 μέτρα για οποιανδήποτε από τις προαναφερθείσες ζώνες. Μια πρωτογενής απόθεση θα λάβει χώρα κοντά στην πηγή μέσα σε περίπου 3.5 λεπτά, καθώς όλα τα χαλίκια και τα τεμάχια που περιέχονται στη ροή ιλύος απελευθερώνονται αμέσως, ακολουθούμενα από την απόθεση μέρους της συνολικής ροής περίπου 50 μέτρα μακρύτερα. Η άμμος θα είναι το δεύτερο κλάσμα που θα απομακρυνθεί πλήρως από τη ροή μάζας που παραμένει, και αποτίθεται περίπου 88 μέτρα μακρύτερα (κατά την κατεύθυνση X) για το υλικό που προέρχεται από όλες τις ζώνες. Μια δευτερογενής καταβύθιση ιλύος θα λάβει χώρα σε αποστάσεις μεταξύ 100 μέτρων για όλες τις ζώνες, και 290, 265 και 250 μέτρα (κατά την κατεύθυνση X) για τις Ζώνες 1, 2 και 3 αντίστοιχα, αποθέτοντας την πλειονότητα του αιωρούμενου ιζήματος μέσα στην περιοχή από 150 έως 190 μέτρων και περίπου σε 1 ώρα και 7 λεπτά.

Η παρακάτω εικόνα παρουσιάζει το δυσμενέστερο σενάριο απόθεσης κατά το οποίο η πλειονότητα του καταβυθισμένου υλικού εκτείνεται μέχρι απόσταση 290 m, για χρονική διάρκεια εκροής 1 ώρα και 30 λεπτά.



Συμπερασματικά, η απόθεση των υλικών βυθοκορήσεων στο προτεινόμενο χώρο χαρακτηρίζεται κυρίως από τα αρχικά συμπαγή τεμάχια, που φτάνουν στο βυθό ακαριαία. Η πλειονότητα (99.98%) της ροής ιλύος εναποτίθεται στον πυθμένα μέσα σε μία ώρα και δέκα λεπτά, σε μέγιστη απόσταση 290 μέτρων από την πηγή, για το χειρότερο ενδεχόμενο που παρατηρήθηκε.

Συνεπώς, σύμφωνα με τα παραπάνω, η απόθεση των υλικών βυθοκορήσεων που προέρχονται από αυτές τις τρεις ζώνες θα έχει περιορισμένο αντίκτυπο στο τοπικό περιβάλλον και τη βιοποικιλότητα, λόγω του περιορισμένου χρόνου παραμονής τους στα ανώτερα επίπεδα της στήλης νερού και της περιορισμένης χωρικής του έκτασης.

1. INTRODUCTION

The Cyprus Ports Authority is planning to expand the Limassol Port - Terminal 2 (Vassilikos) to the east.

This will include necessary dredging operations which will be carried out for the creation of the new eastern port basin, the foundation trenches for the new quaywalls, and for the approach channel.

Dredging will be carried out using specialized dredging equipment.

The removal of loose material will be carried out using a trailing suction hopper dredger. The operation of the dredge shall include the sinking of the suction pipes to the required depth and the suction of the loose dredged material which shall be discharged into the dredge storage tank. When the storage tank is full, the suction head is placed on board the vessel and the dredger moves to the predetermined disposal area where it deposits the material through the vessel floor doors. The dredger shall return to the dredging area empty for the same production cycle.

Dredging of cohesive materials is performed by a floating crane equipped with a dredge bucket that drops to the bottom, detaches pieces of cohesive materials and dumps them onto an adjacent barge that transports them to the dumping site where it dumps the material from its floor doors.

The following operations are necessary for the disposal of dredged material in a marine area:

- Conducting chemical analyses of the excavated material to determine its content of hazardous substances e.g. heavy metals and its suitability for disposal in the marine environment.
- Identification of the necessary marine site which complies with all the provisions of international treaties for the disposal of dredged material.

The disposal at sea has significant advantages over disposal on land, namely:

- It is less time-consuming in terms of the period of disposal of the dredged material
- It presents lower economic costs
- It avoids negative impacts on the local man-made environment

Regarding the chemical analyses of the sediments, the analyses carried out as part of the implementation of the Special Background Survey (EBS) study and reported in the next chapter indicate that the material is at acceptable levels.

The proposed disposal area (34^{o} 39.210'N, 33^{o} 18.928'E) is shown in the figure below and is located south of the harbour and approximately 7.2Km from the shore.

In addition, this chapter presents the following simulation model results for the dispersion of sediment-estimated to be approximately 2,690,000 m^3 - during discharge at this site.

Figure 1 Proposed site (by the Fisheries Department) for disposal of dredging material.

<u>Dredged material discharge simulation - Dispersion model</u>

This chapter has considered the quantitative assessment of sedimentation and mixing during the disposal of dredged material from dredging processes. The spatial extent of the sediment and the concentration of sedimentary material were estimated. This assessment leads to useful conclusions on the potential environmental impacts of the disposal processes.

The Cornell Mixing Zone Model (CORMIX) Version 10.E (Doneker and Jirka, 2007), developed by Cornell University on behalf of the US Environmental Protection Agency (USEPA), is used for the calculations. CORMIX is the USEPA-recommended tool for analysing impacts of waste discharge to water bodies (USEPA, 1991a,b). At the same time, it has been applied and calibrated for a range of hydrodynamic conditions on which predictions are made. Comparison with field measurements and laboratory experiments has shown that CORMIX predictions are reliable in the majority of cases (Jirka, 2004).

CORMIX incorporates a suite of hydrodynamic mixing and sediment dispersion models from excavation processes (Purnama et. al., 2016). To select the appropriate mixing model(s), it applies a set of rules based on the characteristics of the disposal system and the receptor. That is, it has the ability to identify the hydrodynamic conditions in the discharge area, evaluate the predictive ability of the hydrodynamic models and select the appropriate ones.
The discharge of dense (high sediment concentration) material leads to submergence until the bottom with simultaneous dilution of the plume by the surrounding water. The material is then dispersed on the bottom, forming a layer, which is diluted by water infiltration and resuspension of sedimentary material.

2. ENVIRONMENTAL DATA – ASSUMPTIONS

The following table (Table 1) contains information about certain parameters:

1. Effluent Discharge: This refers to the volume flow rate of the liquid being discharged. In this case, it is 0.926 cubic meters per second (m^3/s). This parameter is crucial in understanding the rate at which the liquid is released.
2. Temperature: The temperature of the effluent is given as 20 degrees Celsius (°C). Temperature is a key factor as it can influence the behavior and characteristics of the liquid, such as its viscosity and density.
3. Density: The density of the liquid is provided as 1270.08 kilograms per cubic meter (kg/m^3). Density is a measure of mass per unit volume and is an important property in fluid dynamics.

Table 1 Effluent characteristics.

Parameter	Value
Effluent Discharge	0.926 m^3/s
Temperature	20°C,
Density	1270.08 kg/m^3

Table 2 Environmental characteristics. , contains information related to the environmental characteristics.

1. Depth at Discharge: This parameter indicates the depth at which the fluid is being discharged and is specified as 200 meters. The depth is a significant factor in understanding the vertical extent of the fluid flow.
2. Bed Slope: The bed slope is given as 1.6%. Bed slope refers to the inclination or gradient of the bed or bottom surface of a channel through which the fluid is flowing. It is expressed as a percentage in this case.
3. Current Velocity: This parameter specifies the velocity of the fluid current and is given as 0.075 meters per second (m/s). Current velocity is a critical parameter in fluid dynamics as it describes the speed at which the fluid is moving.

Table 2 Environmental characteristics.

Parameter	Value
Depth at Discharge	200 m
Bed Slope	1.6 %
Current Velocity	0.075 m/s

2.1. Data - Assumptions – Dredged Material and Disposal System

The Dredged material composition was derived by consulting the Final Report on *Geotechnical Investigation at the Site of the Proposed Extension of the Existing Breakwater of Vasiliko Port, Terminal 2 (Vasiliko) Tender No. 1/2017 Volume 1.*

According to the above report the Dredged area is divided in 3 zones, which in turn are characterized based on the geotechnical cross sections provided in the report.

The area to be dredged is shown is *Figure 2*

Table 3 Soil types present in the site and their percentage correlation with CORMIX available choices.

Soil Class in the study area	Gravel/Chunks	Sand	Silt	Clay
Coarse Soils	58%	25%	9%	8%
Loose Soils	17%	62%	22%	0%
Marl	90%	1%	6%	3%
Fine Soils	6%	47%	42%	6%

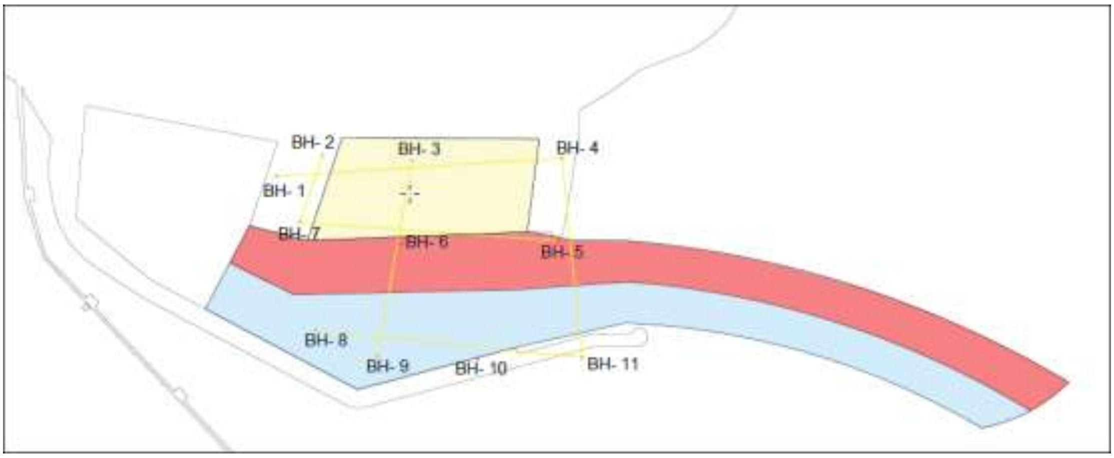


Figure 2 The separation of the dredging area in to 3 zones, Zone 1 is represented by the Cyan hatch, Zone 2 by the Red and Zone 3 by the Yellow hatch.

Table 4 Soil types percentages present in each designated Zone.

Soil Class	**Zone 1 BH8-BH11**	**Zone 2 BH7-BH5**	**Zone 3 BH2-BH4**
Coarse Soils	59.0%	0.0%	22.4%
Loose Soils	5.6%	12.7%	0.0%
Marl	21.0%	65.0%	55.3%
Fine Soils	14.4%	22.3%	22.3%
Note: All silt is assumed as Fine Silt as there is no criteria to categorize it in to Coarse and Fine.			

Table 5 CORMIX soil class percentages per Zone.

Soil Class	**Particle Size (mm)**	**Settling Velocity (m/s)**	**Zone 1 %**	**Zone 2 %**	**Zone 3 %**
Chunks	> 2	Instantly	54.8	61.8	64
Sand	0.062 – 2	0.31×10^{-1}	25.5	19	16.8
Coarse silt	0.016 – 0.062	0.42×10^{-3}	0	0	0
Fine silt	0.004 – 0.016	0.26×10^{-4}	13.5	16.2	14.7
Clay	< 0.004	0.65×10-6	6.2	3	4.6

Table 6 Discharge characteristics.

Parameter	Value
Port Diameter	1 m
Vertical Port Angle	-90°C
Horizontal Port Angle	0°C
Discharge Depth	185 m
Shoreline Distance	7200 m

3. RESULTS

3.1. Zone 1:

Zone 1 is represented by the cyan area in *Figure 1*, while below the series of images depict the plume dispersion in the Near and Far Field Regions (NFR/FFR). The plume at the end of NFR (286 m) will reach a width of 500 m and thickness layer of around 9 m within 0.98 hours. While within 29.18 hour the plume will have reached the end of the FFR (10,000 m) and will have a width of 1500 m and a layer thickness around 5 m.

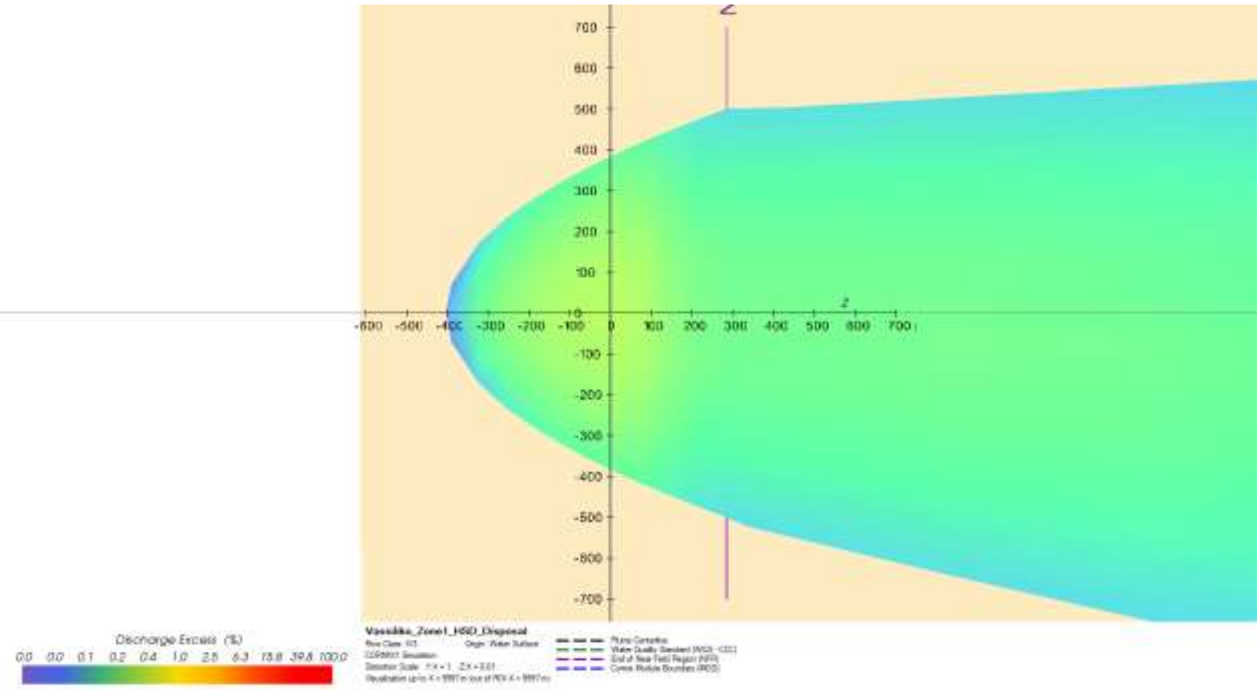


Figure 3 Y-X view of the plume in the Near Field Region (NFR).

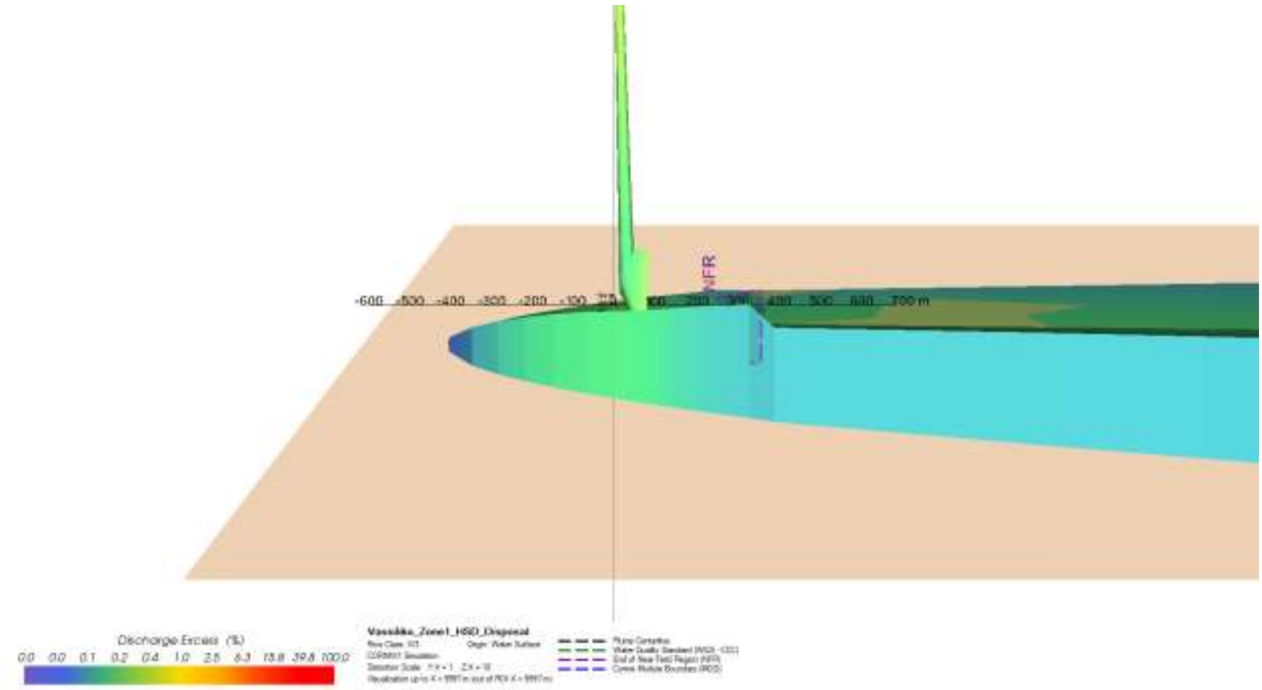


Figure 4 X-Z view of the plume in the Near Field Region.

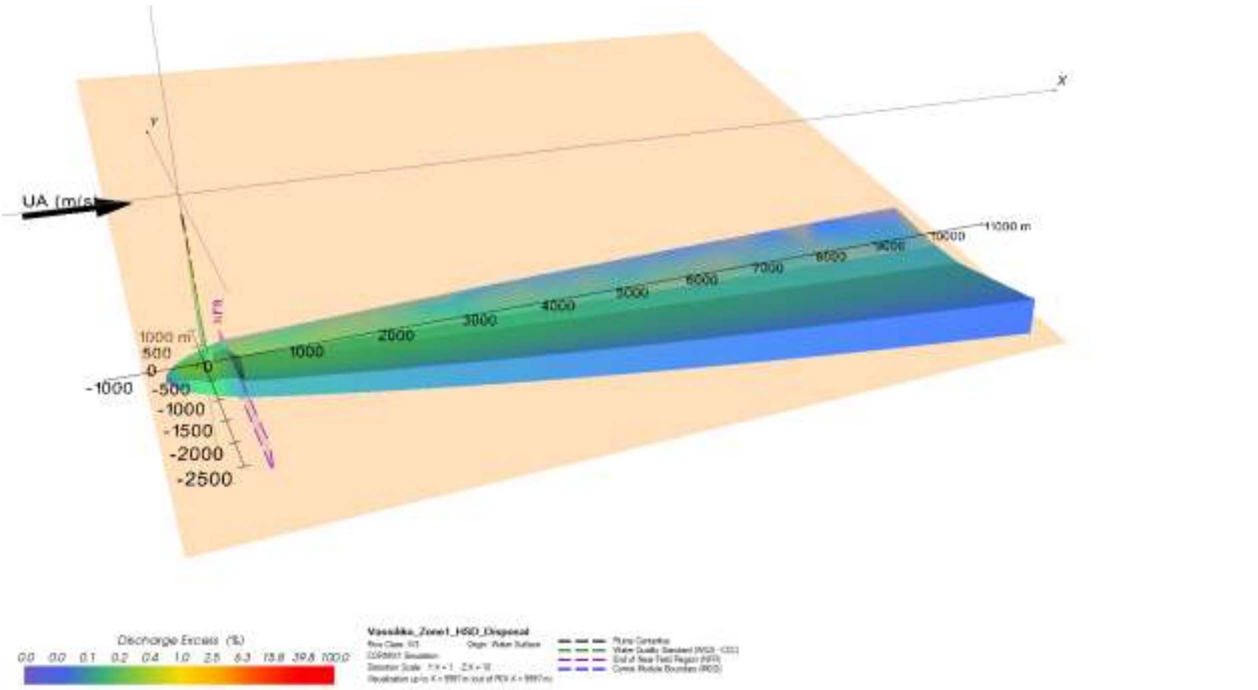


Figure 5 3D plume view of the Far Field Region (FFL).

In Figure 4 we can observe the plume undertaking a rather steep dive towards the sea bed, reaching the bottom around the 35 m mark in the X (downstream) direction. While upstream intrusion will be encountered, spanning at a distance of around 440 m upstream, with a half width of 500 m.

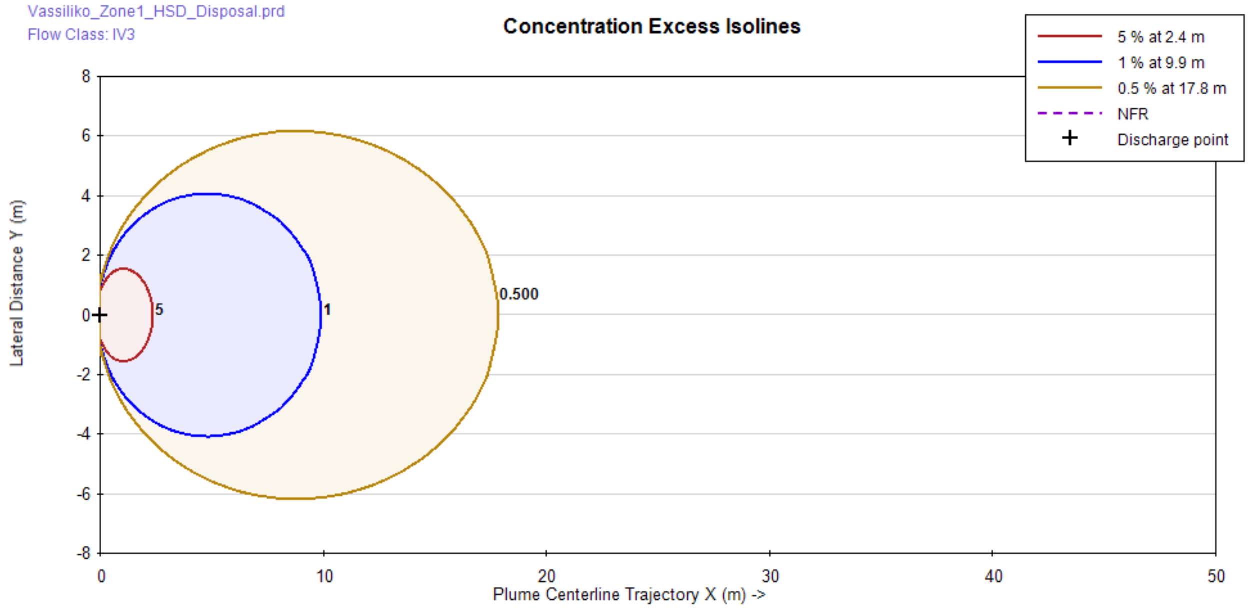


Figure 6 Isolines of excess soil concertation, 5%, 1%, 0.5%.

The Figure above depicts the spatial extent covered by the plume for three different states of plume concentration 5 %, 1 % and 0,5 %. These are encountered at 2.4, 9.9 and 17.8 m respectively and present the low spatial extent of the plume after its disposal at the site, due to the very low ambient current velocity.

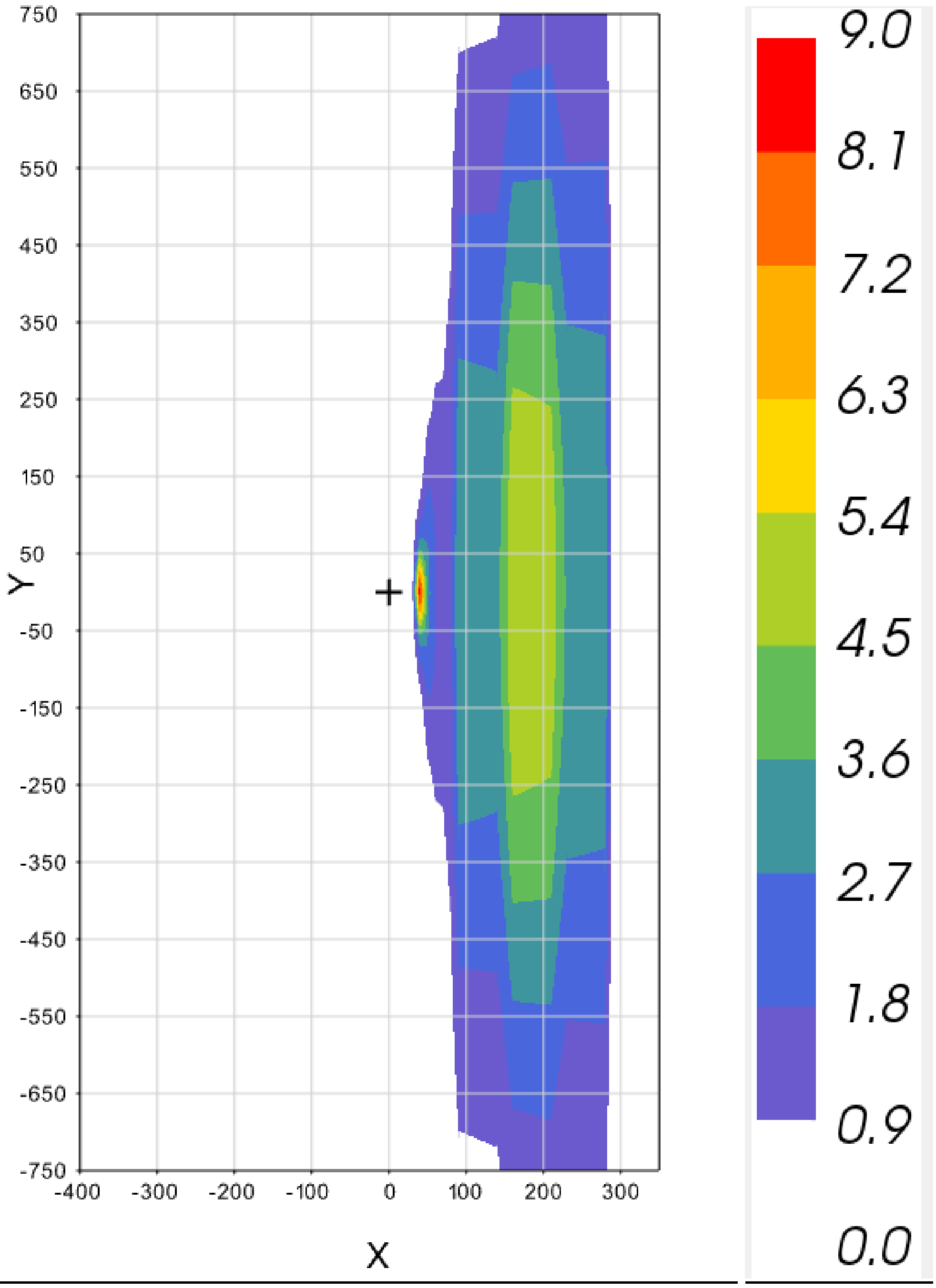


Figure 7 Deposition of total material in Kg/m², in the X - Y directions.

The figure above presents the mass loading in Kg/m² of material with the discharge point represented as a cross. It can be observed that the vast majority of the material will be deposited from the plume within about 290 m in the X direction and at a half-width of 250 m.

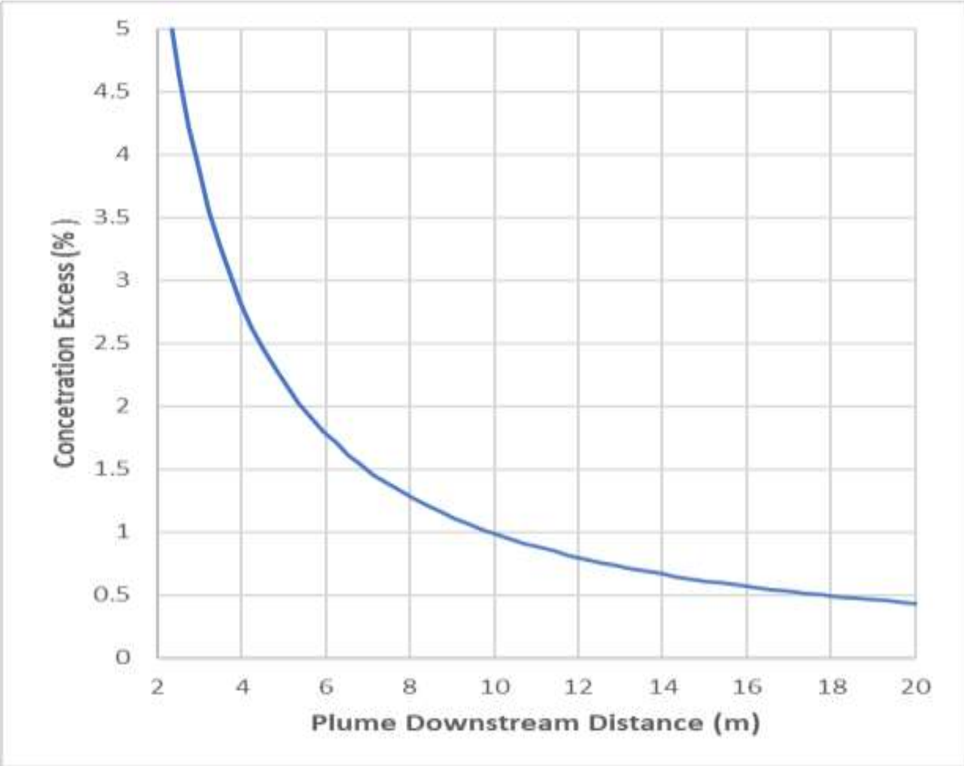


Figure 8 Concentration excess % versus Downstream Distance X (m).

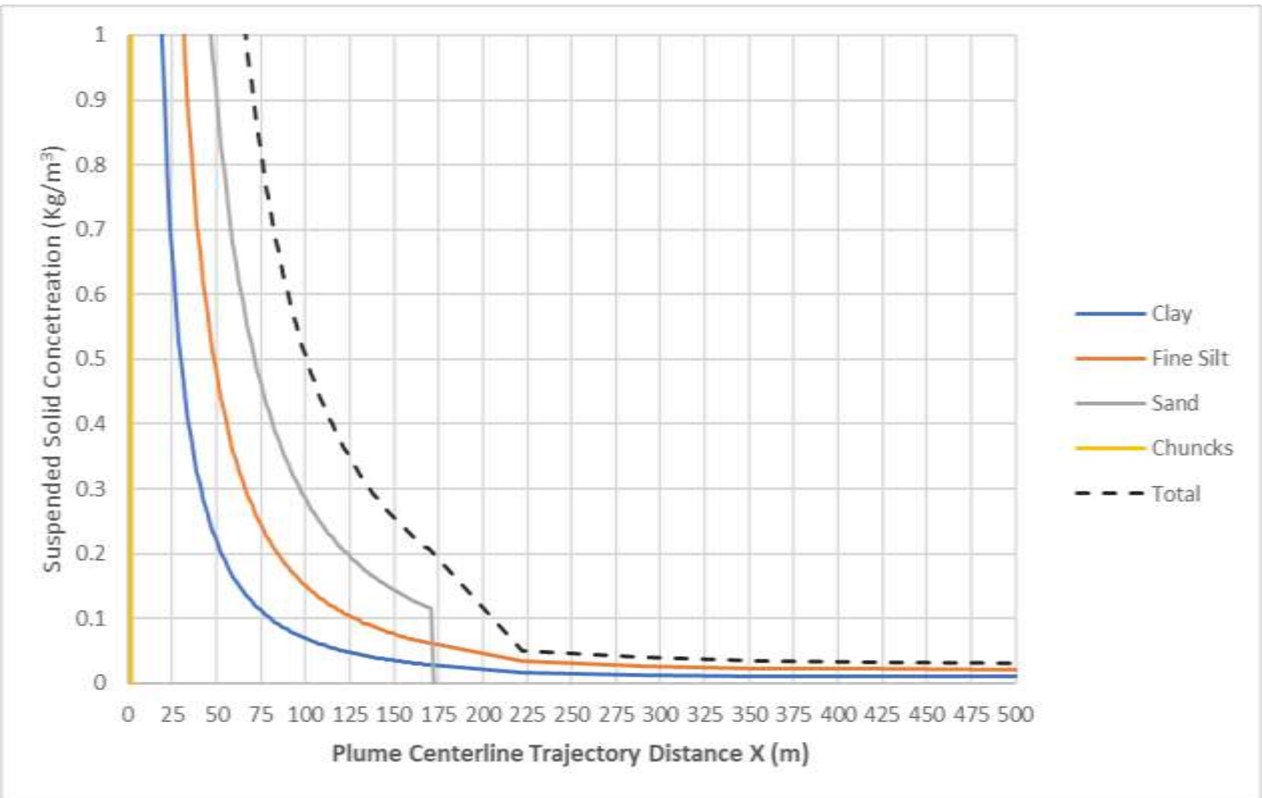


Figure 9 Suspended soil concertation per class, in Kg/m^{3}versus the plume centreline trajectory in meters.

In Figure 8 a rapid decrease in the plume concentration is observed with a few meters from the outfall. Notably after 10 m and 16 m in the X direction the plume's concentration falls below 1 and 0.5 % respectively.

In Figure 9 the suspended sediment concentration (Kg/m^3) per sediment class is depicted along the plume's centreline trajectory. As expected, the chuncks leave the plume instantaneously, followed by sand at around 88 m in the X direction, while fine silt, clay and consequently the total concentration drop below 0.1 Kg/m^3 past the 200 m mark. Although after 300 m the concentration drops below 0.05 Kg/m^3 and decreases very smoothly until the end of the FFR, reaching around 0.01 Kg/m^3 for fine silt.

3.2. Zone 2

Zone 2 is represented by the cyan area in *Figure 2*, while below the series of images depict the plume dispersion in the Near and Far Field Regions (NFR/FFR). The plume at the end of NFR (263 m) will reach a width of 450 m and thickness layer of around 10 m within 0.89 hours. While within 29.25 hour the plume will have reached the end of the FFR (10,000 m) and will have a width of 1500 m and a layer thickness around 5 m.

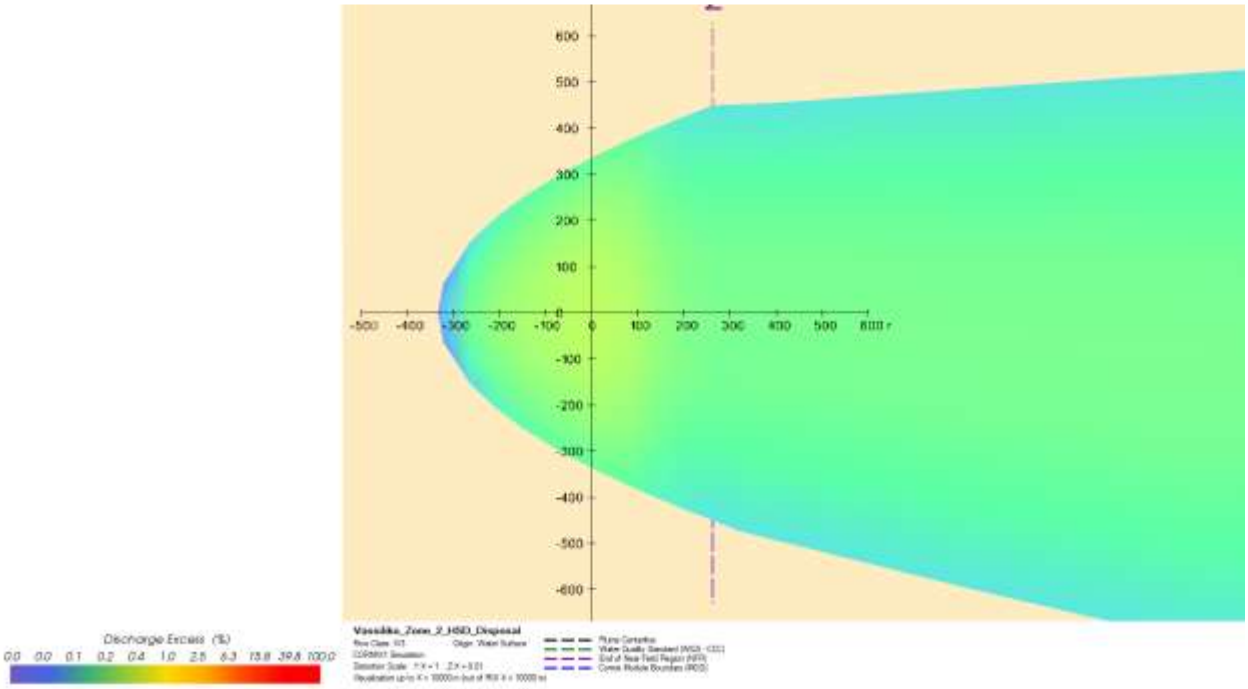


Figure 10 Y-X view of the plume in the Near Field Region (NFR).

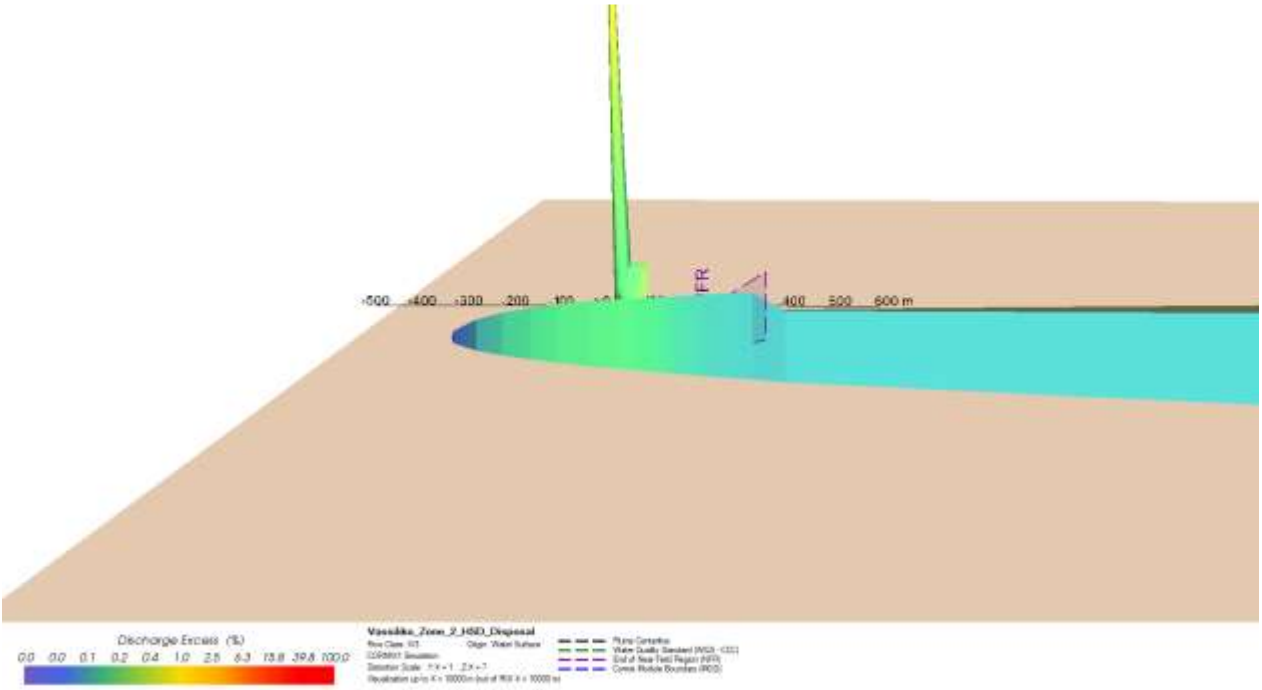


Figure 11 X-Z view of the plume in the Near Field Region.

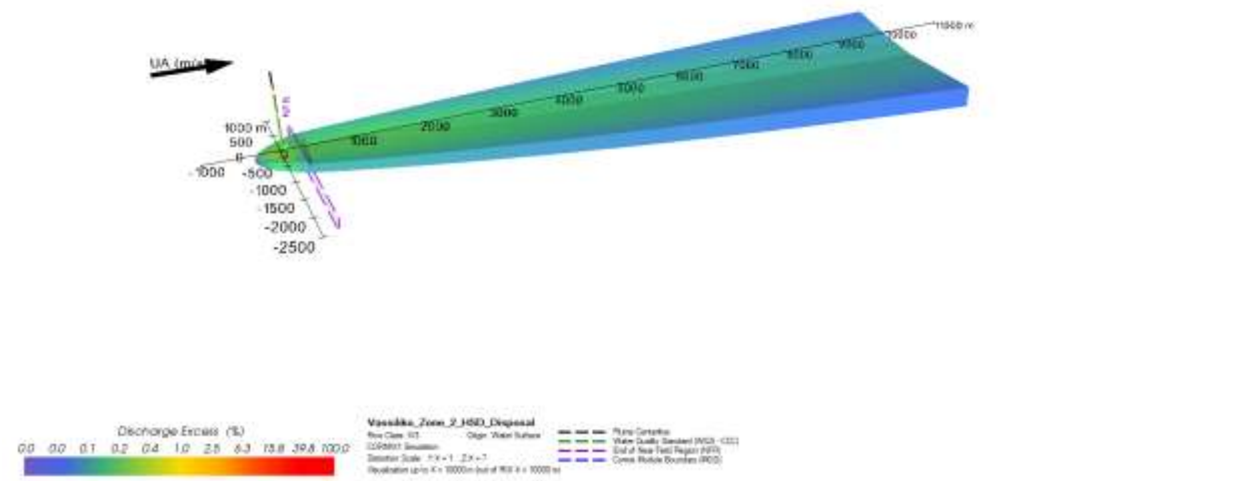


Figure 12 3D plume view of the Far Field Region (FFL).

In Figure 11 we can observe the plume undertaking a rather steep dive towards the sea bed, reaching the bottom around the 37 m mark in the X (downstream) direction. While upstream intrusion will be encountered, spanning at a distance of around 370 m upstream, with a half width of 450 m.

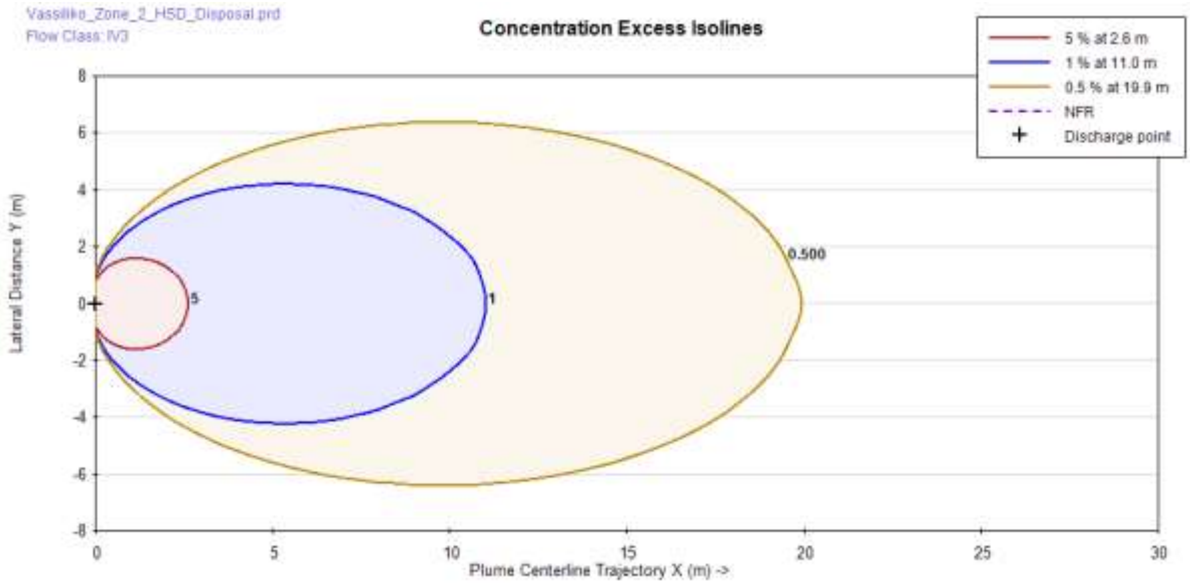


Figure 13 Isolines of excess soil concertation, 5%, 1%, 0.5%.

The Figure above depicts the spatial extent covered by the plume for three different states of plume concentration 5 %, 1 % and 0,5 %. These are encountered at 2.6, 11 and 19.9 m respectively and present the low spatial extent of the plume after its disposal at the site, due to the very low ambient current velocity.

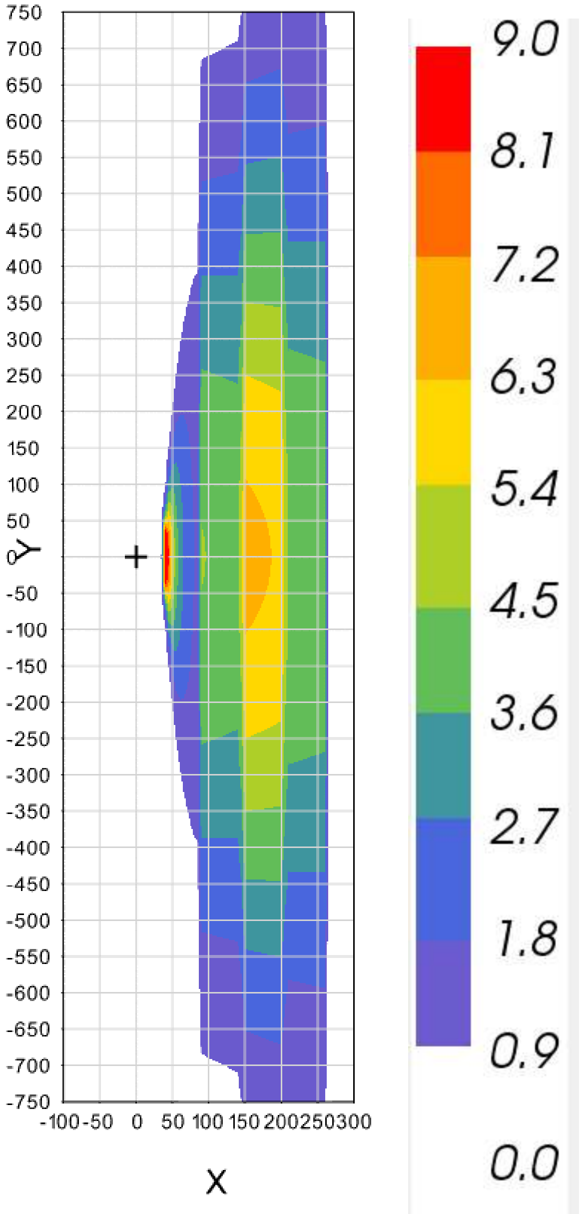


Figure 14 Deposition of total material in Kg/m^2, in the X - Y directions for 1,5 hours.

The figure above presents the mass loading in Kg/m^2 of material with the discharge point represented as a cross. It can be observed that the vast majority of the material will be deposited from the plume within about 265 m in the X direction and at a half-width of around 350 m.

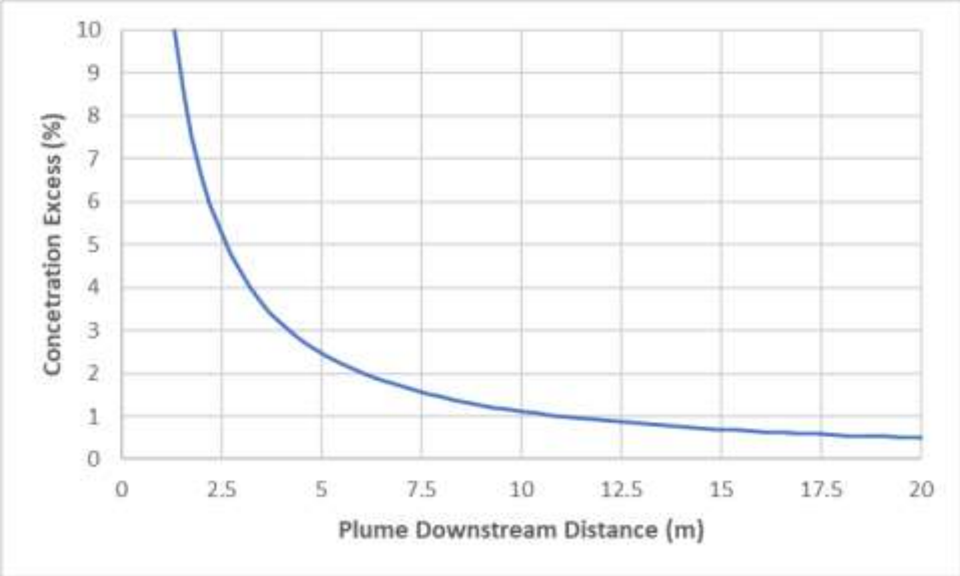


Figure 15 Concentration excess % versus Downstream Distance X (m).

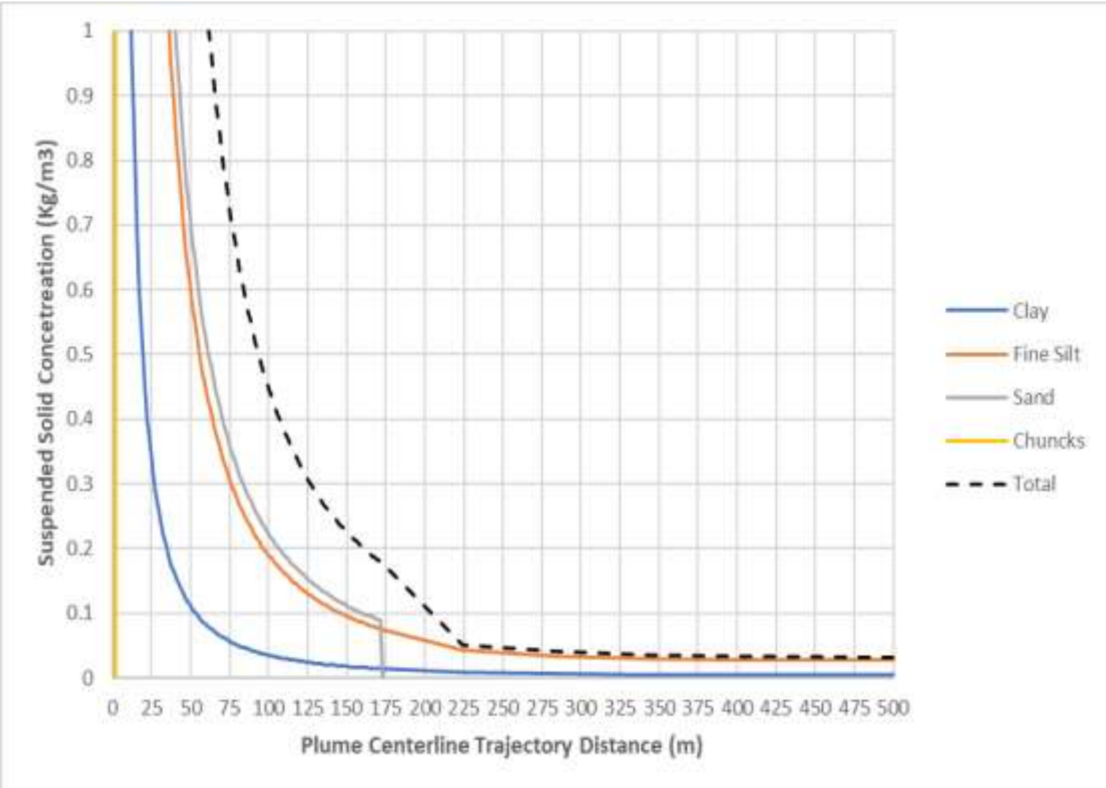


Figure 16 Suspended soil concertation per class, in Kg/m^{3}versus the plume centreline trajectory in meters.

In Figure 15 a rapid decrease in the plume concentration is observed with a few meters from the outfall. Notably after 10 m and 17.5 m in the X direction the plume's concentration falls below 1 and 0.5 % respectively.

In Figure 16 the suspended sediment concentration (Kg/m^3) per sediment class is depicted along the plume's centreline trajectory. As expected, the chuncks leave the plume instantaneously, followed by sand at around 88 m in the X direction, while fine silt, clay and consequently the total concentration drop below 0.1 Kg/m^3 past the 200 m mark. Although after 300 m the concentration drops below 0.05 Kg/m^3 and decreases very smoothly until the end of the FFR, reaching around 0.01 Kg/m^3 for fine silt.

3.3. Zone 3

Zone 3 is represented by the cyan area in *Figure 2*, while below the series of images depict the plume dispersion in the Near and Far Field Regions (NFR/FFR). The plume at the end of NFR (236 m) will reach a width of 436 m and thickness layer of around 10 m within 0.86 hours. While within 29.32 hour the plume will have reached the end of the FFR (10,000 m) and will have a width of 1500 m and a layer thickness around 4.62 m.

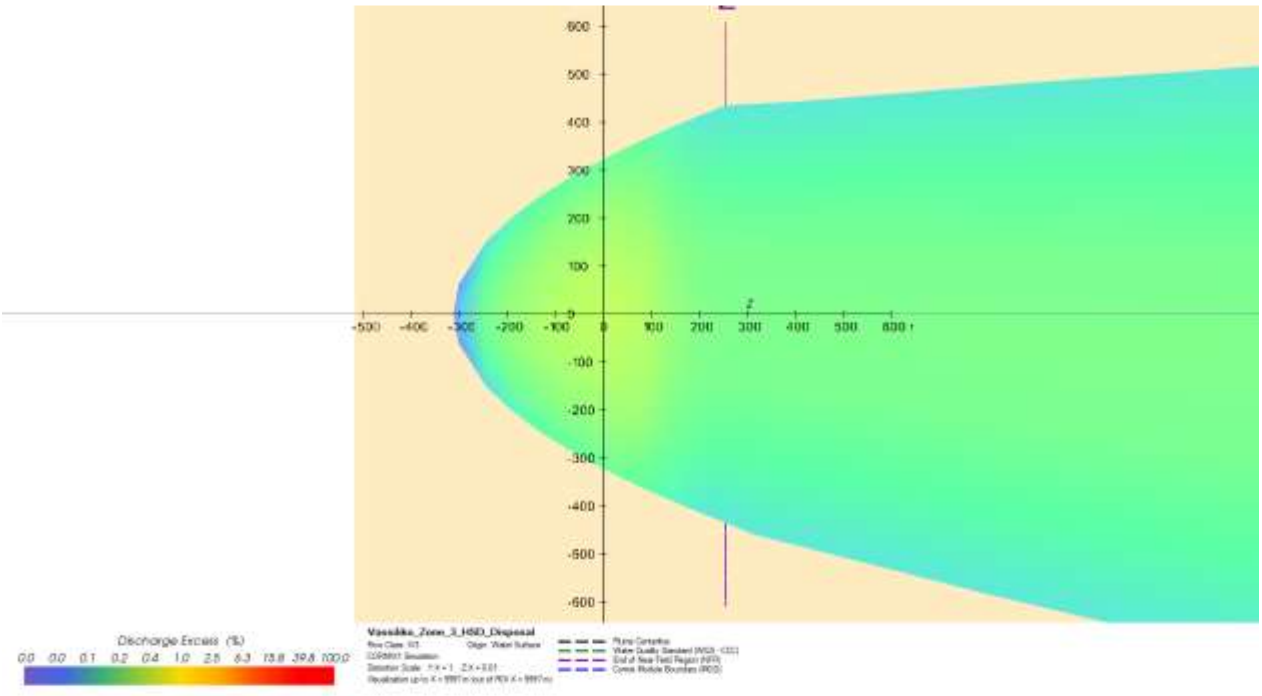


Figure 17 Y-X view of the plume in the Near Field Region (NFR).

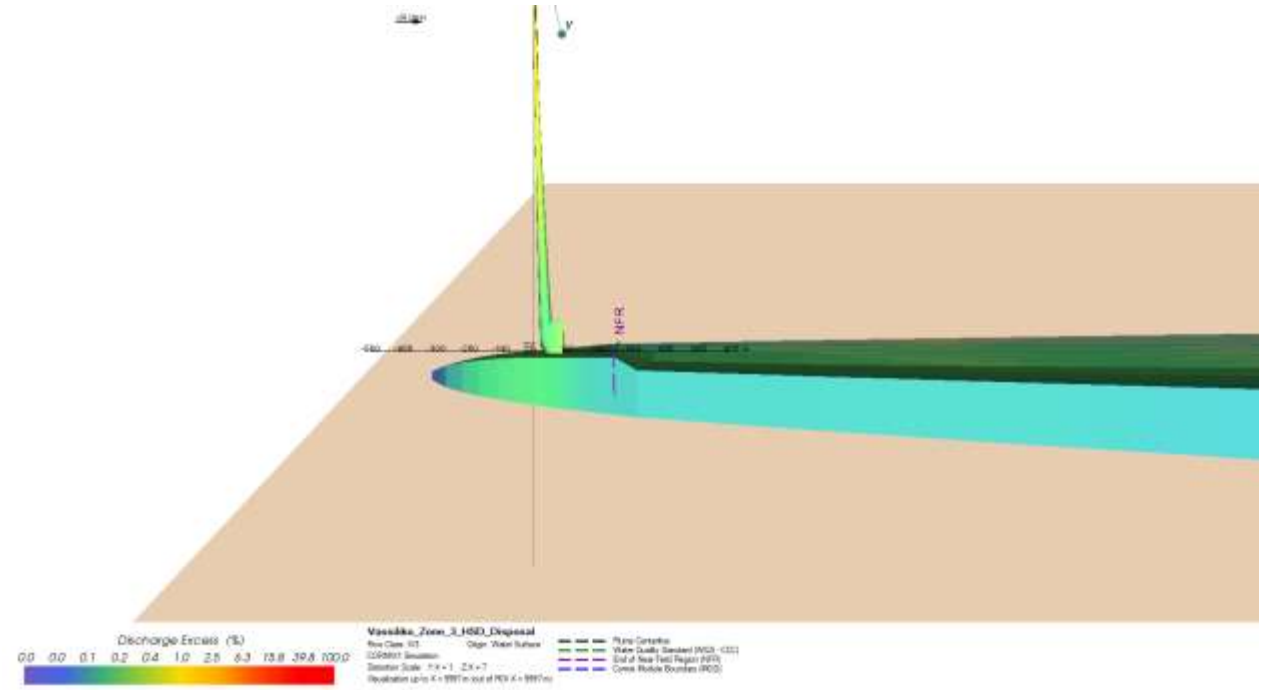


Figure 18 X-Z view of the plume in the Near Field Region.

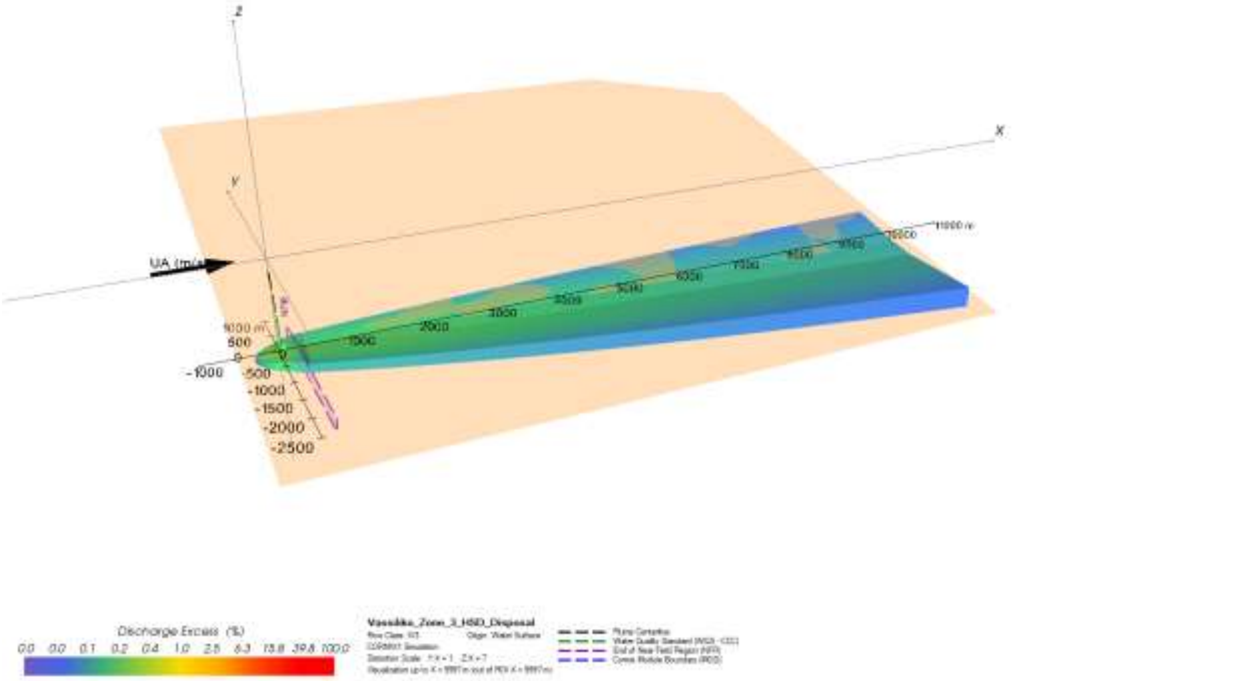


Figure 19 3D plume view of the Far Field Region (FFL).

In Figure 18 we can observe the plume undertaking a rather steep dive towards the sea bed, reaching the bottom around the 33 m mark in the X (downstream) direction. While upstream intrusion will be encountered, spanning at a distance of around 350 m upstream, with a half width of 436 m.

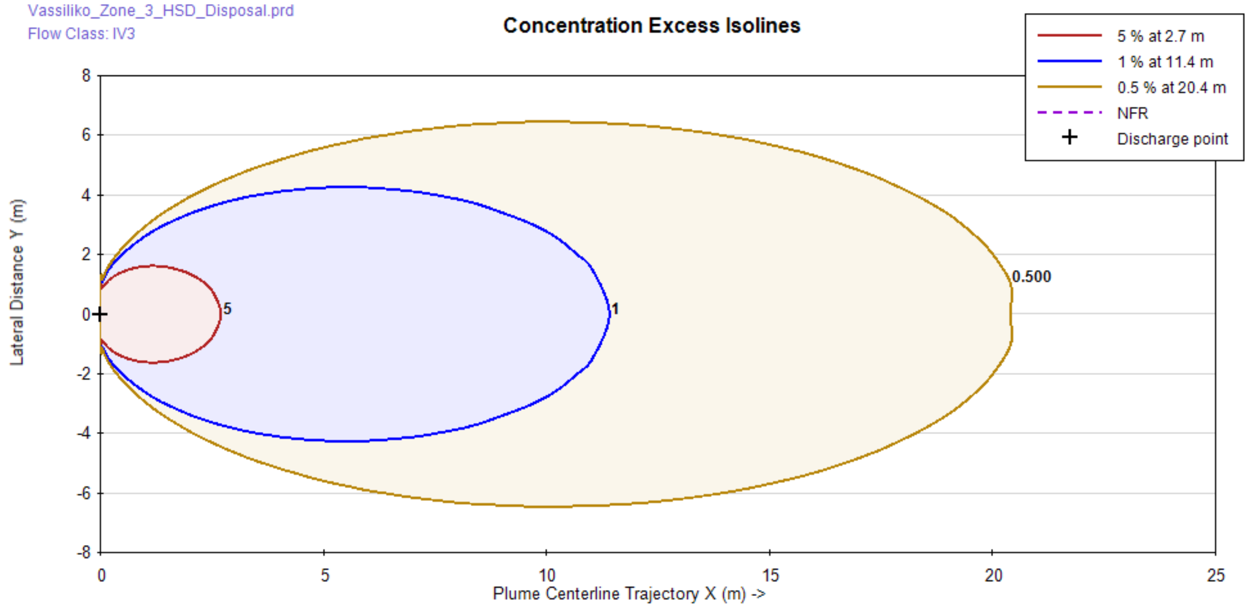


Figure 20 Isolines of excess soil concertation, 5%, 1%, 0.5%.

The Figure above depicts the spatial extent covered by the plume for three different states of plume concentration 5 %, 1 % and 0,5 %. These are encountered at 2.7, 11.4 and 20.4 m respectively and present the low spatial extent of the plume after its disposal at the site, due to the very low ambient current velocity.

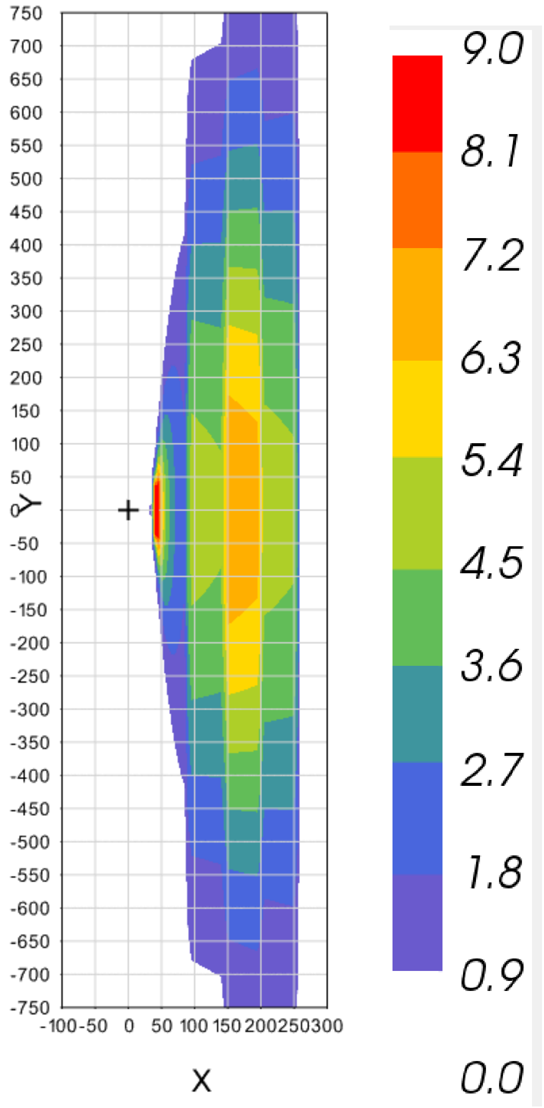


Figure 21 Deposition of total material in Kg/m^2, in the X - Y directions.

The figure above presents the mass loading in Kg/m^2 of material with the discharge point represented as a cross. It can be observed that the vast majority of the material will be deposited from the plume within about 250 m in the X direction and at a half-width of around 360 m.

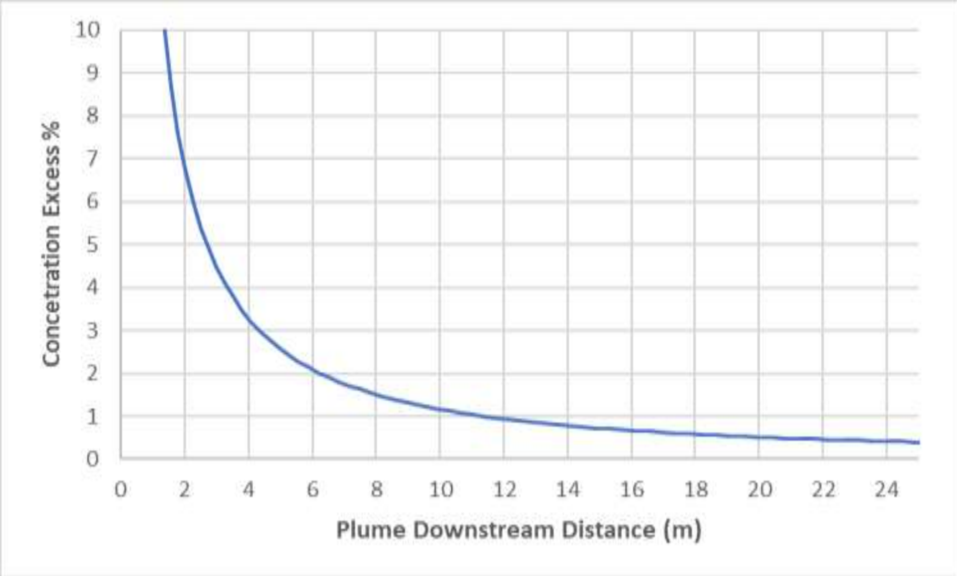


Figure 22 Concentration excess % versus Downstream Distance X (m).

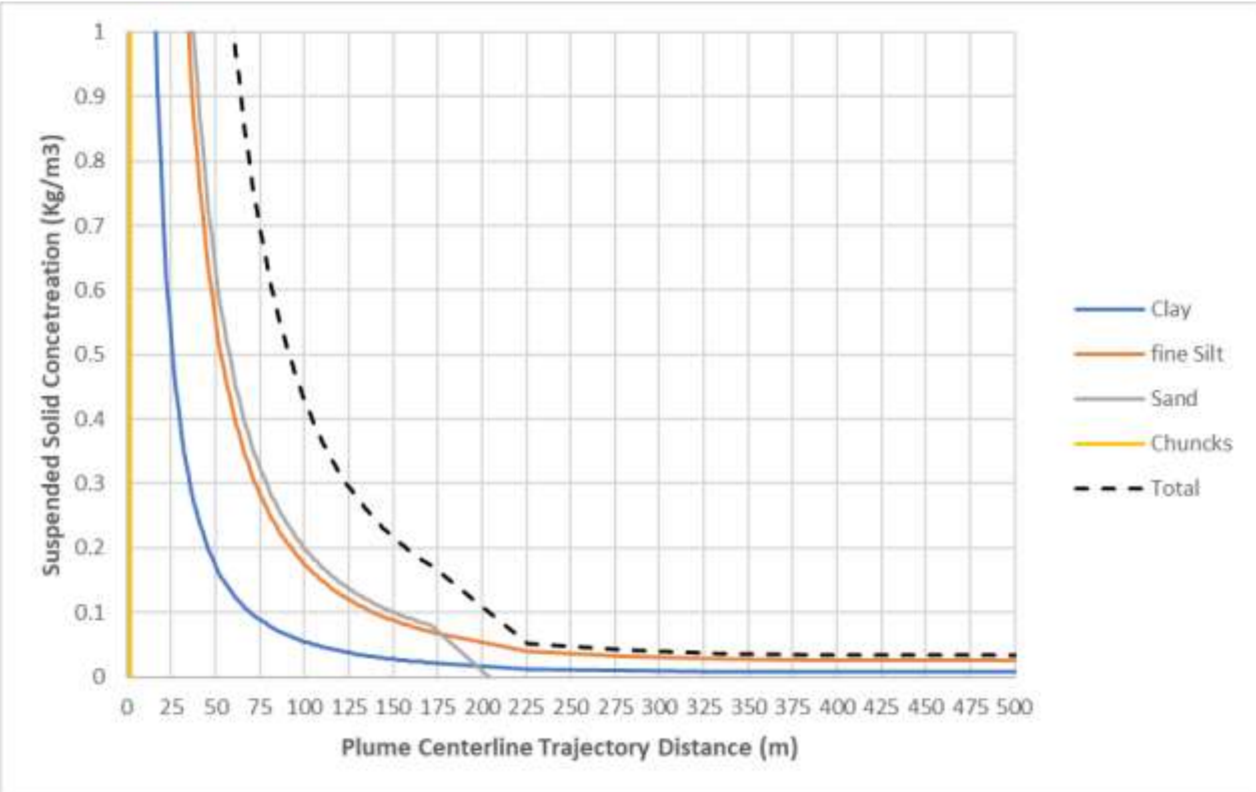


Figure 23 Suspended soil concertation Kg/m^3versus the plume centreline trajectory in meters.

In Figure 22 a rapid decrease in the plume concentration is observed with a few meters from the outfall. Notably after 11 m and 20 m in the X direction the plume's concentration falls below 1 and 0.5 % respectively.

In Figure 23 the suspended sediment concentration (Kg/m^3) per sediment class is depicted along the plume's centreline trajectory. As expected, the chuncks leave the plume instantaneously, followed by sand at around 88 m in the X direction, while fine silt, clay and consequently the total concentration drop below 0.1 Kg/m^3 past the 200 m mark. Although after 300 m the concentration drops below 0.05 Kg/m^3 and decreases very smoothly until the end of the FFR, reaching around 0.01 Kg/m^3 for fine silt.

4. CONCLUSIONS

The results for the three Zones of varying soil characteristics prove to be quite similar, as their percentage concentration isoline of 0.5 % does not exceed 21 m for any of the Zones mentioned above. A primary deposition will take place near the source within about 3.5 minutes, all the gravel/ chunks contained in the sediment flux are shed instantaneously, followed by deposition of a portion of the total flux around 50 m, sand will be second class to fully leave the mass flux remaining, deposited at around 88 m downstream (X direction) for all Zones. A secondary sediment shedding occurs between 100 m for all Zones and 290, 265, and 250 m (X direction) for Zones 1, 2 and 3 respectively, depositing the majority of suspended sediment within the 150 to 190 m area and 1 hour and 7 minutes approximately.

Concluding, disposal of the dredged sediments at the proposed site is characterized by the initial heavy sediments reaching the sea bed within a few minutes, the majority (99.98 %) of sediment flux is lost within an hour and ten minutes, at a maximum of 290 m from the source for the worst case observed. Therefore, according to the above, disposal of sediments from these three Zones will have limited impact on local environment and biodiversity, due to their limited residence time in the upper levels of the water column and their limited spatial extent.