MODELING OF CONTINUOUS DREDGE DISPOSAL TO FORM A NATURAL LIFE ISLAND IN THE GULF OF IZMIR

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ABSTRACT

MODELING OF CONTINUOUS DREDGE DISPOSAL TO FORM A NATURAL LIFE ISLAND IN THE GULF OF IZMIR

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This thesis analyzes the process of continuous dredge disposal of dredged material from the Gulf of İzmir, under the Gulf and Harbor Rehabilitation Project, in the Gulf of İzmir to form a natural life island. In this thesis, GTS (Sediment) version of CORMIX (The Cornell Mixing Zone Expert System) is used in modelling of sediment plume formation, transportation of particles in short - long terms and deposition of the particles on the sea bed. Different cases are discussed.

Keywords: Sediment Plume, Continuous Dredge Disposal, CORMIX

ÖZ

İZMİR KÖRFEZİ İÇİNDE DOĞAL YAŞAM ADASI OLUŞTURMAK İÇİN SÜREKLİ TARAMA MALZEMESİ BOŞALTIMI MODELLEMESİ

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Bu tez, İzmir Körfezi ve limanı iyileştirme çalışmaları çerçevesinde taranmış olan materyalin, bir doğal yaşam adası oluşturmak üzere açık denize, İzmir körfezine, dökülmesini analiz eder. Bu tezin içeriğinde, CORMIX'in (Cornell Karıştırma Alanı Uzman Sistemi) GTS (Sediment) versiyonu, sediment bulutu oluşumunun, tarama materyali parçacıklarının kısa - uzun vadede taşınımının ve parçacıkların deniz tabanında birikmesinin modellenmesinde kullanılmıştır. Farklı durumlar tartışılmıştır.

Anahtar Kelimeler : Sürekli Tarama Malzemesi Boşaltımı, CORMIX

To my mother and my father,

To Siu Family,

And

To my love, Deniz'im,

To my handsome bro, worldwide known director, Gürkan

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CMS	Circulation Canal Main Sounds
CORMIX	Cornell Mixing Zone Expert System Software
CWA	Clean Water Act
EFDC	Environmental Fluid Dynamics Code
EPA	US Environmental Protection Agency
HCS	Harbor Canal Sounds
HPI	Heavy Metal Pollutant Index
IZSU	Izmir Metropolitan Municipality Water and Sewerage Administration
NMS	Navigation Canal Main Sounds
ODMDS	Open – water dredged material disposal site
TCDD	Turkish State Railways
TDZ	Toxic dilution zone
RMZ	Regulatory mixing zone
USAK	National Watery Area Commission

CHAPTER 1

INTRODUCTION

1.1 General Description

Coasts have always been an attraction for humanity from the beginning of the civilization for the benefits, opportunities and facilities offered as economic potentials. After the realization of opportunities offered by coastal regions, migration to these areas increased even more in recent years. As a result, coastal regions have become the most populated and developed regions of the world. However, with the new inventions of the inevitable rise of civilizations, coastal structures such as ports, harbors, quays, etc. were constructed for several needs and uses without much understanding or caring for the consequences and response of coastal systems and processes to these structures.

Nearshore processes play one of the crucial roles in these stages as they cause several of the leading effects on coastal dynamics. Waves, currents, tides and sediment transportation are the most critical parameters that govern the nearshore processes. As coastal sediment transportation severely determines the nearshore bathymetry characteristics and coastal topography, which significantly affects these processes, it has always been one of the main concerns of coastal engineers. Wind wave or current induced sediment transportation can occur not only by erosion or removal of seabed, but also by dredging operations and disposal of dredged material. Therefore, disposal operations can directly affect disposal site and accumulation amount of disposed material is important for bathymetry and benthic fauna – flora. Since awareness of the environment and anthropogenic contribution to the state of nearshore regions increases, knowing the effects of dredge disposal operations in open water has become important. Appreciable regulations are conducted and by increasing awareness of the effects of these operations, higher regulations will be done.

Importance of understanding the parameters that govern the sediment transportation processes is vital in order to overcome the problems, which occur after the sediment discharge process. Without a proper understanding of these processes, outcomes of open – water disposal may not be anticipated accurately. There are many models describing suspended material dilution after disposal operations and short – long term spreading of dredged material. Numerical models that simulate transport of sediment are being constructed primarily to aid the development of management strategies as they predict distribution of concentrations of suspended sediments and their transport or fate in coastal waters. Modeling of disposal process in order to understand the results of the work to be done is required in many ways to reduce unnecessary spending and for unforeseen wildlife results.

1.2. The Scope and Extent of This Study

In this study dredged material disposal on open water and sediment transport in disposal areas are analyzed with a case study for Gulf of Izmir. Environmental Impact Assessment Report on the dredging and disposal operations under the Gulf of Izmir and Harbor Rehabilitation Project is analyzed to get input parameters. Sediment transportation and deposition are two main issues to be investigated. In order to develop the controlling strategies, wind and current induced sediment transportation and associated sediment accumulation ability and related sediment deposition data should be investigated. In order to make a detailed analysis on these subjects the hydrodynamic model is used, which is called Cornell Mixing Zone Expert System Software (CORMIX).

In Chapter 2, literature review of dredging and disposal operations are given together with contributions to coastal sedimentation modeling software and brief information about dredging.

In Chapter 3, a case study on dredging and disposal operations under the Gulf of Izmir and Harbor Rehabilitation Project will be conducted.

In Chapter 4, general methodology of this thesis is summarized. General knowledge about Cormix software and Cormix GTS version is introduced.

In Chapter 5, input and output files of case study simulated in Cormix is detailed and some discussion is conducted.

In the last chapter, Chapter 6, the conclusion, a brief summary of results and issues recommended for future studies is detailed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Dredging and underwater works are important aspects in the design and construction of coastal infrastructures. Capital dredging, which is called for excavation steps in the design of a new port, navigation channel or if the excavation of a basin conducted for the first time, and maintenance dredging, which is used for keep access channels, fishing basins and canals open to navigation, are two main types of dredging.

Though there is serious effort to search areas to use the dredged materials, it is hard to find cases where disposal could be used alternatively. Therefore, disposal of the material is much more preferable, although it might be misunderstood easily. There are enough alternatives to dispose of the materials on appropriate conditions, whether it is contaminated or uncontaminated; or hazardous or non – hazardous, such as:

- Open water disposal operations
- Disposal in nearshore regions, shoreline disposal
- Disposal on the land, onshore disposal

In deciding where to dispose the material, the level of contamination plays a huge role in terms of minimizing the impacts of the contamination on environment.

2.1.1 Disposal at Sea

Disposal at sea has come to be undoubtedly the one of the best methods for disposal in that it is the easiest as undesired material is easy to dispose of. (See Figure 2.1).

Figure 2.1. Open – water dredge disposal

Yet, there are a series of effects on the environment in this method of disposal. These include:

- Suspended solid material concentrations,
- Changes in the sediment regime of seabed,
- Fauna – flora destruction,
- Fishery damages and fish breeding zone problems,
- Pollutant release, such as heavy metals.

Pollutant release is a very important topic in this sense. If not taken care of properly, the disposal could be dangerous. However, this method can safely be continued by applying the required pre – studies and material should be defined clearly as hazardous, non – hazardous, or inert.

2.2 Open – Water Disposal Alternatives

Open – water disposal areas are called in two ways: retentive areas and dispersive areas. Retentive areas confine the dredged material; while dispersive areas disperse the material via sediment transporting processes. According to Holiday (1978), there are four types of open – water disposal areas that have been identified, which are:

- The deep ocean: 200 meters or deeper and under the continental shelf break. Material deposition on the ocean bed stays there is the basic assumption.
- The open shelf: From the continental shelf break to 40 – meter depth contour. Tidal current or wave – induced, relatively high – energy areas.
- The near – shore: Between the 40 meter depth contour up to the wave – breaking zone. Wave, long – shore drift and tidal current induced high – energy zone. In this zone considerably high sediment movement potential is available.
- The inlet zone: Large – scale sediment movement occuing areas, which are near to estuaries, rivers and inlets. Similar energy levels with the near – shore zone, excluding that strong tidal currents or irregular coastal structures may conclude in complex, multi – directional wave and current patterns.

In open – water disposal, four basic methods for dredged material are considered:

- Unconfined dumping in licensed disposal areas,
- Disposal into seabed depressions,
- Dyke – confined disposal,
- Formation of islands (See Figure 2.2).

Figure 2.2. Formation of islands and bars

Dispersal method is only applicable on condition of unconfined dumping; while the others only require an isolated area for the contamination.

2.2.1 Unconfined Disposal in Licensed Dredge Disposal Areas

This traditional type of disposal involves dilution and dispersion up to certain levels depending on the material's structure and hydrodynamics at the site.

In order for the unconfined dumping not to have a huge impact on the environment around the site, pre – studies must be carried out in detail.

There are both permanent and temporary impacts of unconfined disposal, which include prejudicial changes to water and sediment transport due to changing seabed form; coastal erosion increase due to near – shore disposal areas; and permanent loss of sediment from a long – shore transport system due to regular maintenance dredging; and increased turbidity; water quality decrease; release of pollutants into solution; recreational value decrease; and possible contamination of nearby beaches in temporary.

In unconfined dumping options, disposal in a specified area is usually the one that is used the most. Another approach is 'thin layer', in which the material is spread in thin shapes as possible around the area. Therefore, water quality and fisheries data can be kept almost the same as before (Nester and Rees, 1988).

Similarly, deep ocean disposal has also a lot less effect on nature, compared to shallow waters. As Miller et al. (1980) stated, after six months from dumping:

- Zooplankton population increase in disposal operations should be returned to baseline level in six – month – period.
- Heavy metal concentrations should be returned to background values in six months.
- At the dumping site and at a control site, significant variations between heavy metal concentrations in shrimps and zooplankton should not be found.

2.2.2 Disposal In Seabed Depressions

Seabed depressions, introduced by Carpenter (1973), are kinds of semi – confined disposal. Dredge disposal of dredged sediments with pollutant into a deep depression in the James River in Virginia is described by DeLoach and Waring (1984). A vertical pipeline at a depth of about five meters below sea level was used to discharge the material.

2.3 Open – Water Disposal Technique

Using direct pipeline discharge, direct mechanical placement, or release from hopper dredges or scows, dredged material can be placed in open – water sites. For open – water disposal adjacent to channels, pipeline dredges are commonly preffered. Solids concentration in slurry, which is formed by dredging operations, ranges from a few grams per liter to several hundred grams per liter. The slurry may contain clay balls, gravel or coarse sand material, which quickly settles to the bottom, depending on material characteristics. The disposal site water has a lower density than the mixture of dredging site water and finer particles and therefore can descend to the bottom forming a fluid mud mound. Continuous discharge may result in spreading the mound. During descent, some fine material is "stripped" and a turbidity plume is formed. Discharge rate, characteristics of the slurry (both water and solids), water depth, currents, meteorological conditions, salinity of receiving water, and discharge configuration determines the characteristics of the plume.

2.4 Management and Controls for Open – Water Disposal

In some situations, conventional open – water dredge disposal techniques can be used and water quality criteria regarding effects of direct physical impacts, ambient capacity or contaminant routes can not be met. In these cases, several management measures and contaminant limitation actions should be considered. Such methods include operational revisions, use of underwater discharge spots, diffuser usage, and underwater horizontal confinement, thin – layer installation, or constraining of contaminant with clean dredge. The management and control operations have both a site – limited and a case – limited basis, which means that in all cases or all situations, case – special options should be considered. Two types of the management strategies are detailed below, since dredged material transportation, settlement and particle settlement is important for this thesis.

2.4.1 Modification of Dredging and Disposal Operations

Modifications in disposal process can be useful control for both substantial effects and water – column or contaminated dredge routes. The aim of operational variation as a control measure is to decrease water – column relation and / or spread of dredge on the bottom surface. The most preferred control for open – water operations is changing the technique or equipment used for disposal. Other modification alternatives include limitations on disposal point, discharge of disposal, and scheduling of disposal.

2.4.2 Submerged Discharge

Underwater discharge could be used to reduce water – column impacts. Discharge with a pipe placed underwater decreases the interaction zone in the water column and the suspended material in the water column convenient to dispersion as seen on Figure 2.3. Moreover, diffusers used to reduce the discharge velocities are useful for hydraulic placement, having a more certain placement and decreasing both re – suspension and spread of the dredged material. Expediency of a submerged discharge is dependent on water depth, topography at the sea bottom, current regime, type of dredged material, and ambient capacity. Submerged diffusers have been used in dredge disposal operations and design specifications are available (Neal, Henry, and Green, 1978; Palermo, 1994).

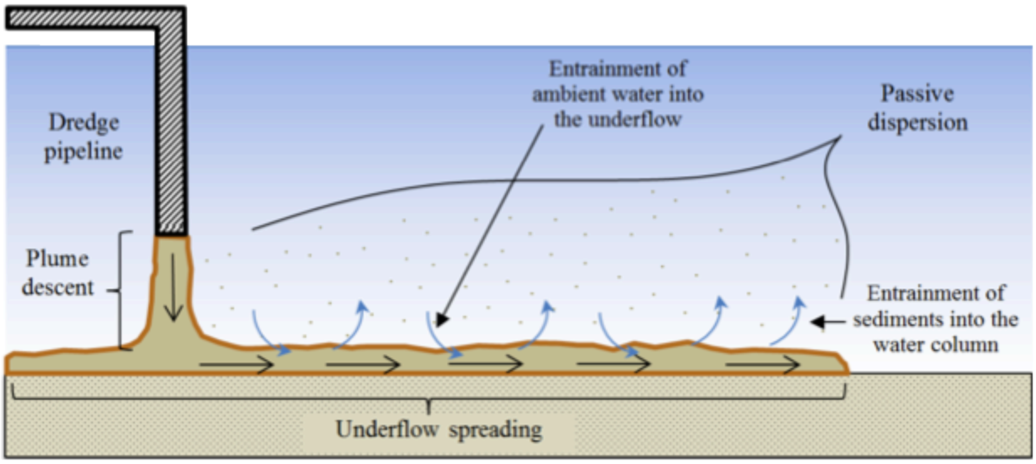

Figure 2.3. Lowering suspended sediment dispersion using submerged discharge

2.5 Process of Open Water Disposal

The option of placing dredged material in the open water, although often more cost effective than upland disposal, introduces additional concerns for the overall management of dredged material disposal. The management of an open – water dredged material disposal site (ODMDS) includes environmental requirements such as obtaining and maintaining regulatory approval for site use and operational constraints concerning navigation issues and disposal efficiency. To satisfy environmental requirements and operational constraints, the project manager of an ODMDS will likely address one or more of the following site – management issues:

- Demonstrate that dredged material placed in open water does not violate applicable water quality standards.
- Ensure that dredged material placed in open water does not accumulate in a fashion that would pose a navigational hazard.

- If required, demonstrate that placed dredged material stays within the boundaries of a designated ODMDS.
- Design an ODMDS with areal boundaries commensurate with dredging disposal requirements and attain maximum utilization of ODMDS volumetric capacity.
- In the case of an ODMDS sited within the littoral zone, ensure that placed dredged material is transported alongshore away the point of dredging or accretes toward a terrestrial resource.

The common management link between operational constraints, environmental requirements, and efficient site management is the ability to accurately predict and track the placement of dredged material in a given ODMDS. A major consideration is whether a given ODMDS is either dispersive or non – dispersive. At non – dispersive sites, approximately 95 to 99 percent of dredged material placed within the ODMDS reaches the immediate benthos. However, at a dispersive ODMDS, most of the placed dredged material is transported along the bottom or dispersed through the water column by ambient currents and waves. Without proper evaluation, dredged material disposal could inadvertently impact sensitive resources or the ODMDS capacity may be exceeded sooner than expected. ODMDS capacity can roughly be defined as that quantity of material that can be placed within the legally designated disposal site without extending beyond the site boundaries or interfering with navigation (Poindexter – Rollings, 1990).

Depending on local statutes, obtaining regulatory approval for a new permanent ODMDS may require considerable time and resource expenditures, e.g., $ 500.000 or more per disposal site in the United States. The key to a successful ODMDS designation is to know in advance (or reliably predicting) the fate of dredged material placed at the disposal site. In addition, proper life – cycle management of an ODMDS requires an approach to quantitatively predict and assess the behavior of dredged material placed in open water. This requires knowledge of the physical processes acting on placed dredged material and the subsequent modeling of those processes to enable the quantitative prediction of the placed material.

2.5.1 Behavior of Dredged Material Placed In Open Water

In the simplest terms, the physical forces affecting dredged material placed in open – water include gravity and forcing due to waves and currents. Field evaluations and laboratory tests have shown that open – water disposal of dredged material conforms to a three – step process:

- Convective descent, during which the material falls through the water column under the influence of gravity,
- Dynamic collapse during which the descending plume impacts the bottom or arrives at a level of neutral buoyancy,
- Passive transport – diffusion commencing, when material transport is governed more by ambient processes than by the dynamics of the disposal operation.

Apart from gravity, water – column currents are the dominating factor in terms of the environmental forces that act on dredged material when placed in open water. Currents generally result from the combined actions of several components, e.g., large – scale coastal current regimes due to tidal circulation and/or storm – surge propagation, locally generated wind – stress – generated currents, short – and long – wave – induced currents, inertial currents, and estuarine / riverine plume effects.

2.5.1.1 Short – Term Fate

At the point of release from the disposal vessel, dredged material convects through the water column under the influence of gravity while entraining ambient water, advects and diffuses laterally, and eventually comes to rest on the seafloor. This scenario characterizes the short – term fate of dredged material placed in open water. Depending on the speed of the disposal vessel, water depth, water – column current and density, ambient bathymetry, and dredged material type, the dredged material can spread out on the seabed to varying degrees. In some cases, dredged material placed in open water can be dispersed a considerable distance (thousands of meters) within the water column with little deposition near the point of disposal. This occurs at dispersive ODMDSs and is referred to as far – field dispersion. ODMDS siting and management considerations will be significantly different for dispersive disposal sites as compared to non – dispersive sites. Dredged material dispersion can also occur after the placed material has come to rest on the receiving benthos if environmental forces result in erosion of the deposited material.

2.5.1.2 Long – Term Fate

After dredged material has come to rest on the seabed, it can be eroded and transported by waves and / or currents. Furthermore, if the dredged material is cohesive, it can experience self – consolidation due to gravity. In addition, if many loads of dredged material are placed one on top of another such that a steep aggregate mound develops on the ambient benthos, the mound will avalanche and material will be transported down slope as a function of gravity and material characteristics. The combination of these processes defines the long – term fate of dredged material placed in open water. In addition to sediment characteristics, water depth, wave activity, and current regime are the primary factors that contribute to the long – term fate of dredged material placed at a given ODMDS.

Depending on the type of dredged material to be placed at an ODMDS and surrounding resource, long – term dispersiveness may or may not be a desirable aspect. If the placed dredged material is expected to remain within an ODMDS (due to incompatibility issues with ambient or adjacent resources), a site should be selected that minimizes long – term dispersiveness. If the goal of the ODMDS is to facilitate reintroduction of dredged material into the littoral system, then an ODMDS should be selected that maximizes long – term dispersiveness. The degree of long – term stability for dredged material placed at an ODMDS is an important factor that dictates the amount of dynamic site capacity for a given location.

An ODMDS can exhibit little dispersiveness during dredged material disposal, while having a higt degree of long – term dispersion during moderate to severe wave or current activity. To predict the fate of dredged material placed in open water, the dispersiveness of an existing or new candidate ODMDS must be fully considered for both short and long term aspects. Numerical models are required for these predictions.

2.6 Numerical Modeling of Dredged Material Placed in Open Water

Until recently, estimating the fate of dredged material placed in open water in terms of the resulting distribution through the water column and on the ambient bathymetry was performed by;

- Direct point measurement of sediment dispersion through field monitoring,
- Estimated point prediction of sediment transport potential by empirical methods,
- Comparison of consecutive hydrographic surveys for bathymetric accumulation and transport.

All these sediment fate prediction methods have a high degree of uncertainty when applied to complex large – scale conditions and do not provide the flexibility to address the variations associated with "what if" scenarios. Point measurement/estimation methods do not address the need for examining the (sub) areal distribution of placed dredged material within the water column and on the receiving benthos required for total site management. In addition, point estimate methods assume equal transport potential throughout a given area. Comparison of predisposal to post – disposal bathymetry provides a "hind – cast" for dredged material fate, but precludes a predictive means for managing dredged material.

Some examples of numerical methods using for modeling sediment discharges are listed below.

2.6.1 PDFATE Underflow Analysis

The PDFATE model is used to evaluate the underflow spreading and predict the deposition of sediments on the bottom and the entrainment of sediments into the overlying water column.

2.6.1.1 Model Description

The PDFATE model simulates the spreading dynamics of a particle laden, dense underflow under the effect of gravity. PDFATE is a quasi – steady state model in which the time derivatives are ignored in the governing equations. However, the model updates at discrete time intervals by solving for time of travel at every location along the underflow and updating bed elevations based on the cumulative depositional thickness from the preceding time steps.

2.6.1.2 Model Inputs

The PDFATE model requires two input files:

- puf_file, which specifies the discharge characteristics, the transition condition, underflow sediment conditions, run control parameters, and initial depth data,
- bc_file, which specifies the ambient current velocity time series.

2.6.2 EFDC – SEDZLJ Long – Term Fate Analysis

The long – term stability of the sediments deposited on the bottom is generally evaluated using the Environmental Fluid Dynamics Code (EFDC) coupled with the SEDZLJ sediment transport model (EFDC – SEDZLJ). The goal of the software is to determine the stability of the sediments deposited on the bottom during the typical tidal current conditions that affect the placement site.

2.6.2.1 Model Description

EFDC is a general – purpose model for simulating three – dimensional flow, transport and biogeochemical process in surface water systems (Hamrick, 1996). The EFDC model was originally developed by Dr. John Hamrick at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software. EFDC is currently supported by Tetra Tech for the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD), EPA Region 4, and EPA Headquarters.

As described by Hamrick (1996), the physics of the EFDC model, and many aspects of the computational scheme, are equivalent to the widely used Blumberg – Mellor model. The EFDC model solves the three – dimensional, vertically hydrostatic, free surface, turbulent averaged equations of motions for a variable density fluid. EFDC also solves dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity and temperature. The transport equations use the Mellor – Yamada level 2.5 turbulence closure scheme. The EFDC model uses a stretched or sigma vertical coordinate, and curvilinear orthogonal horizontal coordinates.

Sandia National Laboratories (Sandia) modified the EFDC model to include the SEDiment dynamics algorithms as developed by Ziegler, Lick and Jones (SEDLZJ) (James, et al., 2010; Thanh et al., 2008). The state – of – the – science SEDZLJ model simulates sediment dynamics, including the processes of erosion, bedload transport, bed sorting, armoring, settling of sediment particles, and deposition. SEDZLJ uses a unified treatment of cohesive and non – cohesive sediments, and it includes the ability to incorporate site specific data to characterize sediment bed properties and erosion characteristics. SEDZLJ was designed to directly use the results obtained using the SEDflume method (McNeil et al., 1996) of testing sediment bed critical shear stresses and erosion rates. Also, for depth – averaged simulations, the model assumes a Rouse profile for the suspended noncohesive sediments, and the calculated near – bottom concentration is used in determining the deposition rate. James et al. (2010) provides a detailed description of the model formulation.

2.6.2.2 Model Inputs

The EFDC model requires specification of the model geometry (i.e., the computational grid and depths) and the model boundary conditions. Generally, the hydrodynamic model is set up as a one – dimensional depth – averaged model to test the stability of the deposited sediments under the typical tidal current conditions. The model includes an open boundary at each of the two ends of the grid. Tidal water levels are input for each open boundary based on predicted astronomical tides. The phase difference (i.e., the time difference) between the two boundaries is iteratively adjusted until the peak depth – averaged currents in the model reached, which is representative of the typical peak current speeds that affect the placement site. The SEDZLJ sediment model setup requires specification of the bottom sediment characteristics, including initial sediment particle size distribution, bed density, erosion rates, and critical shear stresses for the initiation of erosion.

CHAPTER 3

METHODOLOGY

3.1 CORMIX – Cornell Mixing Zone Expert System Software

CORMIX (Cornell Mixing Zone Expert System) is a US Environmental Protection Agency (EPA) supported modeling software system for the analysis, prediction, and design of outfall mixing zones resulting from discharge of aqueous pollutants into diverse water bodies. It contains mathematical models of point source discharge mixing within an intelligent computer – aided – design (CAD) interface. Its focus is environmental impact assessment and regulatory management.

Single point discharges are not evaluated by “end of pipe” concentration standards but in a way that allows for the initial dilution of the discharge within a mixing zone. This has lead to the concept of a “regulatory mixing zone” (RMZ) around the discharge point. Figure 3.1 illustrates the situation that the discharge contains toxic substances, a more restrictive region within the RMZ called the toxic dilution zone (TDZ) for toxic discharges is formed. Within the RMZ and TDZ, water quality criteria may be exceeded as long as the water body as a whole is not impaired. Regulations concerning the size and shape of the mixing zone vary widely depending upon the regulatory authority. Channel bottoms or benthic areas are ecologically and commercially important and are often the most sensitive to the effects of point source discharges.

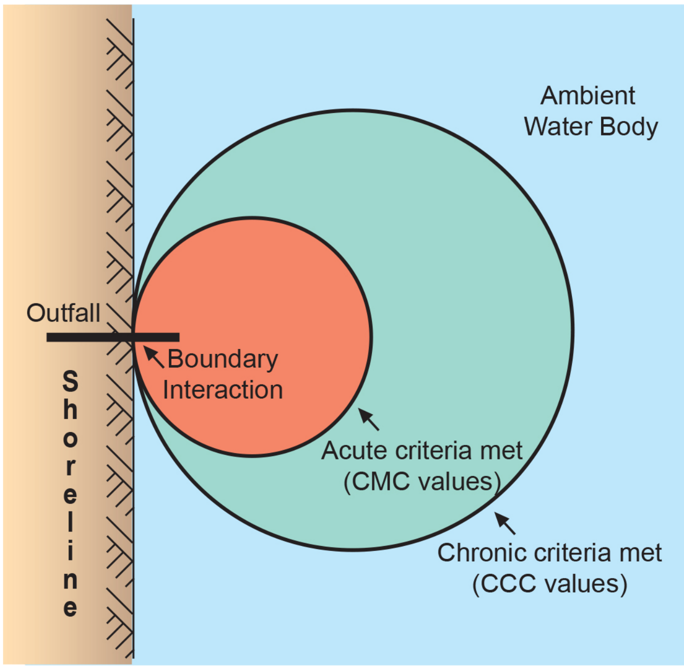

Figure 3.1. Conceptual diagram for a regulatory mixing zone (RMZ). Water quality criteria apply at the boundary of the RMZ. Within the RMZ may be a Toxic Dilution Zone.

Although the system's major emphasis is predicting the geometry and dilution characteristics of the initial mixing zone so that compliance with water quality regulatory constraints may be judged, the system also predicts the behavior of the discharge plume at larger distances.

Among available environmental simulation models, CORMIX is unique because of its data – driven approach to simulation model selection. CORMIX employs a rule – based expert system to screen input data and select the appropriate core hydrodynamic simulation model to simulate the physical mixing processes contained within a given discharge – environment interaction (See Figure 3.2).

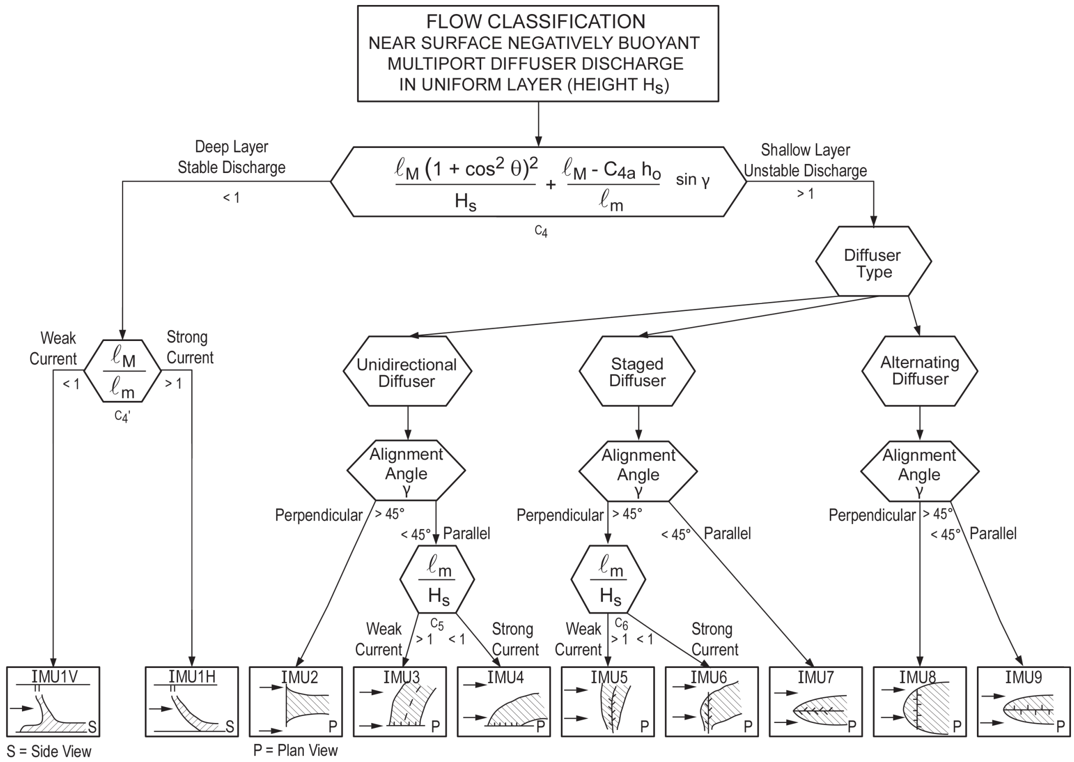

Figure 3.2. Rule – based flow classification system of CORMIX

The highly user – interactive CORMIX modeling system is implemented on Windows computers, and consists of four integrated core hydrodynamic simulation models and two post – processor simulation models. The simulation models are:

1. Simulation models for single port discharges (CORMIX1),
2. Simulation models for submerged multiport diffusers (CORMIX2),
3. Simulation models for buoyant surface discharges (CORMIX3),
4. Simulation models for dense brine and/or sediment discharges from single port, submerged multiport, or surface discharges in laterally unbounded coastal environments (DHYDRO),

5. Post – processor simulation models for detailed near – field mixing of submerged single port and multiport diffusers in unbounded environments (CorJet),

6. Post – processor simulation model for far – field plume analysis (FFL).

The basic hydrodynamics are equivalent for all CORMIX release versions. However, CORMIX versions have different input (pre – processors) and output (post – processor) options. Only the Evaluation (E), Sediment (GTS), and Research (GTR) versions contain routines to simulate suspended sediment plumes. In this study, the accumulation of continuous disposal of dredged material is visualized considering settlement time and concentration using Cormix GTS.

3.1.1 D – CORMIX – Sediment Tool

D – CORMIX, which is a mixing zone model developed for near – field and far – field, is designed to measure water quality for continuous negatively buoyant source releases with suspended sediment loads. Although the system was mainly designed for dredge discharge sources, it can model density current plumes that are based on storm water discharge or desalination concentrate disposal. The measuring of water quality within the water column is the main purpose of the model by focusing on the produced suspended sediment density current. Nevertheless, specifications and accretion rate of deposited sediment are also estimated. Since this is intended to be a basic water quality assessment and sediment deposit screening tool, no prediction is made for dynamic bottom scour, the affect of changing bathymetric topography due to sediment deposition on plume mechanics, or the possibility of re – entrainment of previously deposited material into the suspended sediment density current plume.

3.1.1.1 D – CORMIX System Description

The system uses the same user – interface with CORMIX (Jirka et al. 1996) to input data. It follows a similar classification scheme for submerged discharges as

CORMIX1 (Doneker and Jirka 1990) and for surface discharges as CORMIX3 (Jones et al. 1996) to determine the near field flow structure. This approach is based upon a classification scheme that determines the flow regimes that are important to a given discharge / ambient combination, and applies the appropriate jet – integral or length – scale model appropriate to each flow regime. Central to the methodology is the ability to predict dynamic boundary interactions of dense jets and plumes. Particle settling is accounted for once bottom contact has occurred.

Several different discharge configurations are considered including submerged, surface, and above surface discharges. Figure 3.3 shows typical discharge configurations considered by D – CORMIX. Above surface discharges can be sprayed which are sometimes used to spread material during pipeline dredge material disposal. Below surface jet discharges are restricted to the upper third or lower third of the water column. Shoreline discharges occur at the surface of the ambient water body, from a pipe or discharge canal.

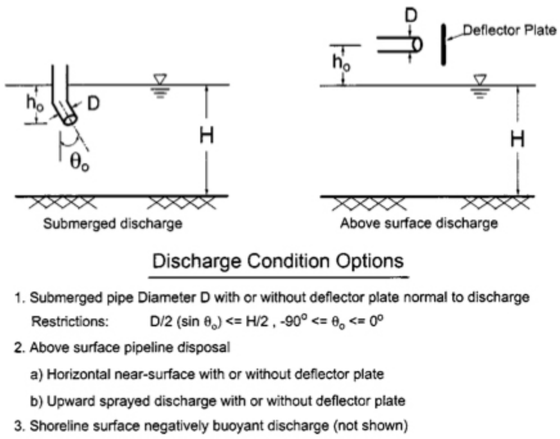

Figure 3.3. D – CORMIX discharge conditions assumptions.

Five sediment class sizes can be considered (large chunky solids, sand, coarse silt, fine silt, and clay) and sedimentation is modeled using Stokes settling. Chunks are assumed to deposit on the bottom immediately after discharge, while the other particle size fractions are available for transport within the density current.

In addition, a conservative or non – conservative pollutant may be issued in the discharge. A non – conservative pollutant can be assigned a first order decay or growth. Of course, the model can also be run without any pollutant present in the discharge flow.

As shown in Figure 3.4, the ambient water body may have either one or two zones (near – shore and off – shore), where different ambient velocities u_a , bottom slopes S, and Darcy friction factors f may be entered. The offshore slope S_2 may be either flat or inclined, while the near – slope S_1 must have some inclination. Ambient stratification, also shown in Fig. 3.4, is described by a surface density value, and up to three density values that are known at different submergence levels below the water surface. A piecewise linear stratification is assumed to exist between these levels.

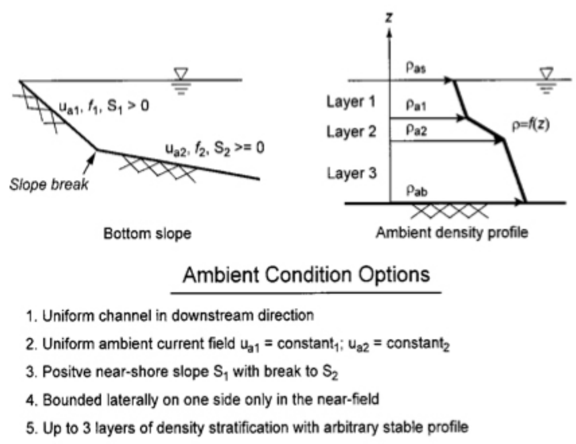

Figure 3.4. D – CORMIX ambient condition assumptions

3.1.1.2 Hydrodynamic Simulation and Flow Classification

Mixing zone processes are controlled by the interplay of discharge and ambient conditions. As the discharge plume travels away from the source, the flow will interact with the ambient boundaries, current, and density profile. The CORMIX methodology emphasizes the role of these boundary interactions on mixing processes (Doneker and Jirka 1990). Vertical boundary interaction occurs when the flow contacts the water surface, channel bottom, or forms an internal terminal layer in a density – stratified ambient environment. Boundary interaction can define the transition from near – field to far – field mixing. Near – field mixing processes are those for which the initial momentum, buoyancy, and geometric orientation of the discharge has the predominant effect on flow behavior. Far – field mixing processes are largely controlled by ambient conditions. Figure 3.5 shows mixing processes representative of a typical dredge discharge scenario: near – field buoyant jet mixing, bottom boundary interaction with upstream density current intrusion, and a far – field with lateral density current spreading followed by passive ambient diffusion.

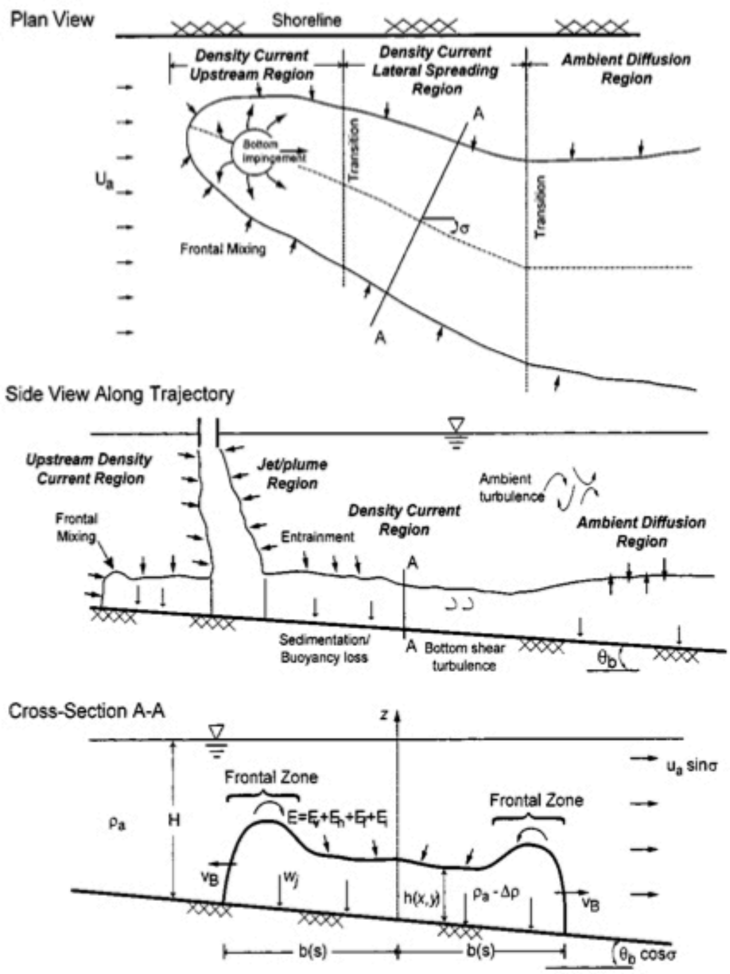

Figure 3.5. Mixing processes for a typical dredge discharge scenario.

The computational modules used in D – CORMIX are similar to those used in CORMIX1 (Doneker and Jirka 1990) and CORMIX3 (Jones et al. 1996) with a number of modifications and additions. Table 3.1 shows abridged output from the simulation model and contains details from the sediment density current.

Table 3.1. D – CORMIX simulation output example

```
BEGIN MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING

  Vertical angle of layer/boundary impingement    =     -72.92 deg
  Horizontal angle of layer/boundary impingement  =       0.00 deg

 UPSTREAM INTRUSION PROPERTIES:
        Upstream intrusion length               =     974.47 m
        X-position of upstream stagnation point =    -970.21 m
        Thickness in intrusion region           =       0.03 m
        Half-width at downstream end            =     959.28 m
        Thickness at downstream end             =       0.07 m

 In this case, the upstream INTRUSION IS VERY LARGE, exceeding 10 times
   the local water depth.
 This may be caused by a very small ambient velocity, perhaps in
   combination with large discharge buoyancy.
 If the ambient conditions are strongly transient (e.g. tidal), then the
   CORMIX steady-state predictions of upstream intrusion are probably
   unrealistic.
 The plume predictions prior to boundary impingement will be
   acceptable, however.

  Control volume inflow:
       X         Y        Z         S        C         B        TT
     4.26      0.00    -5.32      3.0 0.336E+02    0.68 .17337E+01

 Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)
   TT = Cumulative travel time

       X         Y        Z         S        C        BV       BH      ZU       ZL        TT
   -970.21     0.00    -6.00   9999.9 0.000E+00    0.00     0.00   -6.00    -6.00 .17337E+01
   -941.13     0.00    -6.00     13.7 0.727E+01    0.01   135.66   -5.99    -6.00 .17337E+01
   -798.63     0.00    -6.00      5.7 0.176E+02    0.01   329.52   -5.98    -6.00 .17337E+01
   -656.12     0.00    -6.00      4.3 0.234E+02    0.02   445.83   -5.98    -6.00 .17337E+01
   -513.62     0.00    -6.00      3.6 0.275E+02    0.02   537.54   -5.98    -6.00 .17337E+01
   -371.12     0.00    -6.00      3.3 0.305E+02    0.02   615.74   -5.97    -6.00 .17337E+01
   -228.61     0.00    -6.00      3.1 0.324E+02    0.03   685.06   -5.97    -6.00 .17337E+01
    -86.11     0.00    -6.00      3.0 0.334E+02    0.03   747.99   -5.97    -6.00 .17337E+01
     56.39     0.00    -6.00      3.4 0.298E+02    0.03   806.02   -5.97    -6.00 .86751E+03
    198.89     0.00    -6.00      6.9 0.144E+02    0.05   860.15   -5.95    -6.00 .32436E+04
    341.40     0.00    -6.00     10.1 0.994E+01    0.07   911.06   -5.93    -6.00 .56197E+04
    483.90     0.00    -6.00     11.1 0.905E+01    0.07   959.28   -5.93    -6.00 .79957E+04
 Cumulative travel time =        7995.7427 sec  (    2.22 hrs)

END OF MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING
-----------------------------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **
-----------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------
BEGIN MOD310: BOTTOM DENSITY CURRENT

 Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)
   TT = Cumulative travel time

       X         Y        Z         S        C        BV       BH      ZU       ZL        TT
    483.90     0.00    -6.00     11.1 0.905E+01    0.07   959.28   -5.93    -6.00 .79957E+04
    483.91     0.00    -6.00     11.1 0.905E+01    0.03   959.28   -5.97    -6.00 .79958E+04
    483.91     0.00    -6.00     11.1 0.905E+01    0.03   959.28   -5.97    -6.00 .79958E+04
 Cumulative travel time =        7995.8174 sec  (    2.22 hrs)

END OF MOD310: BOTTOM DENSITY CURRENT
-----------------------------------------------------------------------------------------------
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CHAPTER 4

CASE STUDY: DREDGING AND DISPOSAL OPERATIONS UNDER THE GULF OF IZMIR AND HARBOR REHABILITATION PROJECT

The realization of the Gulf of Izmir and Harbor Rehabilitation Project is being planned for the purpose of rehabilitation of the circulation and the quality of in – gulf water; and of the rehabilitation, the efficiency and the capacity of Turkish State Railways (TCDD) Izmir Harbor by Izmir Metropolitan Municipality Water and Sewerage Administration (IZSU) and Turkish State Railways (TCDD) in the State of Izmir, Konak District.

Izmir, being the third greatest metropolitan of Turkey, integrated with trade and industry as a harbor city, is centered by a long and narrow gulf (See Figure 4.1).

Figure 4.1 A Scene from the City, Izmir

The Gulf of Izmir is one of the Mediterranean's greatest natural gulfs, with a total of 200 km^2's of area and 11,5 billion m^3's of water capacity. Izmir is the greatest settlement area around the Gulf with its almost 88.000 hectares of area.

The Gulf of Izmir is divided into three sections as Inner, Middle and Outer Gulfs (Outer Gulf I, II, III), according to its hydrologic and ecological characteristics (See Figure 4.2)

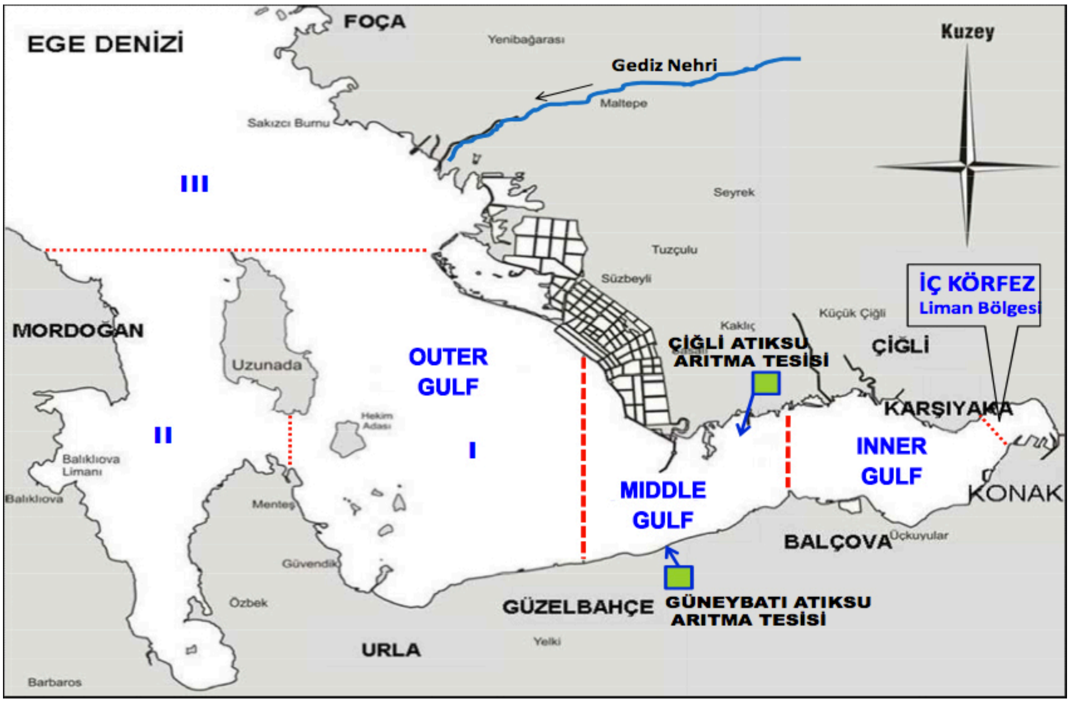


Figure 4.2 The Gulf of Izmir and Sections

Inner Gulf is the part that is in the east of Ragip Pasa Fishery by Yeni Kale Cape. The Middle Gulf is in the west of the Inner Gulf, reaching out to Tuzla and Guzelbahce line. In the west of the Middle Gulf, Outer Gulf lies.

In respect of depth, the Inner Gulf is generally fit for sea transport. The Inner Gulf has a crucial significance in terms of Izmir's transportation. Thanks to its position, it is protected from severe winds.

The Outer Gulf is more open to winds compared to the Inner and Middle Gulfs, also being wider, deeper and has less intensity in terms of transportation. Fishing and trip boating activities could also be performed in Mordogan, Foca and Karaburun along the Outer Gulf.

Northeastern coasts (Foca – Sasali coasts) of the Gulf are one of the areas where Mediterranean seals use as harbor in Aegean. Karaburun coasts, on the other hand, have managed to remain untouched with their pure coves and mountainous deep windy structure. In other words, the fact that transportation is partly insignificant played an important role in this.

Within the studies of harbor rehabilitation;

- Dredging Processes :
    - II. Part Container Terminal Field dredging,
    - Harbor Basin and Evolution Flat dredging,
    - Harbor Navigation Canal dredging,
    - Circulation Canal dredging,

- Filing and construction works to be made within the scope of incomplete II. Part New Container Terminal,

    - Usage of II. Part Container Terminal Field dredging material in filling by applying rehabilitation techniques,

    - Usage of Harbor Basin and Evolution Flat dredging material in filling by applying rehabilitation techniques,

- Usage of a part of Circulation Canal dredging material in filling by applying rehabilitation techniques,

• Recovery of the area that is at Cigli Sewer Water Purification Facility, whose ownership of the dredging material belongs to IZSU, and in north of it (Announcing Special Provision Area in Revised Gediz Delta Management Plan and presenting it to National Wetland Area Commission for approval [USAK]).

  - Transferring Harbor Navigation Canal dredging material to Recovery Area or to the idle area at Gediz Delta Camalti Tuzla, and putting it in a series of processes.

  - Transferring Circulation Canal dredging material to Recovery Area or to the idle area at Gediz Delta Camalti Saline, and putting it in a series of processes.

• Ultimate transfer and areas of usage of the Dredging Material,

  - Usage of the dredging material for the purpose of rehabilitation of sea frontiers of Cilazmak Fishery by consolidating it, following the partial dewatering process.

  - Following the dewatering and partial desalination processes of the dredging material, transporting it to Harmandali Solid Waste Storage Area and laying it as cover material,

  - Following the dewatering and partial desalination processes of the dredging material, usage of the material by Izmir Metropolitan Municipality at parks and gardens for the purpose of environmental planning,

- Following the dewatering and partial desalination processes of the dredging material, transporting the material to Bornova Gokdere, Buca Kiriklar and Guzelbahce Yelki excavation soil, construction and wreckage waste storage areas and laying as cover material,

- Following the partial dewatering of the dredging material, evaluating it in the idle area settled in Gediz Delta Camalti Saline,

- Usage of the dredging material in Izmir Coast Design Project; following the dewatering process of the dredging material, usage of clay and sand as construction building material,

- Usage of the dredging material for the purpose of agriculture, following the processes of dewatering and desalination,

- Usage of the dredging material for the purpose of habitat rehabilitation in the area that is in the use of the Military in Gediz Delta Ecological Exposure Area (on condition that the required allocation is granted),

- Usage of the dredging material in the area, which is in the property of IZSU that is in the west of the Recovery Area (Dewatering Area), for the purpose of habitat rehabilitation (on condition that the required permission is granted),

- Removing the dredging material by creating Natural Life Island (on condition that there are not any re – use alternatives for dredging material),

With the project, it is aimed that a large majority of the dredges until – 14 meters of dredging depth of Harbor Basin and Evolution Flat, all of the II. Part Container Terminal Area dredges and a part of Circulation Canal sand material dredges are used as filling in II. Part Container Terminal Area. The dredged material that will be obtained from other dredges within the scope of the project is also proposed to be recovered and evaluated as explained above.

The processes of Circulation Canal dredges that are going to be transferred to the idle area in Gediz Delta Camalti Saline and to the Recovery Area are going to be carried out by IZSU; and the evaluation of Circulation and Harbor Navigation dredging materials in the idle area in Gediz Delta Camalti Saline and / or Recovery Area and the processes concerning Natural Life Island are going to be carried out by IZSU / TCDD.

4.1 Units, Features and Position of Activities / Services to be realized within the Project

4.1.1 Harbor Navigation Canal, Harbor Basin and Evolution Flat

The harbor that is still in use for the purpose of increasing the prolificacy and capacity of Izmir Harbor and making Izmir Harbor appropriate for Panamax and Post – Panamax ships is being planned to be deepened and widened by dredging in its part that is starting from Yenikale Strait to the harbor. Harbor Navigation's length is nearly 12 km's, and in the first phase, it is going to be dredged until – 14 meters, and then up to – 16 meters; and if necessary, until – 17 meters.

As a consequence of the calculations made, the material amount to be dredged until – 14 meters from Harbor Navigation Canal is almost 1.800.000 m^3; in the second phase, the dredging to be made from – 14 meters to – 16 meters will almost be 3.050.000 m^3, while the dredging that is going to be done as the last phase to reach from – 16 to – 17 will almost be 2.640.000 m^3. The specified dredging material has approximately 66,05 % (32,1 % – 100,0 %) water content in its place.

The material to be dredged in Harbor Basin and Evolution Flat until – 14 meters will almost be 7.600.000 m^3; in the second phase, the dredging to be made from – 14 to – 16 will almost be 4.000.000 m^3; and in the last phase, to reach from – 16 to

– 17 in depth, the dredging will approximately be 2.040.000 m^3. The specified dredging material has almost 66,05 % (32,1 % – 100,0 %) water content in its place.

In total, the material amount to be dredged both from Harbor Navigation Canal and Harbor Basin and Evolution Flat up to – 14 meters is almost 9.400.000 m^3; in the second phase, the dredging to be made from – 14 to – 16 will almost be equal to 7.050.000 m^3; and in the last phase, the dredging to reach from – 16 to – 17 will be 4.680.000 m^3.

There will also be dredging in the area of 2.700.000 m^2 from Harbor Navigation Canal, in Harbor Basin and Evolution Flat in 2.170.000 m^2 of area.

4.1.2 Circulation Canal

For the purpose of healing the water quality in the Gulf of Izmir, a Circulation Recovery Canal is being planned to be built up, besides Harbor Navigation Canal, in the northern flow of the Gulf. Increasing circulation speeds thanks to Circulation Canal, recovering water circulation, controlling pollution transport and enhancing ecological life are amongst the planned activities. The mentioned Circulation Canal is almost 13 km's long and the dredging material of almost 24.840.000 m^3's will be obtained from until – 8 meters at sea, for the canal to be opened, in almost 4.210.000 m^2's of area. Almost 70 % of the specified dredging material is formed of soft – very soft clay; and the rest of it, almost 30 %, is formed of sand. Sand material originally has almost 28,40 % (21,9 % – 34,9 %) and soft – very soft clay material originally has almost 62,95 % (25,9 % –100,0 %) water content.

4.2 The Amounts of the Material to Be Dredged from the Bottom Dredge and Pollution Analysis

The sediment samples obtained as the result of the sounding studies realized within the scope of the Gulf of Izmir and Harbor Rehabilitation Project have been obtained from three different zones as Harbor Canal Sounds (HCS), Navigation Canal Main Sounds (NMS) and Circulation Canal Main Sounds (CMS). The analysis of 89 of the sediment samples have been completed and reported within the scope of "Regulations Concerning Regular Stock of the Waste". 59 copies of these belong to HCS; 20 belong to NMS and 10 belong to CMS. The analysis of the sediment samples taken from the specified points in regional maps are evaluated as "hazardous waste", "non – hazardous waste", and "inert waste", according to their consistency to the criteria of the relevant, mentioned regulations.

When the obtained analysis results were evaluated within the terms of the disposal of the dredging material, by means of measurement obscurities in the related analysis reports, deep sea sediments in the Gulf were specified as "Non – Hazardous Waste" category. According to this, none of the analyzed samples are included in "Hazardous Waste" category.

The analysis results that belong to samples obtained from HCS, NMS and CMS regions within the concept of the project remained considerably below calculated HPI value in terms of threshold value and therefore, the Gulf sediments were determined as "not polluted", when they were analyzed according to average HPI value.

4.3 Dredging Material Recovery Area, Determining the Alternative Areas that the Material to be Dredged from Bottom Dredging

4.3.1 Natural Life Island

Another area that the dredging material that will be obtained from the dredging to be realized within the scope of the project could be used in is Natural Life Island numbered 4 on Figure 4.3.

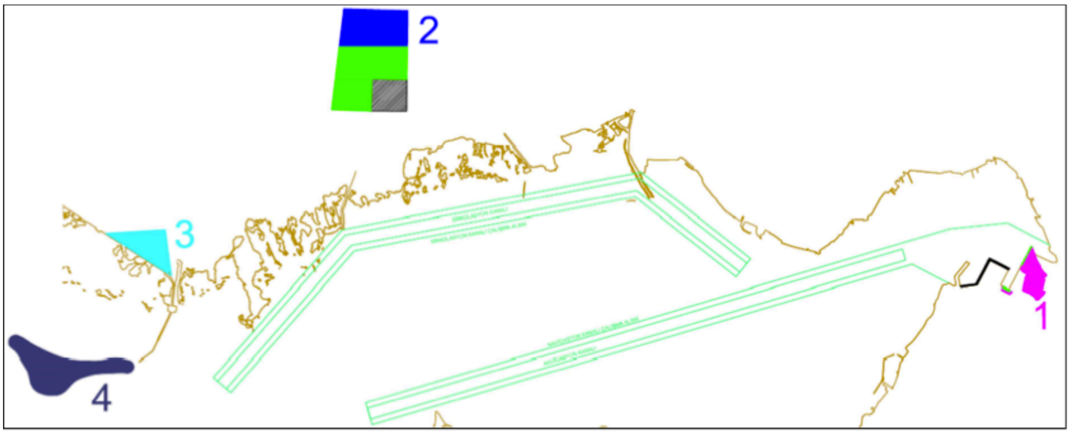


Figure 4.3 Position of Natural Life Island

The approximate possible location of Natural Life Island has been picked based on present bathymetric data; and constituted in an area at which water circulation is thought to be at minimum in the Gulf of Izmir. Natural Life Island needs to affect the water circulation at very little levels and it should not decrease fresh water amount coming into the Gulf. Consequently, following the defining process of possible location alternatives of Natural Life Island, circulation modeling studied should be realized. In this direction, various kinds of pre – study and analyzes were made for the project. The specified information regarding the studies is given below.

4.3.1.1 Natural Life Island Size

The size of the Natural Life Island depends on the factors such as the amount of the dredged material to be used at eventual usage / transfer areas following the process at Recovery Area and II. Part Container Terminal Area's surface rehabilitation and its leading amount of dredging material. The Natural Life Island in Figure 4.3 is almost – 9 meters of water depth and has almost 1.400.000 m^2's of area. Top elevation of the Natural Life Island is planned to be +1 meters over the average water level distance. Accordingly, it has the capacity to cover almost 14.000.000 m^3's of dredging material as its condition in Figure 4.3.

The size of the Island will change according to the dredging material amount to be evaluated at the Natural Life Island. Therefore, the sketches concerning the Natural Life Island were realized relevant to the possible sizes and dimensions in Figure 4.4. The red island in the figure is almost 80.000 m^2's; the blue island is almost 300.000 m^2's; and the green island is almost 380.000 m^2's.

If required, according to the synchronization of the dredges and the level of need, a couple of small islands instead of a huge island is an alternative under consideration. The islands in Figure 4.4 are functioning as a sample display to this system.

4.3.1.2 Natural Life Island Location and Configuration

The distance of the Natural Life Island in Figure 4.3 to the end of Gediz Delta Camalti Saline Pier by the sea is almost 300 meters. If there are any ships using this pier, the presentations involving the ships' edging in with the pier should be evaluated after the official decisions are made regarding the Natural Life Island.

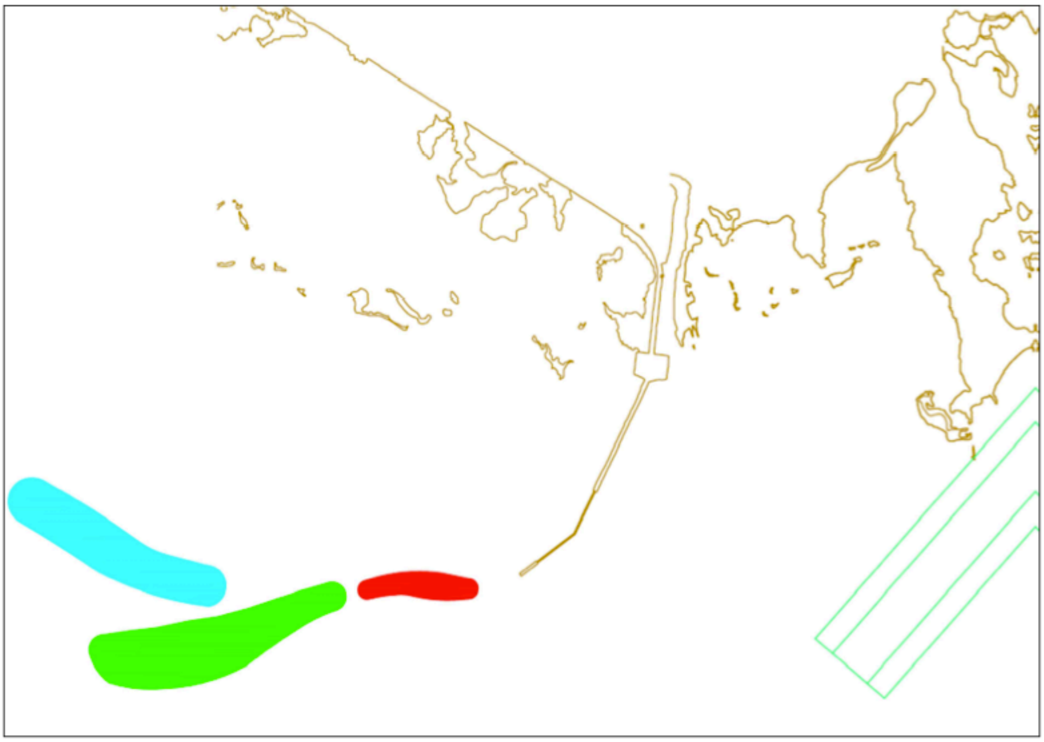


Figure 4.4 Sample Sketch Regarding the Possible Sizes, Dimensions, Locations and Configurations of the Natural Life Island

In this sense, the relation of the Natural Life Island to Gediz Delta Camalti Saline pier and the business using this pier is of huge importance. Following the obtaining process of the information of the specified business's frequency of usage of the pier, what kinds of ships follow which routes and edge in with the pier, the location and the configuration of the Natural Life Island will be clarified.

4.3.1.3 The Structure Ambient in Natural Life Island

It is planned that stone fill is going to be made for the support units around Natural Life Island for them to be in coherence with the nature. According to the results of the realized wave climate studies, it is predicted that 0,4 – 2 tons of stones will be used in stone fill support units.

A typical profile is given in Figure 4.5 for the support units around the Natural Life Island.

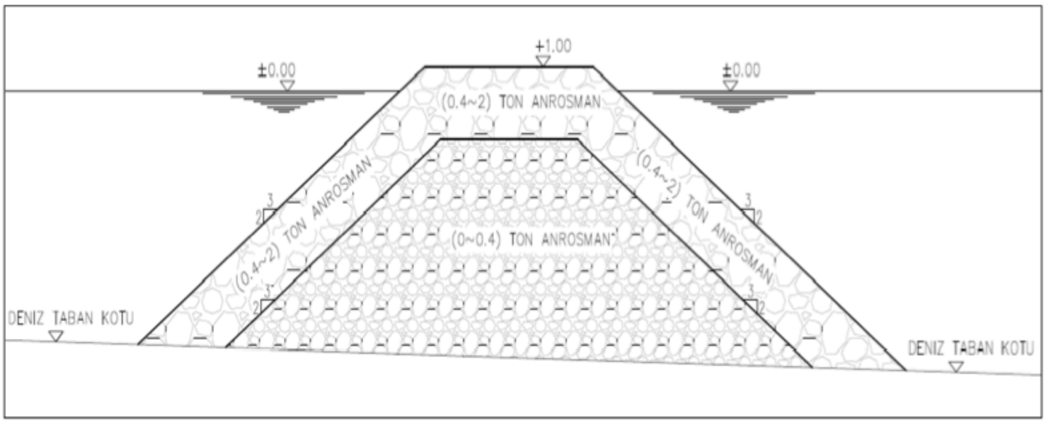


Figure 4.5 Sample Support Unit Profile that might Enclose Natural Life Island

4.3.1.4 Transferring the Dredging Material to the Natural Life Island

Another crucial point is a series of measures in order to prevent the turbidity that might come out in the Gulf of Izmir during the transfer of the dredging material into the Natural Life Island. With this object, for preventing the turbidity that might form and the spreading of the dredging material of the inner part of the stone fill, silt curtains will have to be used during casting process. A sample for a typical silt curtain is given in Figure 4.6.

Stone fill in Figure 4.5 will be effective in preventing the turbidity, as well. Yet, silt curtains will just in case be taken into account.

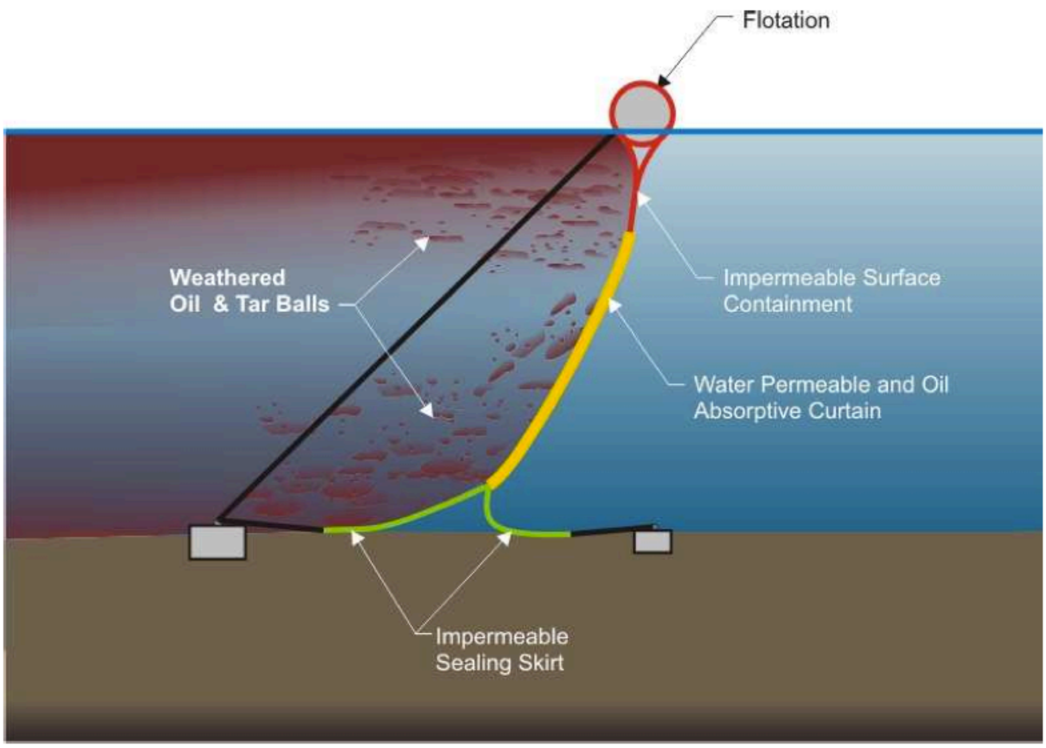


Figure 4.6 Sample Typical Silt Curtain

It is predicted that during the dredging that is close to the Natural Life Island, the transfer of the dredging material to the area specified with the pumps will be more applicable; while bottom door absorber dredging ship may transfer dredging material from a location near the Natural Life Island by pumping with floating pipes or it may leave the dredging material in the specified Natural Life Island in farther points. These sorts of practices are given with samples in Figure 4.7 and Figure 4.8.

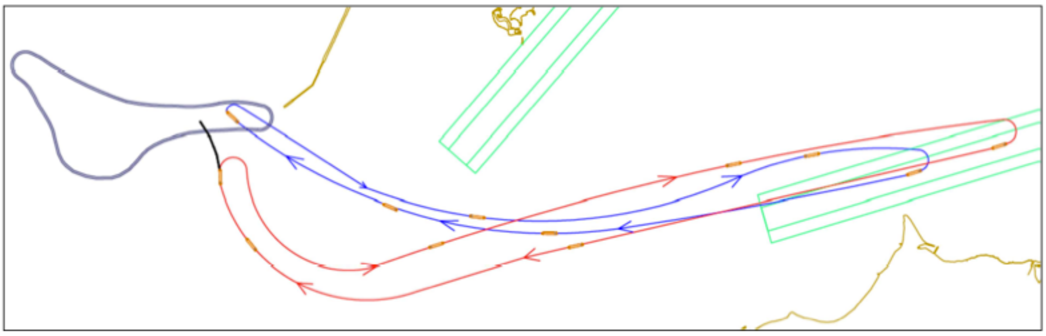


Figure 4.7 Sample Transfer Routes of Harbor Navigation Canal Dredging Materials that could be Transferred to the Natural Life Island

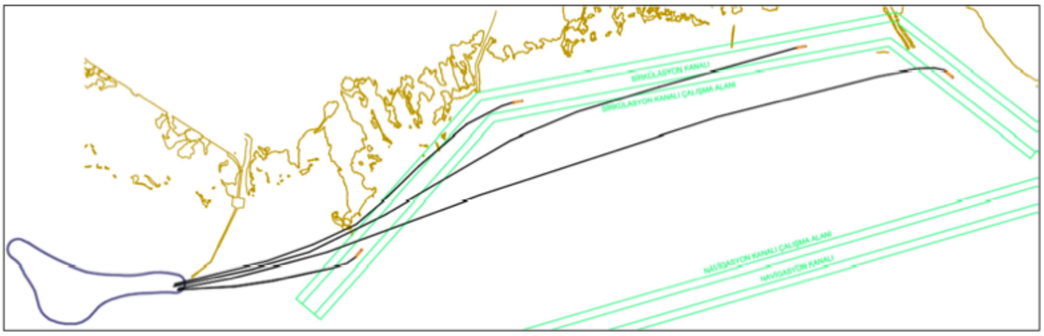


Figure 4.8 Sample Transfer Routes of the Circulation Canal Dredging Materials to be Transferred to the Natural Life Island

It is predicted that stone fill support units may create new living and reproduction spaces for various fish kinds. It is also expected that the Natural Life Island will make a reproduction and nesting area, especially for herons and various species of other birds.

CHAPTER 5

RESULTS AND DISCUSSION

In this study, D – CORMIX model is used to simulate sediment transportation, entrainment and accumulation. Since CORMIX software has some packages, convenient package of the software to use D – CORMIX is CORMIX – GTS version. CORMIX – GTS includes standard CORMIX Evaluaiton module and D – CORMIX sedimentation module.

As detailed in Section 2.4.2, surface discharge increases the dimensions of sediment cloud; therefore, submergence is needed. Since submerged single port discharge is considered, Cormix I model (single port submerged discharges) is chosen. The model input requires environmental conditions, outfall configuration and sediment description.

5.1 Environmental Conditions

The environmental conditions include the ambient conditions and the bottom slope. The currents and wind speed input to the model are determined based on the Gulf of Izmir Rehabilitation Project Environmental Impact Assessment Report. Moreover, friction factors and ocean clear water density values are from Cormix Manual. The ambient conditions input used to represent the project site is shown in Table 5.1.

CORMIX is limited to representing the bottom slope as either a one – slope or two – slope profile. The two – slope input used to represent the project site is shown in Table 5.2.

Table 5.1 Input parameters for ambient conditions

Input Parameter	Value
AMBIENT CONDITIONS	
Nearshore current (m/s)	0,06
Farshore current (m/s)	0,06
Nearshore f	0,025
Farshore f	0,025
Wind speed (m/s)	2,5
Ocean clear water density at discharge (kg/m3)	1025

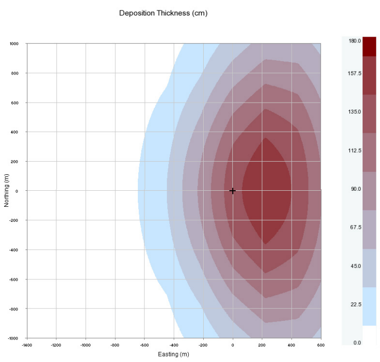
Table 5.2 Input parameters for bottom slope and sediment discharge

Input Parameter	PT1	PT2	PT3	PT4
AMBIENT CONDITIONS				
Onshore slope (%)	0,526	0,498	0,588	0,498
Distance to slope intersection (m)	1140	2010	1020	2010
Farshore slope (%)	1,852	3,093	1,961	3,093
DISCHARGE PARAMETERS				
Distance from onshore slope 0 intersect (m)	1140	2010	1020	1000
Vertical angle (deg)	0	0	0	0
Horizontal angle (deg)	0	0	0	0
Total depth at discharge (m)	6,00	10,00	6,00	4,98
Height of discharge above bottom (m)	4,01	6,70	4,01	3,33

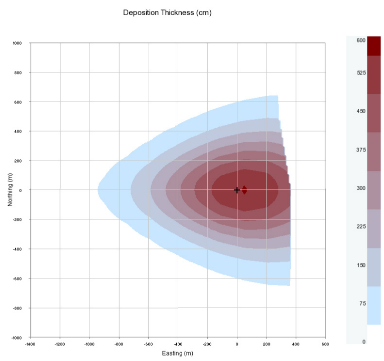
5.2 Outfall Configuration

The outfall configuration input to the model includes: pipe discharge velocity or rate, pipe diameter, horizontal and vertical discharge angles, depth of discharge submergence, and distance of discharge from shoreline.

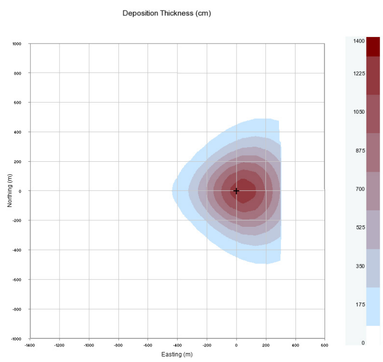
The discharge simulated for this study was a submerged discharge. Cormix I only accepts the submergence height range between the sea surface and 2d/3 or d/3 and the sea floor where d stands for depth. For the first third depth of water column, submerged pipe can have an inclination of maximum 90 degrees. This means a vertical downward oriented discharge. However, for the last third depth of water column, submerged pipe can have an inclination of maximum 45 degrees. This means that the pipe can be at a 45 degree angle toward the bottom. Since deep submergence and direct pressure means high cavitation and dispersion, the first third depth of water column and 0 degree submergence angle is preferred (See Table 5.2). Simulation results for two different depths and different horizontal angles are compared in Figure 5.1 and Figure 5.2.



a) Theta = 45^0 , H_0= 1.95 m, max d_{acc}= 180 cm



a) Theta = 90^0 , H_0= 4.05 m, max d_{acc}= 600 cm



a) Theta = 0^0 , H_0= 4.05 m , max d_{acc}= 1400 cm

Figure 5.1 Comparison of discharge depth and vertical angle Theta effect

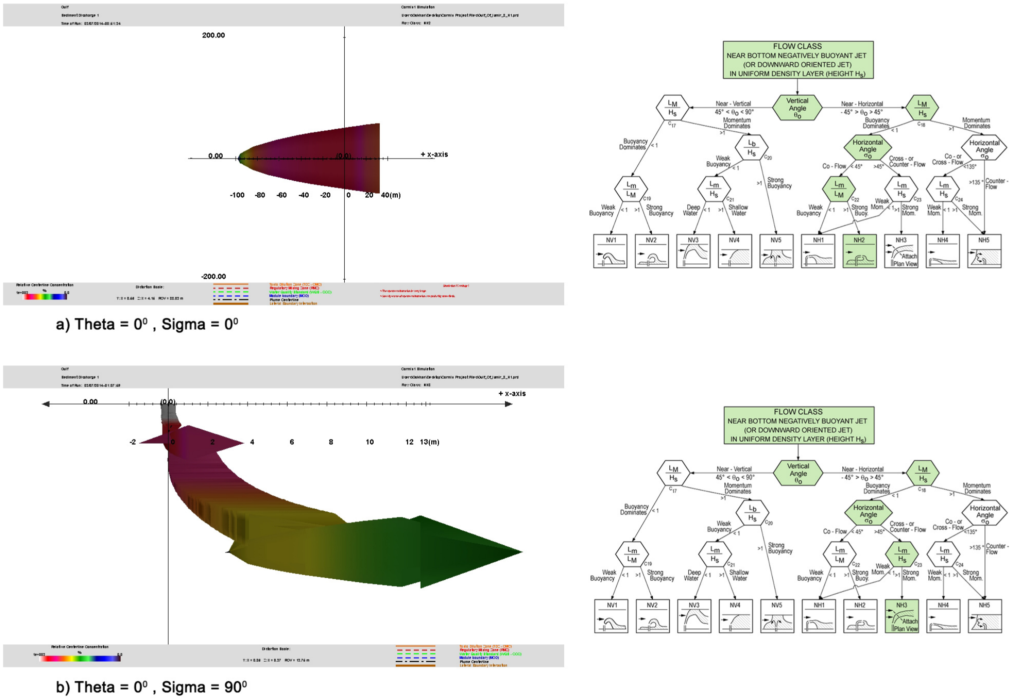


Figure 5.2 Comparison of the horizontal discharge angle Sigma effect

The discharge flow rate is 0,74 m3/s based on the calculation of daily dredged operations shown in Table 5.3.

Table 5.3 Calculations for Dredged Material Discharge

Dredged Material (m^3/hr)	Working Time (hr/day)	Dredged Material (m^3/day)	Dredged Material (m^3/sec)
4000	16	64000	0,74

A sediment concentration of 360 kg/m3 is a typical concentration (20%) for hydraulic dredging of fine and coarse mixed – grained sediments. Due to accumulation risk in the pipeline, velocity of the sediment – water mix should be higher than 4,0 m/s. Therefore, pipe diameter would be 0,25 m minimum and 4 m/s would be a high velocity. In order to minimize the discharge velocity and initial dilution of the discharge, the analysis assumes that a diffuser with a diameter of 0,75 m is used at the outfall as seen in Table 5.4. Diffusers are commonly used and will be specified in the dredging plan for this project.

Table 5.4 Input parameters for discharge and concentration

Input Parameter	Value
DISCHARGE PARAMETERS	
Diameter (at end of diffuser) (m)	0,75
Discharge rate (m^3/s)	0,74
Total sediment concentration (kg/m^3)	360
Effluent density (kg/m^3)	1180

5.3 Sediment Description

For sediment grain sizes, CORMIX requires sorting into five classes: chunks, sand (D > 0.062 mm), coarse silt (0.062 mm > D > 0.016 mm), fine silt (0.016 mm > D > 0.0033 mm), and clay (D < 0.0033 mm). Based on sediment sampling of the areas to be dredged and grain size analysis by Dokay – ÇED Labs (2013), on average, the dredged material is 0% chunks, 18.6% sand, 13.9% coarse silt, 48.1% fine silt and 19.4% clay. The sediment grain size data is summarized in Table 5.5.

Table 5.5 Input parameters for sediment distribution

Input Parameter	Value
SEDIMENT DISTRIBUTION PERCENTS	
Chunks	0
Sand	18,6
Coarse silt	13,9
Fine silt	48,1
Clay	19,4

5.4 Results of Simulation Studies

Above given input values were run on D – CORMIX and output files with a .prd extension are generated. Output files include near shore dispersion such as hydrodynamic centerline dilution, centerline concentration and cumulative travel time. Upstream spreading and far shore sediment settlement results are also expressed as top – hat thickness measured vertically, top – hat half – width measured horizontally, upper and lower plume boundary, hydrodynamic average (bulk) dilution, average (bulk) concentration (includes reaction effects, if any) and cumulative travel time. Bottom density current values and suspended sediment distribution are included in the output report and percentages of sediment mass fluxes are listed according to X position. An example output file can be seen in Appenix A.

Additional modules in CORMIX – GTS, such as CorPlot and CorVue was used to illustrate simulations. An example of CORMIX software screenshot can be seen in Figure 5.3.

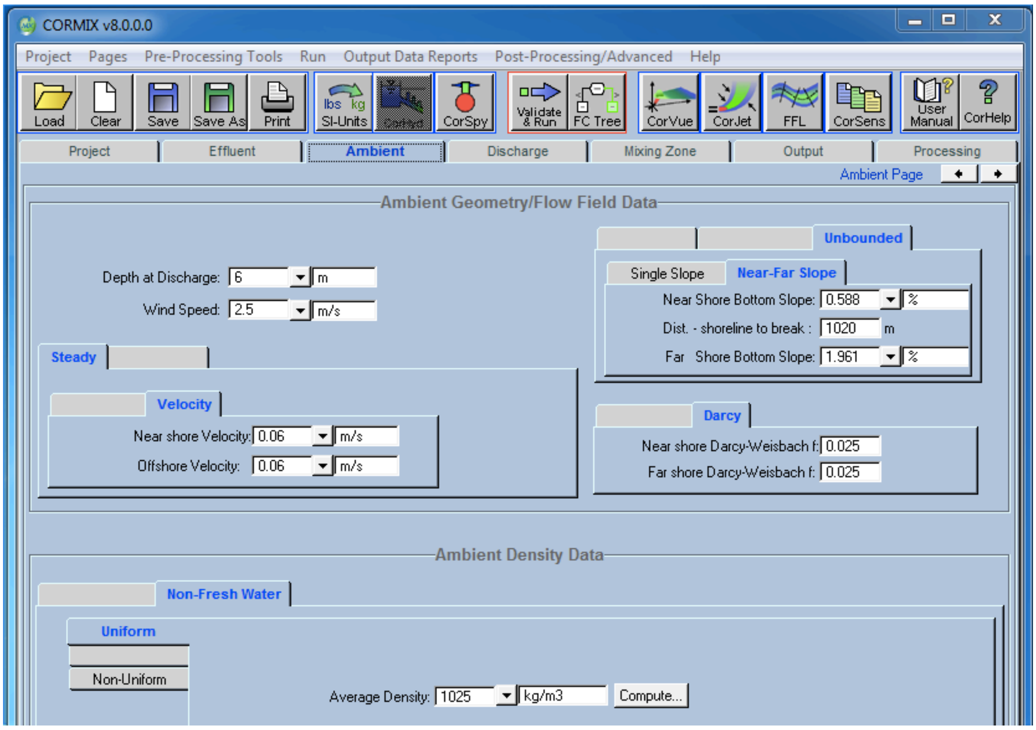


Figure 5.3 An example of CORMIX software screenshot

According to the current pattern of the Gulf of Izmir, directions of currents in northern part of the gulf is North – North – West. Therefore, shoreline would be right – hand side of the Natural Life Island. Bathymetric data was obtained from AutoCAD drawings included in the Environmental Impact Assesment Report. Considering the size of the Natural Life Island, four disposal points were decided. As seen in Figure 5.4, depth at disposal points is between 5 and 10 meters. Continuous dredge disposal simulations were run for these four disposal points and accumulation graphs can be seen in Figure 5.5, Figure 5.6, Figure 5.7 and Figure 5.8 respectively.

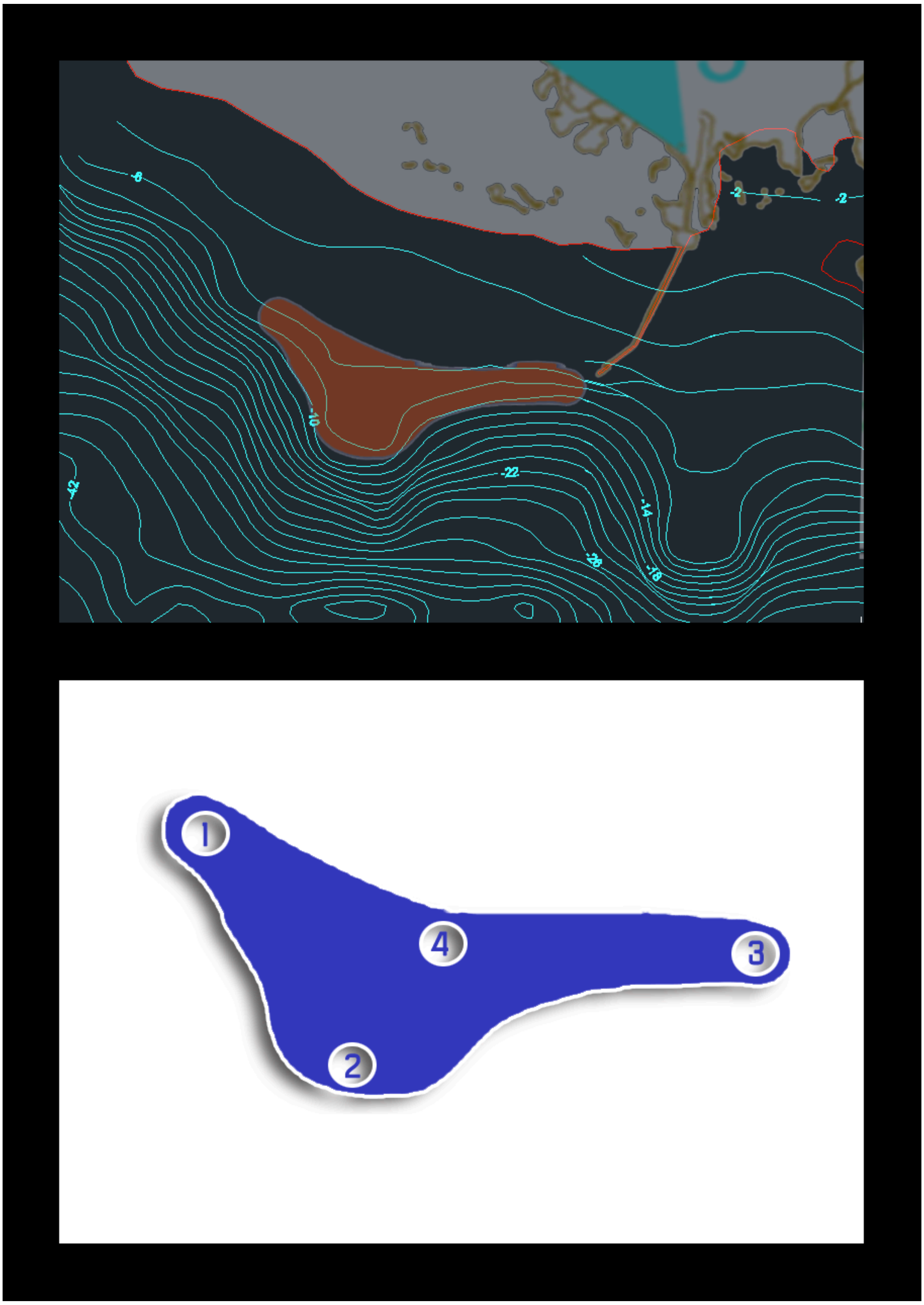


Figure 5.4 Bathymetric data of Natural Life Island and disposal points.

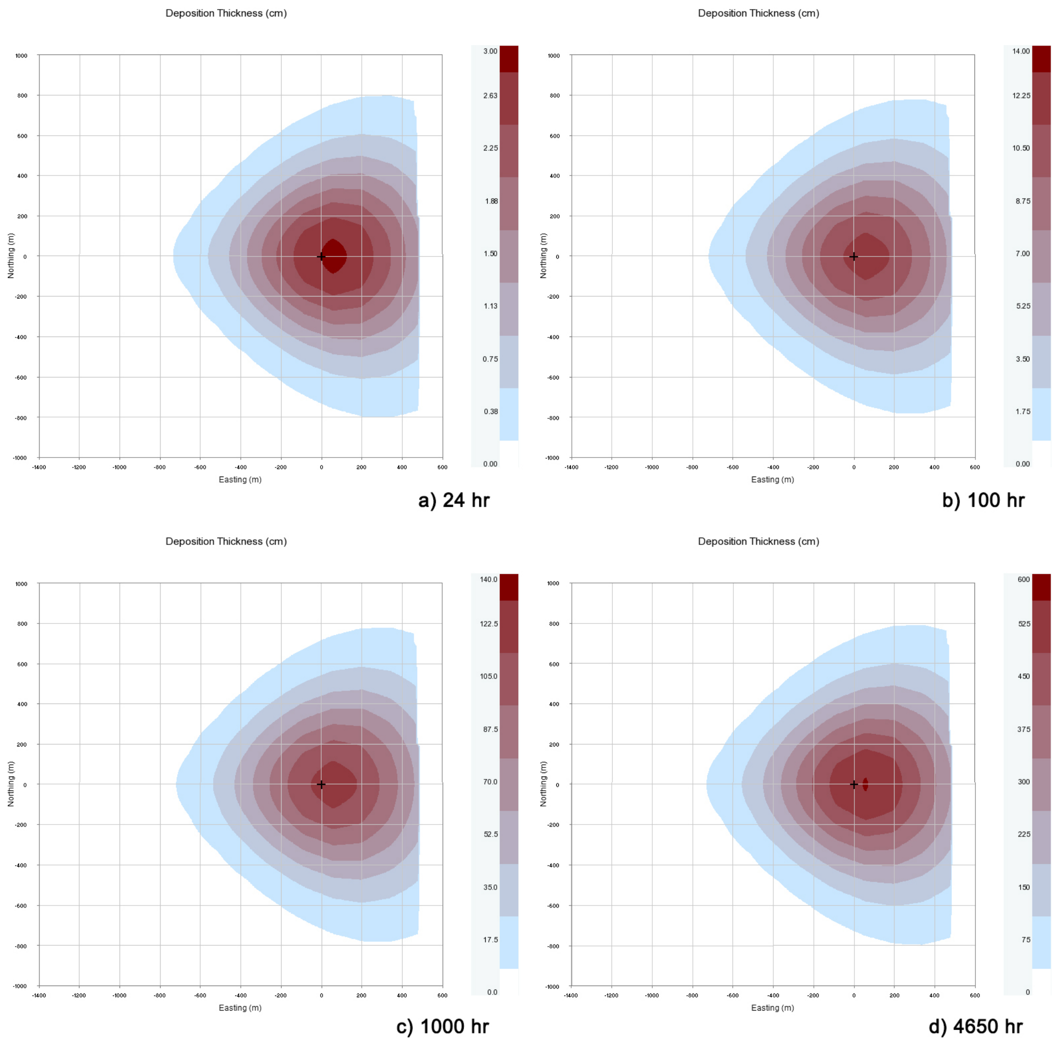


Figure 5.5 Disposal point 1 sediment accumulation vs. time graphs

According to Figure 5.5 a), in the first 24 hours, maximum 3 cm sediment accumulation is observed. Figure 5.5 b), c) and d) illustrate the deposition 14 cm, 140 cm and 600 cm (sea surface) maximum, respectively.

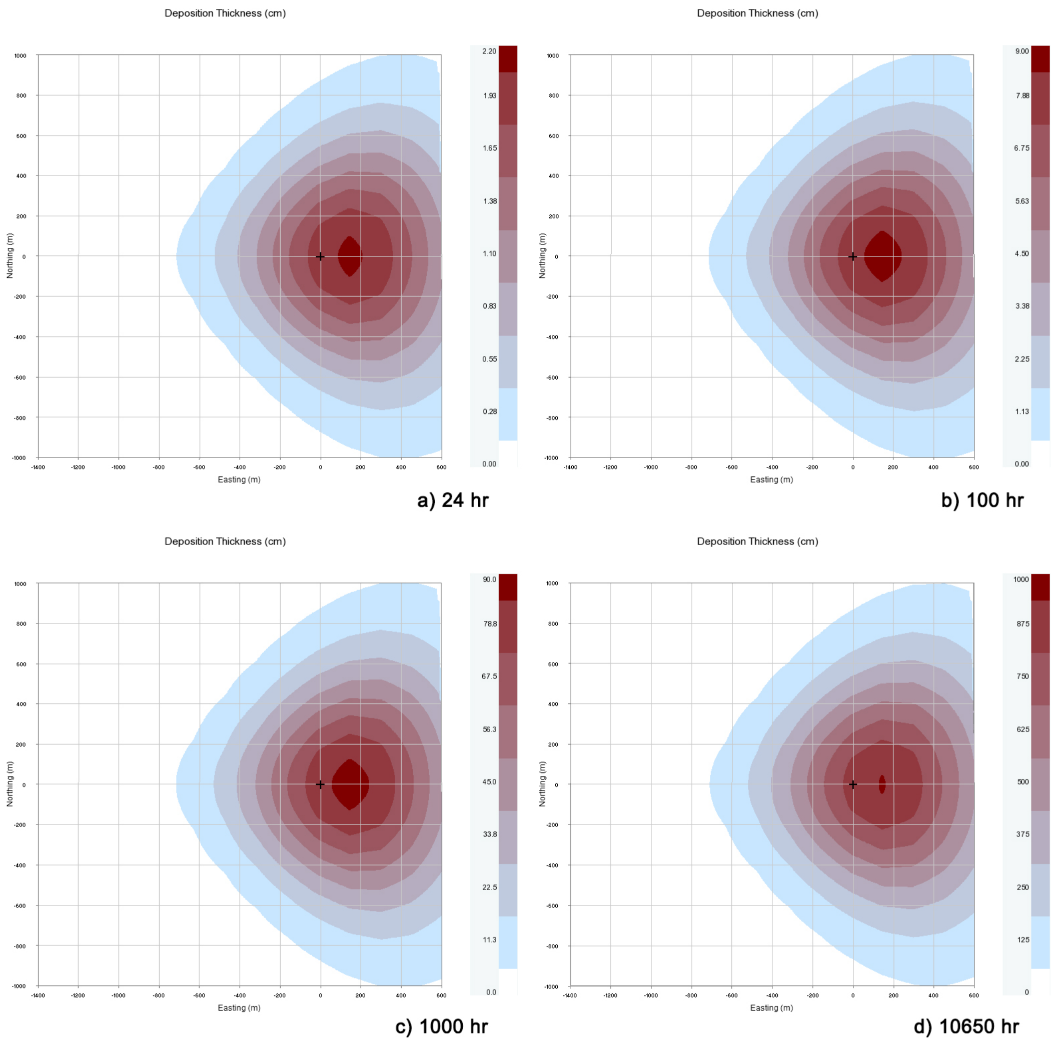


Figure 5.6 Disposal point 2 sediment accumulation vs. time graphs

According to Figure 5.6 a), in the first 24 hours, maximum 2,2 cm sediment accumulation is observed. Figure 5.5 b), c) and d) illustrate the deposition 9 cm, 90 cm and 1000 cm (sea surface) maximum respectively.

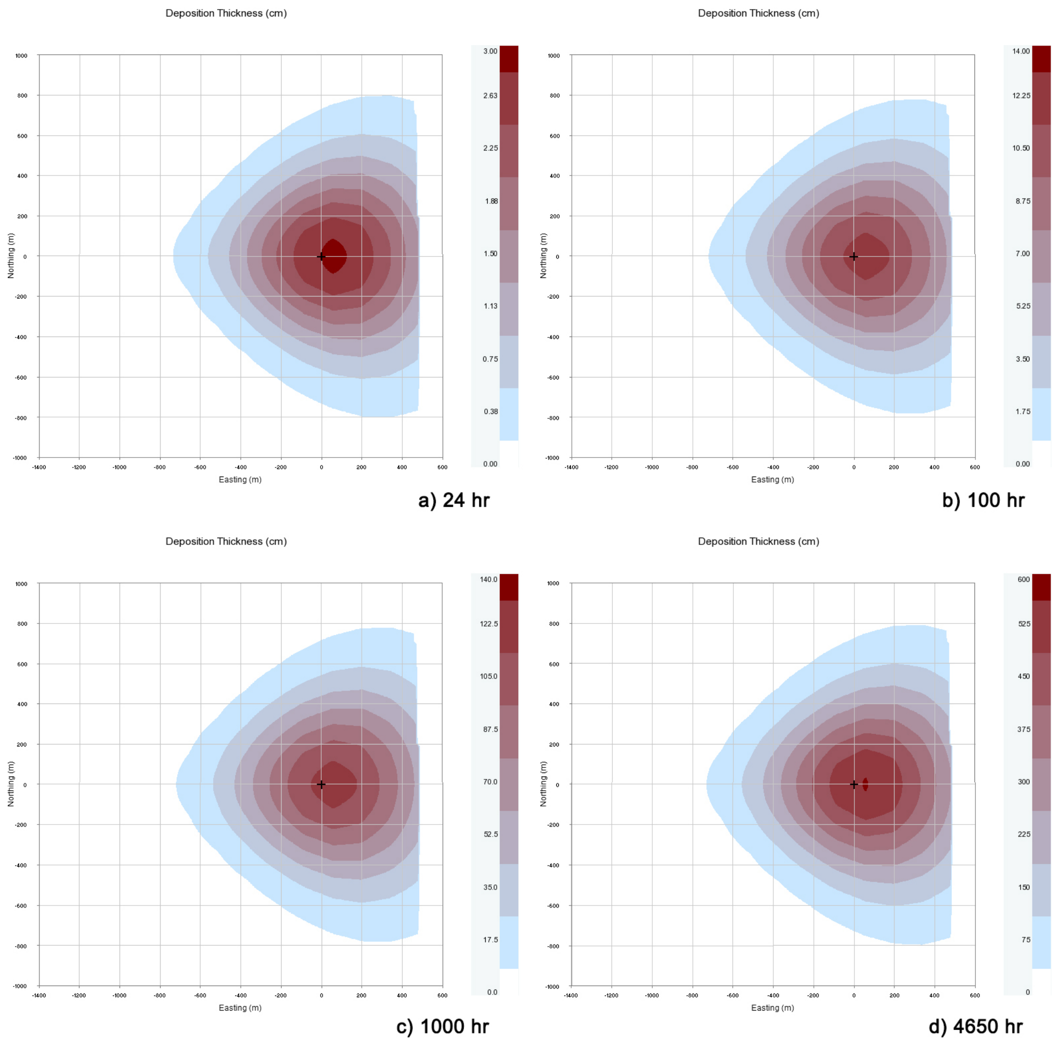


Figure 5.7 Disposal point 3 sediment accumulation vs. time graphs

According to Figure 5.7 a), in the first 24 hours, maximum 3 cm sediment accumulation is observed. Figure 5.5 b), c) and d) illustrate the deposition 14 cm, 140 cm and 600 cm (sea surface) maximum respectively.

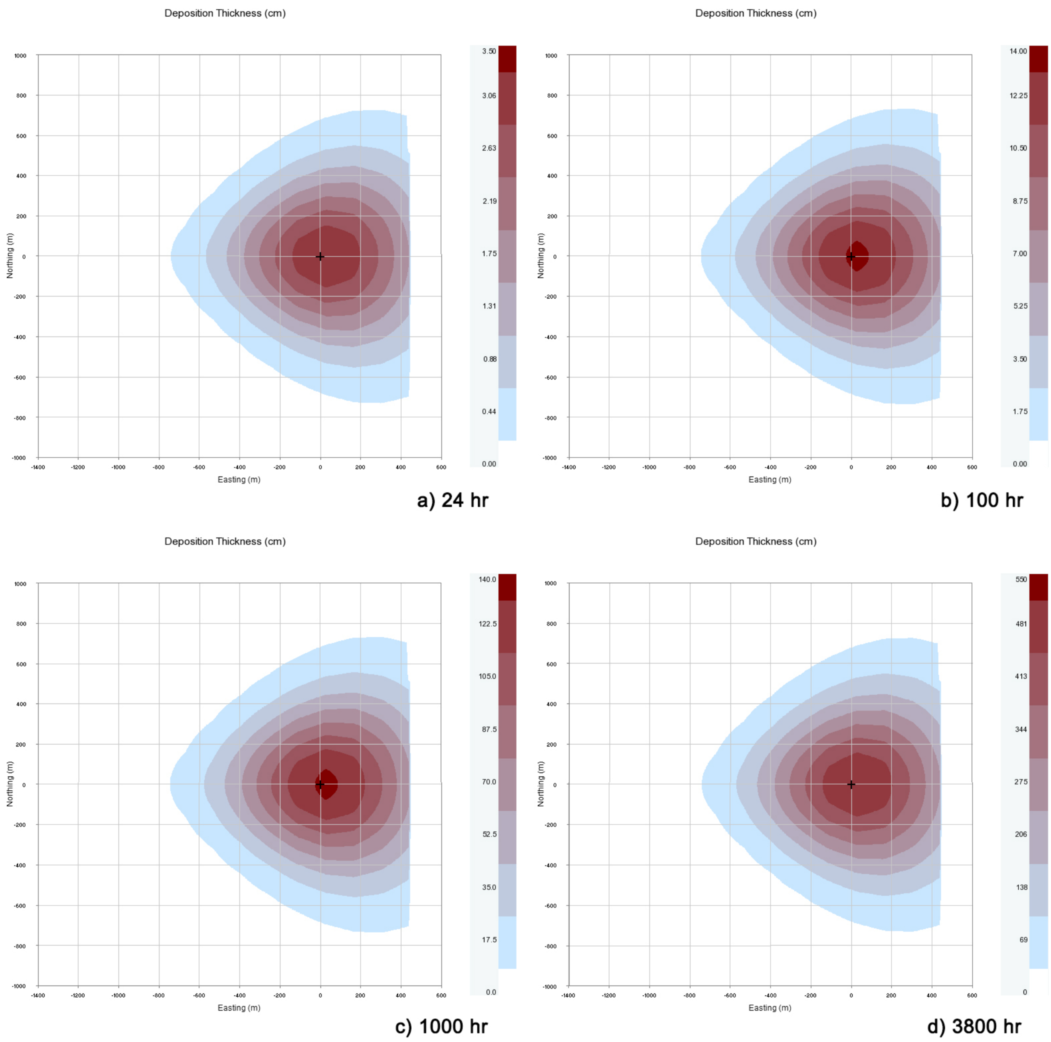


Figure 5.8 Disposal point 4 sediment accumulation vs. time graphs

According to Figure 5.8 a), in the first 24 hours, maximum 3,5 cm sediment accumulation is observed. Figure 5.5 b), c) and d) illustrates the deposition 14 cm, 140 cm and 500 cm (sea surface) maximum respectively.

When accumulation datas of four points converged on the Natural Life Island, it is clearly seen that dispersion and upstream intrusion values are much higher than expected (See Figure 5.9).

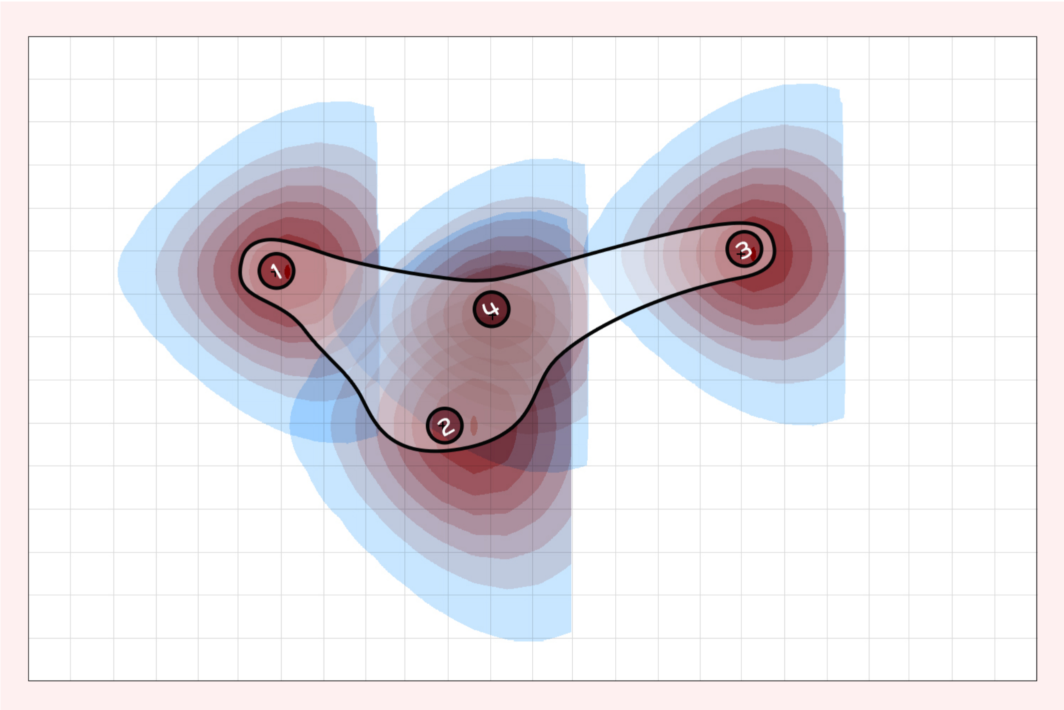


Figure 5.9 Converged sediment accumulation vs. time graphs for four disposal points on the Natural Life Island.

5.5 Discussion of Results

Sediment accumulation data obtained from simulation studies shows that, sediment accumulation through the sea depth, takes 3800 to 10650 hours for limited areas such as 10 meter diameter earth on the sea surface.

With a simple calculation,

$$14.000.000 \text{ m}^3 / (0,74 \text{ m}^3\text{/s x } 0,20 \text{ x } 3600 \text{ s/hr}) = 26275 \text{ hr}$$

can be obtained. This calculation means that, if there is no dispersion effect, the whole island should be formed in 26275 hours by a continuous dredge disposal of 0,74 m^3/s with a 20% dredged material mix.

Since just one point of accumulation from sea bed to the sea surface takes 10650 hours, (See Figure 5.6) this unconfined disposal operation will cost much more than expected. Dispersion is distinguishably higher than foreseen, therefore, silt curtains mentioned in Section 4.3.1.5 and shown in Figure 4.6 are highly recommended.

On the other hand, there are some important reasons to be worried about the accuracy of simulation outputs from CORMIX software. Since CORMIX is developed for near field plume simulations and works with one – point continuous dredge disposal principle, rough outputs could be got from the simulations of disposal points.

Regarding inputs of CORMIX, at first, slope input is limited to represent the bottom slope as either a one – slope or two – slope profile. Therefore, detailed bathymetric data cannot be input to the system. Effect of accumulation and bathymetry is not added to the simulation assumptions and this results in smooth transportation on the sea bed which is not realistic. Secondly, current pattern of the Gulf of Izmir more complex than a one – direction current regime. More than one layer of currents or multi directional current pattern will conclude with more accurate simulation results. Symmetrical and less detailed outputs of simulation could be resulted by these less detailed inputs.

As a result, CORMIX is a succesful software in near field dispersion and sediment transport simulation studies, but it is a rough approach considering far field simulations due to lack of detailed input values on bathymetry and current pattern. If simulation results are accepted as reliable outputs, dispersion and upstream intrusion is too high and additional precautions are needed.

CHAPTER 6

CONCLUSION

The aim of this study was to contribute to understanding sediment transport due to dredge disposal processes and simulate the operation of open water disposal. For this purpose, a case study in the Gulf of Izmir is conducted by modeling a certain continuous dredge disposal. Steps of these modeling study are;

- deciding the disposal points,
- determining environmental conditions, outfall configuration and sediment description according to Environmental Impact Assesment Report on the Gulf of Izmir, CORMIX Manual or using the general Coastal Engineering knowledge,
- Simulating the continuous dredge disposal on D – CORMIX,
- using output files of the simulation, generating graphs on Corplot and CorVue.

Finally, in order to clarify the dispersion and dilution of the sediment mix, generated graphs are combined on the Natural Life Island Plot. With the application of case study simulations, it is clearly seen that, dispersion and upstream intrusion is much higher than expected value. Consequently, it is inevitible that, silt curtains should be used due to have lower dispersion.

For future studies, even though CORMIX is a well accepted modeling software, due to inefficiency on far field data, some other softwares or numerical models should be used for detailed results.

Moreover, even though general current pattern is taken into consideration in the CORMIX software, other simulations could be used to input a detailed current pattern since underwater movement and transportation of sediment is predominantly linked to current velocity. This situation should be handled with the future studies. In addition, in case of bottom deposition, more detailed bathymetric data is needed for more accurate accumulation data. Future studies may be performed on these conditions.

In conclusion, dredging and underwater excavation are important aspects in the design and construction of certain key elements of coastal infrastructures. To protect the natural life and to keep basins and canals open to navigation, open water disposal of dredged material should be carried carefully. However, due to economic necessity, the applicability and effectiveness of nature – friendly executions can be ignored. Consequently, modeling can be used as a low – cost tool to simulate the probable sediment deposition changes reflecting the bottom accumulation.

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APPENDIX A: EXAMPLE CORMIX SIMULATION OUTPUT FILE

```
D-CORMIX PREDICTION FILE:
DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD
                           D-CORMIX: CORMIX MIXING ZONE EXPERT SYSTEM
                              SEDIMENT DISCHARGE SUB-SYSTEM
                 Subsystem CORMIX1: Single Port Discharge
                                        CORMIX Version 8.0GTS
                   DHYDRO Version 5.0.0.0 April 2012
-----------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:
 Design case:
 FILE NAME:         \\v...5 - V 25 - Near 06 - Far 06 - Theta 0 - 1850h.prd
 Time stamp:        09/01/2014--01:56:52

COASTAL ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 Near and far offshore slopes:
 SLOPE1=  0.34 deg. UA1   =     0.060  F1    =      0.025 USTAR1=0.3354E-02
 YBREAK=   1020.00  ZBREAK=      6.00
 SLOPE2=  1.12 deg. UA2   =     0.060  F2    =      0.025 USTAR2=0.3354E-02
 UW    =      2.500 UWSTAR=0.2781E-02
 Uniform density environment:
 STRCND=  U         RHOAM = 1025.0000

DISCHARGE PARAMETERS (metric units) for submerged_offshore
 BANK  =  RIGHT     DISTB =   1020.00  HD    =      6.00  LEVDIS=  0
 D0    =      0.750 A0    =      0.442 H0    =      4.05  SUB0 =      1.95
 THETA =      0.00  SIGMA =      0.00
 U0    =      1.675 Q0    =      0.740       =0.7400E+00
 RHO0  = 1180.0000  DRHO0 =-.1550E+03  RHOCW =  948.9083  GP0   =-.1483E+01
 PSD   = 2650.0000
 C0    =0.1000E+03  CUNITS=  %
 IPOLL =  1         KS    =0.0000E+00  KD    =0.0000E+00

SEDIMENT DISTRIBUTION
                             Total     Chunks       Sand     C.Silt     F.Silt       Clay
Distribution %             100.000      0.000     18.600     13.900     48.100     19.400
Concentrations (kg/m^3)    360.000      0.000     66.960     50.040    173.160     69.840
Mass Fluxes (kg/s)         266.400      0.000     49.550     37.030    128.138     51.682
Settling Velocities (m/s)            0.00E+00   0.31E-01   0.42E-03   0.26E-04   0.65E-06


FLUX VARIABLES (metric units)
 Q0    =0.7400E+00  M0    =0.1240E+01  J0    =-.1097E+01  SIGNJ0=     -1.0
 Associated length scales (meters)
 LQ    =      0.66  LM    =      1.12  Lm    =     18.56  Lb    =   5080.50
                                       Lmp   =  99999.00  Lbp   =  99999.00

NON-DIMENSIONAL PARAMETERS
 FR0   =      1.59  R     =     27.92

FLOW CLASSIFICATION
 DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD
 D  Flow class (D-CORMIX)     =    IH4-0    D
 D  Applicable layer depth HS =     6.00    D
 DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    =0.1000E+03  CUNITS=  %
 NTOX  =  0
 NSTD  =  0
 REGMZ =  0
 XINT  =   1000.00  XMAX  =   1000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the SURFACE and:
    1) directly above the port center for submerged discharges, OR
    2) at the point of entry into the water for above surface discharges:
      1020.00 m  from the RIGHT bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP =100 display intervals per module
-----------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------
BEGIN MOD101: DISCHARGE MODULE

       X        Y        Z        S        C        B        Uc        TT
      0.00     0.00   -1.95     1.0 0.100E+03   0.38    1.615   .00000E+00

END OF MOD101: DISCHARGE MODULE
-----------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION

 Jet/plume transition motion in weak crossflow.

 Zone of flow establishment:            THETAE=      0.00  SIGMAE=      0.00
  LE    =      1.85  XE    =      1.85  YE    =      0.00  ZE    =     -1.95
```

```
Profile definitions:
  B = Gaussian 1/e (37%) half-width, normal to trajectory
  S = hydrodynamic centerline dilution
  C = centerline concentration (includes reaction effects, if any)
 Uc = Local centerline excess velocity (above ambient)
 TT = Cumulative travel time

      X         Y        Z         S        C         B        Uc         TT
     0.00      0.00    -1.95      1.0 0.100E+03    0.38     1.615   .00000E+00
     1.85      0.00    -1.95      1.0 0.100E+03    0.38     1.615   .95402E-02
 Maximum jet height has been reached.
     1.89      0.00    -1.95      1.0 0.100E+03    0.38     1.615   .28774E-01
     1.94      0.00    -1.95      1.0 0.100E+03    0.39     1.615   .48186E-01
     1.98      0.00    -1.96      1.0 0.100E+03    0.39     1.615   .67747E-01
     2.02      0.00    -1.96      1.0 0.100E+03    0.39     1.615   .87423E-01
     2.07      0.00    -1.97      1.0 0.100E+03    0.40     1.615   .10718E+00
     2.11      0.00    -1.98      1.0 0.100E+03    0.40     1.615   .12700E+00
     2.15      0.00    -1.99      1.0 0.100E+03    0.40     1.615   .14684E+00
     2.19      0.00    -2.00      1.0 0.100E+03    0.41     1.615   .16669E+00
     2.24      0.00    -2.02      1.0 0.100E+03    0.41     1.615   .18651E+00
     2.28      0.00    -2.03      1.0 0.100E+03    0.41     1.615   .20628E+00
     2.32      0.00    -2.05      1.0 0.100E+03    0.41     1.615   .22599E+00
     2.36      0.00    -2.07      1.0 0.100E+03    0.41     1.615   .24562E+00
     2.40      0.00    -2.09      1.0 0.996E+02    0.42     1.615   .26516E+00
     2.43      0.00    -2.11      1.0 0.983E+02    0.42     1.615   .28460E+00
     2.47      0.00    -2.13      1.0 0.970E+02    0.42     1.615   .30393E+00
     2.51      0.00    -2.15      1.0 0.957E+02    0.42     1.615   .32313E+00
     2.55      0.00    -2.18      1.1 0.944E+02    0.42     1.615   .34222E+00
     2.58      0.00    -2.20      1.1 0.932E+02    0.43     1.615   .36118E+00
     2.62      0.00    -2.23      1.1 0.919E+02    0.43     1.615   .38002E+00
     2.65      0.00    -2.26      1.1 0.907E+02    0.43     1.615   .39873E+00
     2.69      0.00    -2.29      1.1 0.895E+02    0.43     1.615   .41732E+00
     2.72      0.00    -2.31      1.1 0.883E+02    0.43     1.615   .43578E+00
     2.75      0.00    -2.34      1.1 0.871E+02    0.43     1.615   .45413E+00
     2.78      0.00    -2.37      1.2 0.859E+02    0.44     1.615   .47235E+00
     2.81      0.00    -2.40      1.2 0.848E+02    0.44     1.615   .49046E+00
     2.85      0.00    -2.43      1.2 0.836E+02    0.44     1.615   .50846E+00
     2.88      0.00    -2.47      1.2 0.825E+02    0.44     1.615   .52636E+00
     2.91      0.00    -2.50      1.2 0.814E+02    0.44     1.615   .54415E+00
     2.93      0.00    -2.53      1.2 0.802E+02    0.44     1.615   .56185E+00
     2.96      0.00    -2.56      1.3 0.792E+02    0.45     1.615   .57945E+00
     2.99      0.00    -2.60      1.3 0.781E+02    0.45     1.615   .59696E+00
     3.02      0.00    -2.63      1.3 0.770E+02    0.45     1.615   .61438E+00
     3.05      0.00    -2.67      1.3 0.760E+02    0.45     1.615   .63173E+00
     3.07      0.00    -2.70      1.3 0.749E+02    0.46     1.615   .64900E+00
     3.10      0.00    -2.73      1.4 0.739E+02    0.46     1.615   .66619E+00
     3.13      0.00    -2.77      1.4 0.729E+02    0.46     1.615   .68332E+00
     3.15      0.00    -2.81      1.4 0.719E+02    0.46     1.615   .70038E+00
     3.18      0.00    -2.84      1.4 0.710E+02    0.47     1.615   .71738E+00
     3.20      0.00    -2.88      1.4 0.700E+02    0.47     1.615   .73432E+00
     3.23      0.00    -2.91      1.4 0.691E+02    0.47     1.615   .75121E+00
     3.25      0.00    -2.95      1.5 0.681E+02    0.47     1.615   .76805E+00
     3.27      0.00    -2.99      1.5 0.672E+02    0.48     1.615   .78484E+00
     3.30      0.00    -3.02      1.5 0.663E+02    0.48     1.615   .80159E+00
     3.32      0.00    -3.06      1.5 0.654E+02    0.48     1.615   .81829E+00
     3.34      0.00    -3.10      1.5 0.646E+02    0.48     1.615   .83496E+00
     3.36      0.00    -3.14      1.6 0.637E+02    0.49     1.615   .85159E+00
     3.39      0.00    -3.18      1.6 0.629E+02    0.49     1.615   .86819E+00
     3.41      0.00    -3.21      1.6 0.620E+02    0.49     1.615   .88475E+00
     3.43      0.00    -3.25      1.6 0.612E+02    0.50     1.615   .90129E+00
     3.45      0.00    -3.29      1.7 0.604E+02    0.50     1.615   .91781E+00
     3.47      0.00    -3.33      1.7 0.596E+02    0.50     1.615   .93430E+00
     3.49      0.00    -3.37      1.7 0.588E+02    0.50     1.615   .95077E+00
     3.51      0.00    -3.41      1.7 0.581E+02    0.51     1.615   .96722E+00
     3.53      0.00    -3.44      1.7 0.573E+02    0.51     1.615   .98365E+00
     3.55      0.00    -3.48      1.8 0.566E+02    0.51     1.615   .10001E+01
     3.57      0.00    -3.52      1.8 0.558E+02    0.52     1.615   .10165E+01
     3.59      0.00    -3.56      1.8 0.551E+02    0.52     1.615   .10329E+01
     3.61      0.00    -3.60      1.8 0.544E+02    0.52     1.615   .10493E+01
     3.63      0.00    -3.64      1.9 0.537E+02    0.53     1.615   .10656E+01
     3.65      0.00    -3.68      1.9 0.531E+02    0.53     1.615   .10820E+01
     3.67      0.00    -3.72      1.9 0.524E+02    0.53     1.615   .10984E+01
     3.68      0.00    -3.76      1.9 0.517E+02    0.54     1.615   .11147E+01
     3.70      0.00    -3.80      2.0 0.511E+02    0.54     1.615   .11311E+01
     3.72      0.00    -3.84      2.0 0.505E+02    0.54     1.615   .11474E+01
     3.74      0.00    -3.88      2.0 0.498E+02    0.55     1.615   .11638E+01
     3.76      0.00    -3.92      2.0 0.492E+02    0.55     1.615   .11801E+01
     3.77      0.00    -3.96      2.1 0.486E+02    0.55     1.615   .11965E+01
     3.79      0.00    -4.00      2.1 0.480E+02    0.56     1.615   .12128E+01
     3.81      0.00    -4.04      2.1 0.474E+02    0.56     1.615   .12292E+01
     3.82      0.00    -4.08      2.1 0.469E+02    0.56     1.615   .12456E+01
     3.84      0.00    -4.12      2.2 0.463E+02    0.57     1.615   .12619E+01
     3.86      0.00    -4.16      2.2 0.457E+02    0.57     1.615   .12783E+01
     3.87      0.00    -4.20      2.2 0.452E+02    0.58     1.615   .12947E+01
     3.89      0.00    -4.24      2.2 0.447E+02    0.58     1.615   .13111E+01
     3.90      0.00    -4.29      2.3 0.441E+02    0.58     1.615   .13275E+01
     3.92      0.00    -4.33      2.3 0.436E+02    0.59     1.615   .13439E+01
     3.94      0.00    -4.37      2.3 0.431E+02    0.59     1.615   .13603E+01
     3.95      0.00    -4.41      2.3 0.426E+02    0.59     1.615   .13768E+01
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3.97	0.00	-4.45	2.4	0.421E+02	0.60	1.615	.13932E+01
3.98	0.00	-4.49	2.4	0.416E+02	0.60	1.615	.14097E+01
4.00	0.00	-4.53	2.4	0.412E+02	0.61	1.615	.14261E+01
4.01	0.00	-4.57	2.5	0.407E+02	0.61	1.615	.14426E+01
4.03	0.00	-4.61	2.5	0.402E+02	0.61	1.615	.14591E+01
4.04	0.00	-4.65	2.5	0.398E+02	0.62	1.615	.14756E+01
4.06	0.00	-4.70	2.5	0.393E+02	0.62	1.615	.14922E+01
4.07	0.00	-4.74	2.6	0.389E+02	0.62	1.615	.15087E+01
4.08	0.00	-4.78	2.6	0.385E+02	0.63	1.615	.15253E+01
4.10	0.00	-4.82	2.6	0.380E+02	0.63	1.615	.15418E+01
4.11	0.00	-4.86	2.7	0.376E+02	0.64	1.615	.15584E+01
4.13	0.00	-4.90	2.7	0.372E+02	0.64	1.615	.15750E+01
4.14	0.00	-4.95	2.7	0.368E+02	0.64	1.615	.15917E+01
4.15	0.00	-4.99	2.7	0.364E+02	0.65	1.615	.16083E+01
4.17	0.00	-5.03	2.8	0.360E+02	0.65	1.615	.16250E+01
4.18	0.00	-5.07	2.8	0.356E+02	0.66	1.615	.16416E+01
4.19	0.00	-5.11	2.8	0.352E+02	0.66	1.615	.16583E+01
4.21	0.00	-5.15	2.9	0.349E+02	0.66	1.615	.16750E+01
4.22	0.00	-5.20	2.9	0.345E+02	0.67	1.615	.16918E+01
4.23	0.00	-5.24	2.9	0.341E+02	0.67	1.615	.17085E+01
4.25	0.00	-5.28	3.0	0.338E+02	0.68	1.615	.17253E+01
4.26	0.00	-5.32	3.0	0.336E+02	0.68	1.615	.17337E+01

Cumulative travel time = 1.7337 sec (0.00 hrs)

END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION

BEGIN MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING

Vertical angle of layer/boundary impingement = -72.92 deg
Horizontal angle of layer/boundary impingement = 0.00 deg

UPSTREAM INTRUSION PROPERTIES:
- Upstream intrusion length = 974.47 m
- X-position of upstream stagnation point = -970.21 m
- Thickness in intrusion region = 0.03 m
- Half-width at downstream end = 959.28 m
- Thickness at downstream end = 0.07 m

In this case, the upstream INTRUSION IS VERY LARGE, exceeding 10 times the local water depth.
This may be caused by a very small ambient velocity, perhaps in combination with large discharge buoyancy.
If the ambient conditions are strongly transient (e.g. tidal), then the CORMIX steady-state predictions of upstream intrusion are probably unrealistic.
The plume predictions prior to boundary impingement will be acceptable, however.

Control volume inflow:

X	Y	Z	S	C	B	TT
4.26	0.00	-5.32	3.0	0.336E+02	0.68	.17337E+01

Profile definitions:
- BV = top-hat thickness, measured vertically
- BH = top-hat half-width, measured horizontally in Y-direction
- ZU = upper plume boundary (Z-coordinate)
- ZL = lower plume boundary (Z-coordinate)
- S = hydrodynamic average (bulk) dilution
- C = average (bulk) concentration (includes reaction effects, if any)
- TT = Cumulative travel time

X	Y	Z	S	C	BV	BH	ZU	ZL	TT
-970.21	0.00	-6.00	9999.9	0.000E+00	0.00	0.00	-6.00	-6.00	.17337E+01
-941.13	0.00	-6.00	13.7	0.727E+01	0.01	135.66	-5.99	-6.00	.17337E+01
-798.63	0.00	-6.00	5.7	0.176E+02	0.01	329.52	-5.98	-6.00	.17337E+01
-656.12	0.00	-6.00	4.3	0.234E+02	0.02	445.83	-5.98	-6.00	.17337E+01
-513.62	0.00	-6.00	3.6	0.275E+02	0.02	537.54	-5.98	-6.00	.17337E+01
-371.12	0.00	-6.00	3.3	0.305E+02	0.02	615.74	-5.97	-6.00	.17337E+01
-228.61	0.00	-6.00	3.1	0.324E+02	0.03	685.06	-5.97	-6.00	.17337E+01
-86.11	0.00	-6.00	3.0	0.334E+02	0.03	747.99	-5.97	-6.00	.17337E+01
56.39	0.00	-6.00	3.4	0.298E+02	0.03	806.02	-5.97	-6.00	.86751E+03
198.89	0.00	-6.00	6.9	0.144E+02	0.05	860.15	-5.95	-6.00	.32436E+04
341.40	0.00	-6.00	10.1	0.994E+01	0.07	911.06	-5.93	-6.00	.56197E+04
483.90	0.00	-6.00	11.1	0.905E+01	0.07	959.28	-5.93	-6.00	.79957E+04

Cumulative travel time = 7995.7427 sec (2.22 hrs)

END OF MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING

** End of NEAR-FIELD REGION (NFR) **

BEGIN MOD310: BOTTOM DENSITY CURRENT

Profile definitions:
- BV = top-hat thickness, measured vertically
- BH = top-hat half-width, measured horizontally in Y-direction
- ZU = upper plume boundary (Z-coordinate)
- ZL = lower plume boundary (Z-coordinate)
- S = hydrodynamic average (bulk) dilution

C = average (bulk) concentration (includes reaction effects, if any)
TT = Cumulative travel time

X	Y	Z	S	C	BV	BH	ZU	ZL	TT
483.90	0.00	-6.00	11.1	0.905E+01	0.07	959.28	-5.93	-6.00	.79957E+04
483.91	0.00	-6.00	11.1	0.905E+01	0.03	959.28	-5.97	-6.00	.79958E+04
483.91	0.00	-6.00	11.1	0.905E+01	0.03	959.28	-5.97	-6.00	.79958E+04

Cumulative travel time =   7995.8174 sec (2.22 hrs)

END OF MOD310: BOTTOM DENSITY CURRENT

Buoyancy reversal in density current formation in uniform ambient.
COMPLEX far-field flow behavior. SIMULATION STOPS.

PLUME SUSPENDED SEDIMENT DISTRIBUTION:

CENTERLINE (m)		DENSITY			SEDIMENT CONCENTRATIONS (kg/m^3)			
X	Y	(kg/m^3)	Total	Chunks	Sand	C.Silt	F.Silt	Clay
0.00	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
1.85	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
1.89	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
1.94	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
1.98	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
2.02	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
2.07	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
2.11	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
2.15	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
2.19	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
2.24	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
2.28	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
2.32	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
2.36	0.00	1180.00	360.00	0.00	66.96	50.04	173.16	69.84
2.40	0.00	1179.06	358.54	0.00	66.69	49.84	172.46	69.56
2.43	0.00	1176.04	353.83	0.00	65.81	49.18	170.19	68.64
2.47	0.00	1173.05	349.17	0.00	64.94	48.53	167.95	67.74
2.51	0.00	1170.08	344.55	0.00	64.09	47.89	165.73	66.84
2.55	0.00	1167.15	339.98	0.00	63.24	47.26	163.53	65.96
2.58	0.00	1164.24	335.45	0.00	62.39	46.63	161.35	65.08
2.62	0.00	1161.36	330.97	0.00	61.56	46.00	159.20	64.21
2.65	0.00	1158.52	326.54	0.00	60.74	45.39	157.06	63.35
2.69	0.00	1155.71	322.15	0.00	59.92	44.78	154.96	62.50
2.72	0.00	1152.92	317.82	0.00	59.11	44.18	152.87	61.66
2.75	0.00	1150.17	313.53	0.00	58.32	43.58	150.81	60.83
2.78	0.00	1147.45	309.30	0.00	57.53	42.99	148.77	60.00
2.81	0.00	1144.77	305.11	0.00	56.75	42.41	146.76	59.19
2.85	0.00	1142.11	300.98	0.00	55.98	41.84	144.77	58.39
2.88	0.00	1139.49	296.89	0.00	55.22	41.27	142.81	57.60
2.91	0.00	1136.90	292.86	0.00	54.47	40.71	140.87	56.82
2.93	0.00	1134.35	288.89	0.00	53.73	40.16	138.95	56.04
2.96	0.00	1131.83	284.96	0.00	53.00	39.61	137.07	55.28
2.99	0.00	1129.34	281.09	0.00	52.28	39.07	135.20	54.53
3.02	0.00	1126.89	277.27	0.00	51.57	38.54	133.37	53.79
3.05	0.00	1124.47	273.50	0.00	50.87	38.02	131.55	53.06
3.07	0.00	1122.09	269.79	0.00	50.18	37.50	129.77	52.34
3.10	0.00	1119.74	266.13	0.00	49.50	36.99	128.01	51.63
3.13	0.00	1117.42	262.52	0.00	48.83	36.49	126.27	50.93
3.15	0.00	1115.14	258.96	0.00	48.17	36.00	124.56	50.24
3.18	0.00	1112.89	255.46	0.00	47.52	35.51	122.88	49.56
3.20	0.00	1110.68	252.01	0.00	46.87	35.03	121.22	48.89
3.23	0.00	1108.50	248.62	0.00	46.24	34.56	119.58	48.23
3.25	0.00	1106.35	245.27	0.00	45.62	34.09	117.98	47.58
3.27	0.00	1104.24	241.98	0.00	45.01	33.63	116.39	46.94
3.30	0.00	1102.16	238.74	0.00	44.40	33.18	114.83	46.31
3.32	0.00	1100.11	235.54	0.00	43.81	32.74	113.30	45.70
3.34	0.00	1098.09	232.40	0.00	43.23	32.30	111.79	45.09
3.36	0.00	1096.11	229.31	0.00	42.65	31.87	110.30	44.49
3.39	0.00	1094.16	226.27	0.00	42.09	31.45	108.84	43.90
3.41	0.00	1092.24	223.28	0.00	41.53	31.04	107.40	43.32
3.43	0.00	1090.35	220.34	0.00	40.98	30.63	105.98	42.75
3.45	0.00	1088.49	217.44	0.00	40.44	30.22	104.59	42.18
3.47	0.00	1086.66	214.60	0.00	39.92	29.83	103.22	41.63
3.49	0.00	1084.87	211.80	0.00	39.39	29.44	101.87	41.09
3.51	0.00	1083.10	209.04	0.00	38.88	29.06	100.55	40.55
3.53	0.00	1081.36	206.34	0.00	38.38	28.68	99.25	40.03
3.55	0.00	1079.65	203.67	0.00	37.88	28.31	97.97	39.51
3.57	0.00	1077.97	201.05	0.00	37.40	27.95	96.71	39.00
3.59	0.00	1076.32	198.48	0.00	36.92	27.59	95.47	38.50
3.61	0.00	1074.69	195.95	0.00	36.45	27.24	94.25	38.01
3.63	0.00	1073.09	193.46	0.00	35.98	26.89	93.05	37.53
3.65	0.00	1071.52	191.01	0.00	35.53	26.55	91.88	37.06
3.67	0.00	1069.98	188.60	0.00	35.08	26.22	90.72	36.59
3.68	0.00	1068.46	186.24	0.00	34.64	25.89	89.58	36.13
3.70	0.00	1066.97	183.91	0.00	34.21	25.56	88.46	35.68
3.72	0.00	1065.50	181.63	0.00	33.78	25.25	87.36	35.24
3.74	0.00	1064.06	179.38	0.00	33.36	24.93	86.28	34.80
3.76	0.00	1062.64	177.17	0.00	32.95	24.63	85.22	34.37
3.77	0.00	1061.24	175.00	0.00	32.55	24.32	84.17	33.95
3.79	0.00	1059.87	172.86	0.00	32.15	24.03	83.15	33.53

3.81	0.00	1058.52	170.76	0.00	31.76	23.74	82.14	33.13
3.82	0.00	1057.20	168.70	0.00	31.38	23.45	81.14	32.73
3.84	0.00	1055.89	166.67	0.00	31.00	23.17	80.17	32.33
3.86	0.00	1054.61	164.67	0.00	30.63	22.89	79.21	31.95
3.87	0.00	1053.35	162.71	0.00	30.26	22.62	78.26	31.57
3.89	0.00	1052.12	160.78	0.00	29.90	22.35	77.33	31.19
3.90	0.00	1050.90	158.88	0.00	29.55	22.08	76.42	30.82
3.92	0.00	1049.70	157.02	0.00	29.20	21.83	75.52	30.46
3.94	0.00	1048.52	155.18	0.00	28.86	21.57	74.64	30.11
3.95	0.00	1047.36	153.38	0.00	28.53	21.32	73.77	29.76
3.97	0.00	1046.23	151.60	0.00	28.20	21.07	72.92	29.41
3.98	0.00	1045.11	149.86	0.00	27.87	20.83	72.08	29.07
4.00	0.00	1044.01	148.14	0.00	27.55	20.59	71.26	28.74
4.01	0.00	1042.92	146.46	0.00	27.24	20.36	70.45	28.41
4.03	0.00	1041.86	144.80	0.00	26.93	20.13	69.65	28.09
4.04	0.00	1040.81	143.16	0.00	26.63	19.90	68.86	27.77
4.06	0.00	1039.78	141.56	0.00	26.33	19.68	68.09	27.46
4.07	0.00	1038.76	139.98	0.00	26.04	19.46	67.33	27.16
4.08	0.00	1037.77	138.43	0.00	25.75	19.24	66.58	26.85
4.10	0.00	1036.79	136.90	0.00	25.46	19.03	65.85	26.56
4.11	0.00	1035.82	135.39	0.00	25.18	18.82	65.12	26.27
4.13	0.00	1034.87	133.91	0.00	24.91	18.61	64.41	25.98
4.14	0.00	1033.94	132.46	0.00	24.64	18.41	63.71	25.70
4.15	0.00	1033.02	131.02	0.00	24.37	18.21	63.02	25.42
4.17	0.00	1032.11	129.61	0.00	24.11	18.02	62.34	25.15
4.18	0.00	1031.22	128.23	0.00	23.85	17.82	61.68	24.88
4.19	0.00	1030.34	126.86	0.00	23.60	17.63	61.02	24.61
4.21	0.00	1029.48	125.52	0.00	23.35	17.45	60.37	24.35
4.22	0.00	1028.63	124.19	0.00	23.10	17.26	59.74	24.09
4.23	0.00	1027.80	122.89	0.00	22.86	17.08	59.11	23.84
4.25	0.00	1026.97	121.61	0.00	22.62	16.90	58.49	23.59
4.26	0.00	1026.57	120.98	0.00	22.50	16.82	58.19	23.47
56.39	0.00	951.91	4.68	0.00	0.00	0.00	0.01	4.67
198.89	0.00	950.31	2.18	0.00	0.00	0.00	0.00	2.18
341.40	0.00	949.85	1.47	0.00	0.00	0.00	0.00	1.47
483.90	0.00	949.75	1.31	0.00	0.00	0.00	0.00	1.31
483.91	0.00	955.87	1.31	0.00	0.00	0.00	0.00	1.31
483.91	0.00	955.87	1.31	0.00	0.00	0.00	0.00	1.31

CENTERLINE (m)		SEDIMENT MASS FLUXES REMAINING (%)					
X	Y	Total	Chunks	Sand	C.Silt	F.Silt	Clay
0.00	0.00	100.00	0.00	100.00	100.00	100.00	100.00
1.85	0.00	100.00	0.00	100.00	100.00	100.00	100.00
1.89	0.00	100.00	0.00	100.00	100.00	100.00	100.00
1.94	0.00	100.00	0.00	100.00	100.00	100.00	100.00
1.98	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.02	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.07	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.11	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.15	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.19	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.24	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.28	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.32	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.36	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.40	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.43	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.47	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.51	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.55	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.58	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.62	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.65	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.69	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.72	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.75	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.78	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.81	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.85	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.88	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.91	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.93	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.96	0.00	100.00	0.00	100.00	100.00	100.00	100.00
2.99	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.02	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.05	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.07	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.10	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.13	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.15	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.18	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.20	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.23	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.25	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.27	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.30	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.32	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.34	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.36	0.00	100.00	0.00	100.00	100.00	100.00	100.00

3.39	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.41	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.43	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.45	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.47	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.49	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.51	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.53	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.55	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.57	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.59	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.61	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.63	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.65	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.67	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.68	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.70	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.72	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.74	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.76	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.77	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.79	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.81	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.82	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.84	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.86	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.87	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.89	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.90	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.92	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.94	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.95	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.97	0.00	100.00	0.00	100.00	100.00	100.00	100.00
3.98	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.00	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.01	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.03	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.04	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.06	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.07	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.08	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.10	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.11	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.13	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.14	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.15	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.17	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.18	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.19	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.21	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.22	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.23	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.25	0.00	100.00	0.00	100.00	100.00	100.00	100.00
4.26	0.00	100.00	0.00	100.00	100.00	100.00	100.00
56.39	0.00	4.35	0.00	0.00	0.00	0.01	22.41
198.89	0.00	4.21	0.00	0.00	0.00	0.00	21.70
341.40	0.00	4.11	0.00	0.00	0.00	0.00	21.19
483.90	0.00	4.02	0.00	0.00	0.00	0.00	20.73
483.91	0.00	4.02	0.00	0.00	0.00	0.00	20.73
483.91	0.00	4.02	0.00	0.00	0.00	0.00	20.73

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D-CORMIX      End of Prediction File
DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD
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