# NUMERICAL MODEL STUDIES FOR THE DISPERSION OF DREDGED MATERIAL IN OFFSHORE AREA

**A DISSERTATION**
*Submitted in partial fulfillment of the*
*requirements for the award of the degree*
*of*
**MASTER OF TECHNOLOGY**
**in**
**WATER RESOURCES DEVELOPMENT**
**(CIVIL)**

By

**VIKAS KUMAR SHUKLA**

**DEPARTMENT OF WATER RESOURCES DEVELOPMENT & MANAGEMENT**
**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**
**ROORKEE -247 667 (INDIA)**
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# CANDIDATE'S DECLARATION

I hereby certify that work which is being presented in the dissertation entitled "**NUMERICAL MODEL STUDIES FOR THE DISPERSION OF DREDGED MATERIAL IN OFFSHORE AREA**" is in partial fulfilment of the requirement for the award of the degree of master of technology and submitted to the Department of Water Resources Development and Management (WRD&M), Indian Institute of Technology, Roorkee. This is an authentic record of my own work carried out at CW&PRS, Pune, during the period from July, 2008 to November, 2009 under the supervision and guidance of Dr. Nayan Sharma, Professor, WRD&M, IIT, Roorkee and Shri T. Nagendra, Chief Research Officer, CW&PRS, Pune.

The matter presented in this dissertation has not been submitted by me for the award of any other degree.

Dated :- 16 November, 2009
WRD&M, IIT Roorkee

[Vikas Kumar Shukla]
Enrolment No: 076018

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## CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Dr. Nayan Sharma)
Professor
WRD&M, IITR,
Roorkee - 247667
India.

(Shri T. Nagendra)
Chief Research Officer,
CW&PRS,
Pune – 411 024.
India.

Phones : (020) 24103414
E-mail : wapis@mah.nic.in

Fax : 091-020-24381004
Website : www.mah.nic.in/cwprs
Telex : 0145-7390

केंद्रीय जल और विद्युत अनुसंधान शाला
**Central Water & Power Research Station**
भारत सरकार
**Government of India**
जल संसाधन मंत्रालय
**Ministry of Water Resources**
खडकवासला पुणे ४११ ०२४ भारत
**Khadakwasla , Pune – 411 024, India**

## CERTIFICATE

Certified that the dissertation titled "**NUMERICAL MODEL STUDIES FOR THE DISPERSION OF DREDGED MATERIAL IN OFFSHORE AREA**", which is being submitted by Shri Vikas Kumar Shukla in partial fulfillment of the requirements for the award of Degree of Master of Technology in Department of Water Resources Development and Management (WRD&M), Indian Institute of Technology, Roorkee, is a record of student's own work carried out by him at CW&PRS, Pune, under my supervision and guidance. The matter included in this dissertation has not been submitted for the award of any other Degree.

(Shri T. Nagendra)
Chief Research Officer,
CW&PRS,
Pune – 411 024.
India.

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Place: WRD&M, IIT Roorkee
Date : 16 November, 2009

[Vikas Kumar Shukla]
Enrolment No. 076018

# LIST OF SYMBOLS

| | |
|---|---|
| $x,y$ | co-ordinate directions |
| $E_c$ | Eddy viscosity coefficient |
| $\alpha$ | coefficient ($m/N^{1/2}$) |
| $c$ | compound concentration |
| $R$ | rate of mass production or loss (decay) |
| $\overline{u_i'c'}$ | time-averaged turbulent mass transport into direction $x_i$ |
| $\rho_0$ | bulk density |
| $\rho_s$ | particle density |
| $u_i'$ | velocity fluctuation |
| $c'$ | concentration fluctuation |
| $p$ | pressure |
| $K_j$ | unit vector in the direction of g |
| $\nu$ | kinematic molecular viscosity |
| $\rho\overline{u_i'u_j'}$ | time-averaged turbulent eddy transport of momentum |
| $d_{50}$ | mean diameter of bed layer |
| $\vec{V}$ | ($V_x$,$V_y$) - components of depth-averaged flow velocities |
| $s$ | relative density of bed layer material |
| $z_b$ | bed level |
| $K_{sx}$, $K_{sy}$ | dispersion coefficients in x, y directions |
| $t$ | time |
| $\varepsilon$ | diffusion coefficient |
| $d$ | water depth |
| $u_*$ | shear velocity |
| $k_s$ | bed roughness |
| $Z_0$ | the bed roughness height |
| $u$ | velocity in x co-ordinate direction |
| $v$ | velocity in y co-ordinate direction |
| $z$ | surface elevation of water |
| $C_f$ | Coriolis force |
| $x,y$ | co-ordinate directions |
| $E_c$ | Eddy viscosity coefficient |

$T_{ce}$ : critical bed shear stress for erosion ($N/m^2$)

$n$ : power of erosion

$D_x$, $D_y$ : dispersion coefficients in the x ,y directions ($m^2/s$)

$F$ : linear decay coefficient ($sec^{-1}$)

$Q_s$ : source/sink discharge ($m^3/s/m^2$)

$C_s$ : concentration of compound in the source/sink discharge

$w_s$ : settling velocity of flocs (m/s)

$c_b$ : near bed concentration ($kg/m^3$)

$p_d$ : probability of deposition

$\tau_b$ : the bed shear stress ($N/m^2$)

$\tau_{cd}$ : critical bed shear stress for deposition ($N/m^2$)

$w_{s,r}$ : reference value

$w_{s,n}$ : a coefficient

$c_{gel}$ : concentration at which the flocs start to form a real self-supported matrix (referred to as the gel point)

C1, C2 : calibration parameters

$P_e$ : Peclet number

$C_{rc}$ : convective Courant number

$C_{rd}$ : diffusive Courant number

$C_b$ : near bed concentration

$\overline{D_z}$ : depth mean eddy diffusivity

$\varepsilon$ : diffusion coefficient

$z$ : vertical Cartesian coordinate

$C$ : concentration as function of z

$w$ : mean settling velocity of the sediment

$E$ : erodibility of bed ($kg/m^2/s$)

$\mathcal{E}$ : medium porosity factor

# LIST OF FIGURES

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# ABSTRACT

Modern large harbours are faced with the problems of continuous maintenance dredging for maintaining deep access channels. Maintenance dredging constitutes a major portion of the operation expenditure. The cost of maintenance dredging can be minimized by reducing the distance of the disposal ground. A balance has to be struck between the cost of transport of the dredged material and the eventual return of the disposed material to the dredged areas.

A consideration of the dredging/disposal process in even such broad philosophical terms readily points out a need for a more comprehensive understanding of the precise nature of the problems and a need to fill numerous gaps in knowledge regarding the significance of known or suspected environmental effects of dredging and spoil disposal. The problem of disposal of dredged spoil related to NMPT Port, attempted in this study and the solution outlined in this report are dedicated to these goals.

With the increasing expansion of the Port, a need was felt to have a new dumping ground for the dredged material. At present the quantity of annual maintenance dredging is about 6 million m$^3$ in New Mangalore Port. This is expected to increase with further development in the port due to increase in depth of the approach channel and the lagoon.

The radiotracer technique has been widely used to follow the movement of sediments on seabed for last four decades and helps in examining the suitability of the dumping site for dredged material. The studies will also help in selecting right alignments for new navigation channels. In INDIA, these types of studies are generally carried out with the help of Bhabha Atomic Research Centre. BARC report describes results of the two radiotracer investigations carried out at a location north of shipping channel at New Mangalore Port during two different periods i.e. pre south-west and post south west monsoon periods. The investigations were aimed at to evaluate the suitability of the disposal site during two different periods. The first investigation was carried out during October 2007- January 2008 post south-west monsoon period) whereas the second investigation was carried out during January-

April 2009 (pre south-west monsoon period) at the same location. The location map of the study areas is shown in Fig.

The same problem of disposal of dredged spoil related to NMPT Port, attempted to solve with the help of numerical model in this study and the solution obtained are very near to BARC results.

# CONTENTS

6.3 Data Analysis

# INTRODUCTION

## 1.1 GENERAL

Dredging is a process by which sediments are removed from the bottom of streams, lakes, and coastal waters, transported via ship, barge, or pipeline, and discharged (as spoil material) to land or water. The usual purposes of dredging are to maintain, improve, or extend navigable waterways, or to provide construction materials such as sand, gravel, or shell. Because of widespread concern over the wise utilization of the nation's natural resources, a wide variety of questions have arisen over the nature and significance of the environmental impact resulting from disposal of dredge material.

Much of the concern over the actual dredging process is related to the direct destruction of benthic (bottom-dwelling) organisms. Such organisms are known to play an important role in the aquatic ecosystem, and include commercially valuable species such as oysters and clams. Although the direct effects of dredging on benthic organisms may appear to be obvious, there is little information available that permits the prediction or assessment of the overall extent, significance, and duration of the effects. In addition to the direct effects of dredging operations, concern also exists over the possible indirect effects on biological communities. The potential for indirect effects on biological communities is usually attributed to physical alterations of the environment such as changes in bottom geometry and bottom substrate which trigger subsequent alterations in water velocity and current patterns, salinity gradients, and the exchange of nutrients between bottom sediments and the overlying water. Each of these physical changes can, either singly or in combination, initiate varying responses within the biological communities. As an example, a change in the saltwater gradient may be beneficial for young fish and crab transport, yet, due to the greater penetration of predators, detrimental to oysters. Within the current state of knowledge, it is not always possible to definitely assess such effects or to judge whether they are of an adverse or beneficial nature.

Most of the concern over the dredging-disposal process is directed toward the effects of open water disposal on water quality and aquatic organisms. It has long been known that, depending on individual circumstances, bottom sediments are continuously being resuspended by natural processes. Thus, under cursory examination, the open water disposal of bottom sediments may be viewed as an extension of natural processes. However, in contrast to the natural phenomenon of sediment resuspension, open water disposal often results in the resuspension of large volumes of sediments over a relatively short period of time, in a relatively small area. Further, the dredging and redeposition of certain types of polluted sediment may convert a localized problem in a noncritical location to a serious regional problem as pollutants are dispersed by currents and/or carried to critically important areas such as oyster grounds and coral reefs. The effects of open water disposal are, therefore, often similar to effects resulting from normal resuspension, but the intensity and range of the effects can be increased.

**FIG. 1: A SKETCH SHOWING DREDGING OPERATION**

One of the direct effects of open water disposal is sediment buildup, resulting in the smothering of benthic organisms, changes in spawning areas, reduced habitat diversity, changes in sediment/water chemical interchange, and reduced or changed vegetative cover. In addition, increased levels of turbidity reduce light penetration (thus altering biological productivity), decrease the availability of food, and alter the chemistry and temperature of the water. Finally, because much of the sediments in the nation's waters have become contaminated with chemical pollutants, there are grave concerns that man-induced resuspension of such sediments may increase the availability of these pollutants, thus directly affecting biological communities and, indirectly, man. Because of the poor understanding of the possible consequences of these changes and alterations, definitive research is needed to assess all aspects of the open water disposal of dredged sediments.

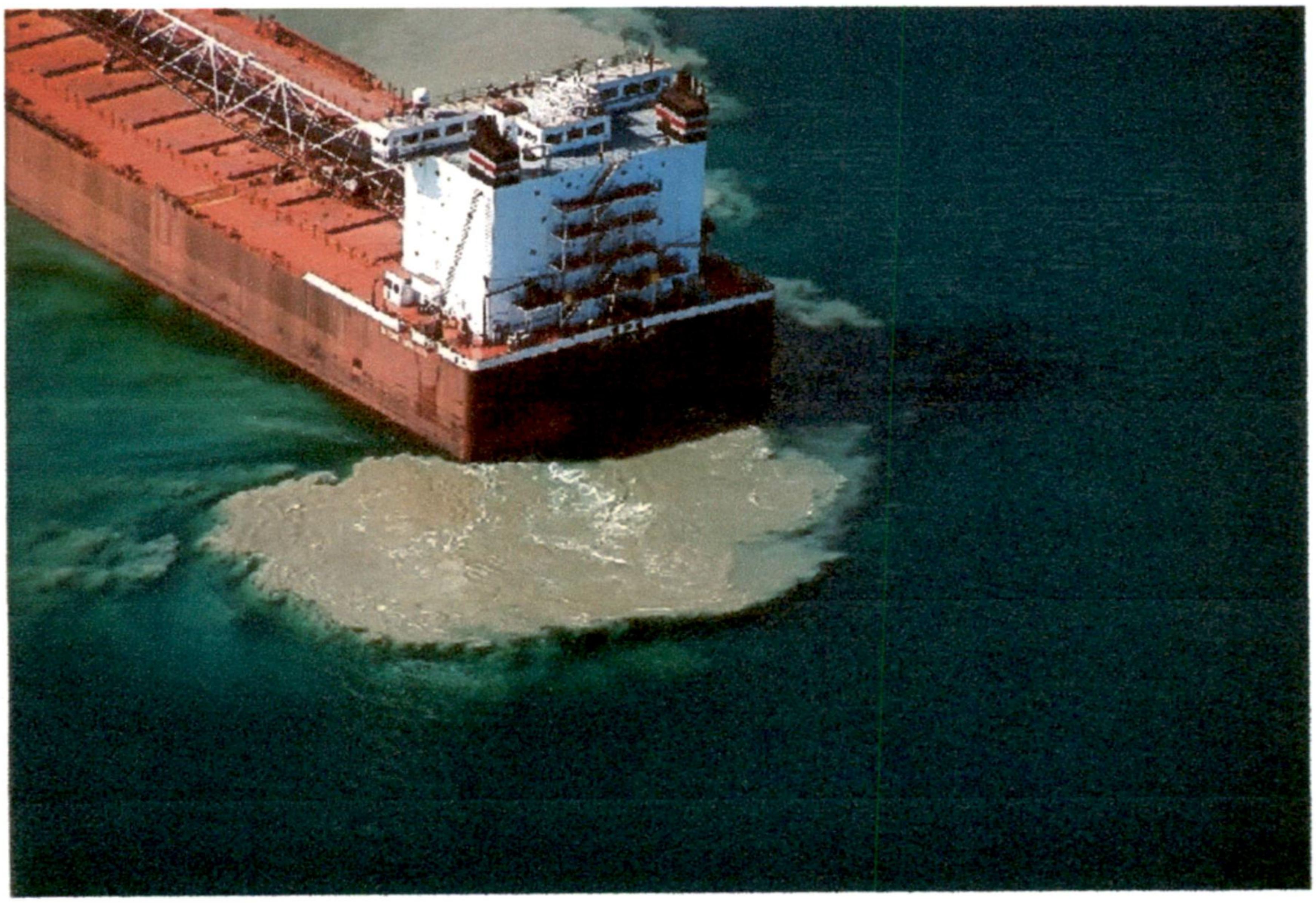


**FIG.2 PICTURE SHOWING OPEN WATER DISPOSAL OF DREDGED MATERIAL**

Primarily because of the concern over the open water disposal of polluted sediments, a trend toward land disposal has developed. Yet, without definitive research, it is not possible to determine from an overall environmental viewpoint in which cases land disposal is in fact a wise alternative to open water disposal. Land disposal often involves marshlands or other wetlands, which are among the most biologically productive areas on earth. The effects of disposal on the role of marshlands as breeding areas, nurseries, and zones of biological production are only marginally understood. In addition to the rather special case of marsh disposal, there are other environmental concerns that must be considered common to all types of land disposal. One of the more intensive concerns involves the possible pollution of groundwater reservoirs and the subsequent effects on main land disposal also alters vegetation assemblages and local relief, thereby triggering changes in drainage patterns and wildlife migration. The relocation of sediments from one biotope to another (e.g., the ocean to the coastal plain) can be an alien intrusion that concerns many ecologists. Finally, as is always the case, each of these alterations can initiate further sequences of events, not only in the terrestrial regime, but the aquatic regime as well.

A consideration of the dredging/disposal process in even such broad philosophical terms readily points out a need for a more comprehensive understanding of the precise nature of the problems and a need to fill numerous gaps in knowledge regarding the significance of known or suspected environmental effects of dredging and material disposal.

## 1.2 OBJECTIVES

The objectives of this study are as follows:

(i) Numerical model studies with the help of available software MIKE-21 for dispersion of dredged material in the offshore area of NMPT Port.

(ii) Checking the suitability of numerical model by comparing the results of numerical model with the results obtained by radioactive tracer investigations carried out by BARC at New Mangalore Port Trust, Mangalore during pre south-west and post south-west monsoon periods.

## 1.3 DISSERTATION ORGANISATION

This dissertation is organized into 7 chapters. The brief description of each chapter is as follows:

Chapter 1 Introduction

This chapter briefly gives the idea about dredging and disposal processes and also requirement of suitable disposal site and the objectives of the study.

Chapter 2 Dredging Equipments and Techniques

This chapter describes about different dredging equipments and operational techniques in brief.

Chapter 3 Disposal Techniques and Treatment Processes

This chapter briefly gives an idea about different methods of disposal, disposal techniques and various treatments required before and after disposal.

Chapter 4 Environmental impact of disposal of dredged material

In this chapter the environmental considerations of disposal of dredged material and various disposal alternatives have been discussed.

Chapter 5 Disposal-Dispersion process of dredged material

This chapter describes the physical process of disposal-dispersion of dredged material.

Chapter 6 RAT studies by BARC at NMPT.

This chapter gives the details of radioactive tracer studies conducted by BARC at NMPT.

Chapter 7 Methodology of simulating dispersion by using MIKE-21.

This chapter gives an idea about MIKE-21 software, modules related to present study and method used for simulation the required task.

Chapter 8 Results and Discussion

This chapter analyses the various results obtained by present study and also compared the same with BARC studies.

Chapter 9 Conclusions and recommendations

This chapter draws important conclusions of the dissertation and also give the recommendations for further studies on this topic.

# DREDGING EQUIPMENTS AND TECHNIQUES

## 2.1 GENERAL

The employment of new equipment and techniques may have both direct and indirect effects on the environment. Certain devices, such as barriers or shields, may limit turbidity. More efficient cutterheads may also reduce turbidity while achieving increased production. Equipment and techniques can increase solids concentration of the slurry, which affects both turbidity and production. Accurate and timely survey and positioning can reduce necessary "advance maintenance".. Specialisation of some equipment can achieve direct environmental benefit through optimum design as well as economy of construction and operation.

## 2.2 DREDGING EQUIPMENTS

**2.2.1 Impeller cutterhead** Ellicott Machine Corporation and others suggest the possibility of designing the cutterhead in such a manner that the blades act as a pump" impeller." This would be particularly applicable in soft materials and should result in greater solids concentration; thus greater output and reduced turbidity may simultaneously result.

**2.2.2 Swivel cutterhead** Also being investigated, in order to increase output and reduce turbidity, is the potential of a swivel-mounted cutterhead which will be able to cut directly into the spoil bank rather than from the side, as is now the case. Fig. 3 illustrates the concept.

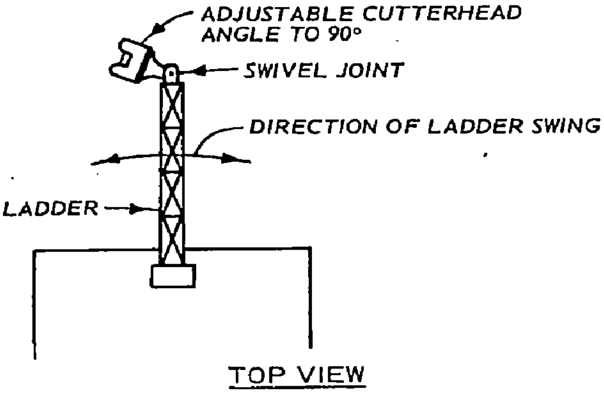


FIG. 3: SWIVEL CUTTERHEAD

**2.2.3 Automated ladder swing and depth control** This equipment is available on the world market today, although not widely used since it was only recently developed (by Europeans). Such controls tend to automate the dredging process and, in many cases, can result in less disturbance of the bottom. A "leverman" is still required.

**2.2.4 Cutterhead shields** Some aggregate dredgers use "covers': or "shields" atop their cutterheads in order to define and shape the desired flow regime required for most efficient production. This "shield" is often shaped like an inverted bowl and placed over the top of the cutterhead (fig. 4). It may be of solid material or even wire screen (for some materials).

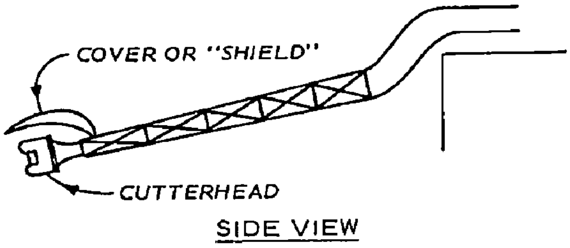


FIG. 4: CUTTERHEAD SHIELDS

**2.2.5 Mud Cat technology** "Mud Cat" is the trade name for a small dredge optimised for removing mud, silt, and aquatic plants with a minimum of turbidity. Noteworthy features include twin horizontal "Archimedean" cutting screws covered by a top shield. The "business end" of this dredge is shown in fig. 5.

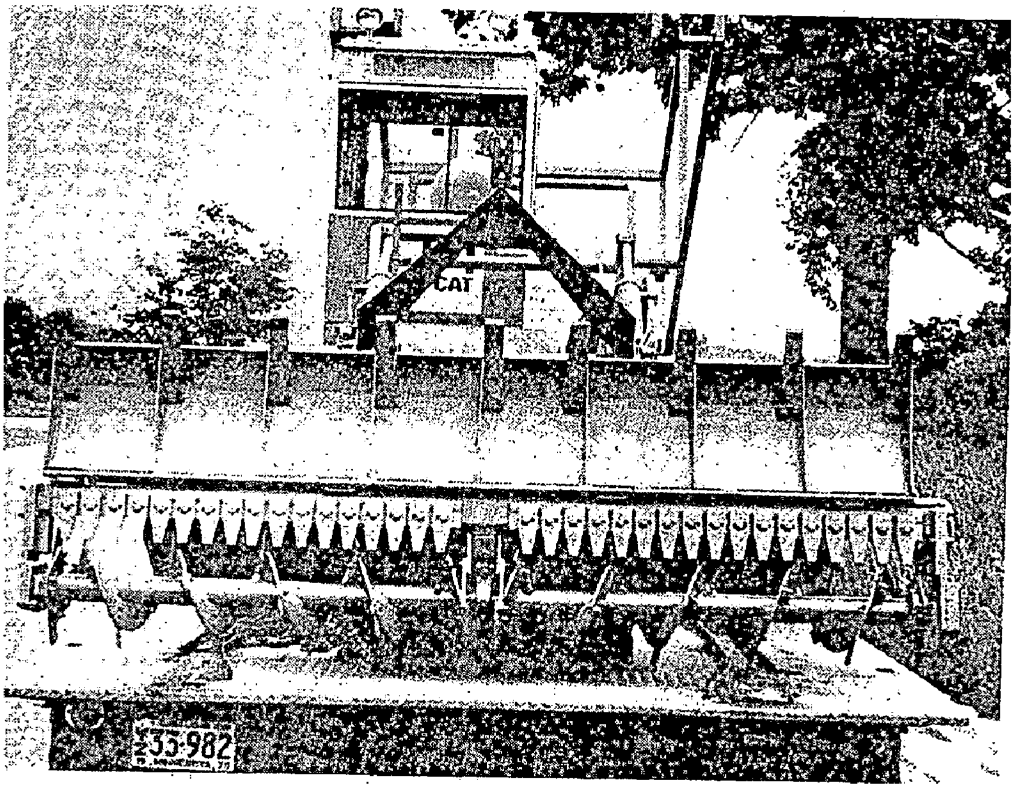


FIG. 5: MUD CAT

Extrapolation of this arrangement to a larger device may, in some cases, be advantageous in terms of reduced turbidity and improved production. It is necessary to emphasise, however, that this principle would be applicable only to work under a limited range of conditions. Hard bottoms, rough weather, types of precision work, and other circumstances could not be handled by such equipment.

**2.2.6 Pneuma** This is an air-lift type of dredge of Italian manufacture which would appear to create a minimum of turbidity. Hydraulic lines remove the material as in conventional pipeline dredging, but the initial lift is provided by compressed air. Although this type of dredge would appear to find application in a variety of general dredging tasks, operation in confined waterways from a barge or wharf looks particularly promising. Evaluation tests have been planned by OCE.

**2.2.7 Specialised dredges** Various regional situations may allow the development and use of full-time specialised dredge equipment. Mobile or self-erecting cutter head or suction pipeline equipment, such as the I.H.C. Holland design illustrated in fig. 6, also may find certain, specific applications. The ability to optimise such equipment for a given set of circumstances offers a real potential for minimizing undesirable environmental effects of the dredge and disposal operation.

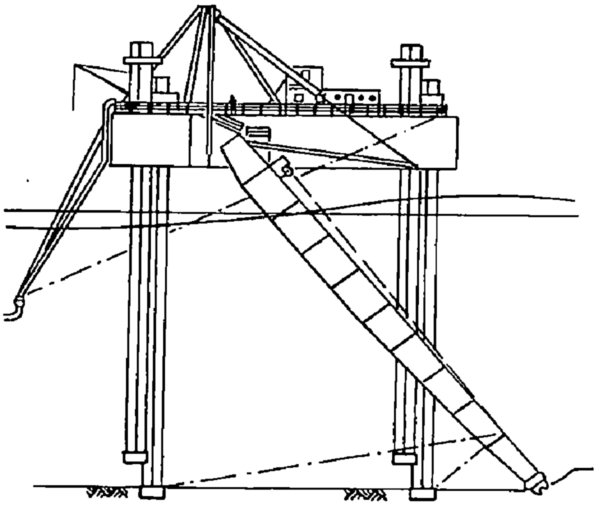


FIG. 6: I.H.C. HOLLAND "WALKING DREDGE"

**2.2.8 Clamshell closure attachment** This clamshell bucket attachment hydraulically forces the jaws of the bucket closed without requiring an upward pull as in conventional systems. This allows bigger bites and tends to disturb both load and bed material less; both production and turbidity parameters are improved over those of conventional operations.

## 2.3 NEW OPERATIONAL TECHNIQUES

**2.3.1 Chemical additives** The use of a "wetting" or friction-reducing chemical has demonstrated the ability to increase both production and solids concentration. The chemical POLYOX may, according to the manufacturer, be added before or after the dredge pump and will give perhaps 15 percent increased production and yet prevent the intake from clogging. Concentrations are nominal. It must be noted that, if any, effects the use of such chemicals has on the environment.

**2.3.2 Cutterhead operations** Elimination of the cutterhead and use of suction dredging will reduce turbidity. If it is necessary to use the cutterhead, reduced speed will also reduce turbidity. Deep cuts increase solids concentration and reduce turbidity. Elimination of the "cleanup" backsweep will also cut down on unnecessary bottom disturbances.

**2.3.3 Precision dredging** Precise and frequent surveys, use of historical data and predictive techniques, and accurate dredging and inspection can reduce the quantities of material to be dredged (to include some "advance maintenance" dredging). Along with these techniques, the criteria for good performance may have to be changed from "solids pumped" to include "accuracy of cut" in order to reflect environmental emphasis. Fortunately, the technology for this is available and in use today.

**2.3.4 Properly timed operations** Many undesirable effects can be ameliorated by timing work so as to have minimum environmental impact. Nearby oyster reefs can be protected by operating only with suitable current conditions, dredging to avoid turbidities around beaches can be scheduled out-of-season or during the night, winter dredging decreases the effect of oxygen sag and operations can be curtailed during fish and wildlife migrations.

CHAPTER – 3

# DISPOSAL TECHNIQUES AND TREATMENT PROCESSES

## 3.1 GENERAL

Disposal techniques and equipment will vary with the nature of the material, the local disposal areas available, and the hydrodynamic activity at the disposal site. Since many of the techniques will necessarily be costly and their full effects unknown, every effort should be made to differentiate between polluted and non-polluted material. Assuming that a given waterway can justify only a finite amount of money to keep it open, costly disposal methods should be reserved for highly polluted material.

Surveillance and enforcement of approved disposal practices are of paramount importance. Since the contractor can be expected to take every convenient shortcut, provision must be made to ensure that adequate standards are maintained in regard to material handling, transporting, and disposal. Additionally, criteria concerned with measuring quality of performance should supplement the "pay yards" standard now used. Use of such criteria would tend to limit overdredging while ensuring better adherence to environmentally compatible practice.

It is difficult to overemphasize the role geographical location plays in the selection of new equipment, techniques, and priorities. Technical consideration can be overriding since disposal areas, distances, local environmental factors, material types and quantities, and existing facilities are so variable; however, specialised equipment and methods should be considered the rule rather than the exception if the challenge is to be met.

## 3.2 METHODS OF DISPOSAL

The importance of our navigable waterways and harbours to the nation's economic growth dictates that large volumes of material will continue to be dredged each year.

The nation's increasing concern over the environmental impact of man's activities will result in significant controls over methods used to dredge and dispose of this spoil material.

Since few objective and definitive assessments of the environmental impact of past disposal operations are available, it is very important that significant research efforts designed to evaluate the environmental impact of current and potential disposal practices be initiated immediately so that these controls can be based on sound scientific information.

Because of the highly variable environmental situations in which dredging and dredge material disposal must be accomplished, there is no universally acceptable method for doing these tasks. Consequently, it is extremely important that there be a number of proven systems from which an appropriate dredging and material disposal method can be selected, depending upon the environmental situation involved.

A broad-based program of research is needed to develop the widest possible choice of technically satisfactory, environmentally compatible, and economically feasible disposal practices. Each disposal practice should be developed to the point where it can be demonstrated and documented as a working system.

Alternative methods designed to make the dredging and material disposal operations more environmentally compatible will in most cases result in increased direct initial costs.

Efforts aimed at reducing dredging volumes could materially help the problem of material disposal. The prudent use of structures and techniques can effectively reduce shoaling in dredged channels and/or control the location of shoaling to minimize material disposal problems.

### 3.2.1 OPEN WATER DISPOSAL

There will be constraints on the type of material which can be disposed of in open water. For the foreseeable future, the constraints will probably refer to the pollution status of the spoil material.

There are strong reservations within the scientific community over the current guidelines which rely upon the chemical composition of spoil material as the sole indicator of pollution status, and thus as the basis for deciding the acceptability of the spoil material for disposal in open water. Research is needed to develop a better understanding of the nature and magnitude of the effects on water quality and aquatic organisms due to varying methods of disposal and types of materials deposited. Constraints should be based on sound technical information with provisions for periodic review and update and for the regional variability found throughout the nation's marine and fresh waters. Because of questions regarding the pollution status of material and the desirability of knowing material composition and characteristics, there should be extensive material sampling and analysis in conjunction with the dredging activities. It is important that the sampling programs be well planned and that adequate guidelines are furnished for sampling, sample preparation, and analysis so that the results of this work will be as meaningful as possible.

Large volumes of the spoil material dredged each year are not polluted even when evaluated according to very conservative pollution criteria. This is particularly true in the riverine environment.

A ban on open water disposal of unpolluted material would not be in the nation's best interest even though it is recognised that such disposal can, in some cases, result in adverse biological effects. One reason for this conclusion is the fact that beneficial material disposal practices such as marsh creation, dredged material island development for wildlife habitat, and beach nourishment require open water disposal. A second reason is concern over confined disposal which encroaches upon estuaries through land fill operations or which takes valuable wetlands, farmland, or land needed for commercial development. Also, land disposal of unpolluted material would in most cases greatly increase direct disposal costs.

Studies to date in which attempts have been made to determine the effects of open water disposal have documented certain short-term effects. These include temporary increases in turbidity, temporary decreases in dissolved oxygen, and the smothering of benthic organisms. Additional research is needed to establish the significance of these effects under different environmental conditions. Careful project planning and supervision of the disposal operation can minimise these effects.

The possibility for detrimental long-term effects due to open water disposal exists, but attempts to document these effects have, to date, been largely inconclusive. Although such effects may be significant, they appear to be quite subtle and, therefore, hard to assess. Research in the form of laboratory studies and field pilot studies in which conditions can be controlled offers the best chance for defining cause-effect relations. However, because such effects are subtle, some monitoring of disposal operations will be necessary.

Many lines of evidence indicate that dredge material can and should be considered as a manageable resource. Numerous cases of beneficial environmental effects of dredged material and disposal operations can be documented and these have been examined from the standpoint of identifying those aspects needing research to permit more widespread application.

The regional practicality and environmental effects of beneficial open water disposal practices should be studied. Potential beneficial uses of dredged material in open water include marsh creation, dredged material island development, beach nourishment, and substrate enhancement.

Marsh creation and enhancement through regulated dredged material disposal and plant recolonisation offers outstanding potential as a new disposal practice alternative. High priority is given to research applicable to developing working systems of marsh creation.

Planned development and colonisation of dredged material islands may permit disposal of large volumes of dredged material in a manner that will produce desirable habitat for terrestrial wildlife. Existing dredged material islands have become valuable habitats for local and migratory waterfowl and other wildlife through natural colonisation.

Beach nourishment and dredged material disposal are related problems that often can and should be approached in a combined and coordinated manner. Efforts should be expanded to use as much suitable dredged material as possible for either direct or indirect beach nourishment. The exploitation of offshore sand resources for beach fill may present an opportunity for backfilling subaqueous borrow pits with undesirable dredged material.

Dredged material offers distinct possibilities for enhancing substrate conditions in open water areas. Both sport and commercial fishing have been and can be improved through selective dredged material disposal. Dredged material can also be used effectively in creating new habitats for shellfish. Dredging also has been shown to create beneficial changes such as cold weather refuge areas, new spawning grounds, and the release of nutrients.

Selection of new offshore disposal sites will require detailed evaluations of environmental conditions. Whereas historic disposal sites were selected largely on the basis of location and economics, new sites will have to be selected largely on the basis of substrate characteristics, biological communities, hydrologic conditions, and related considerations as compared with and evaluated against dredged material composition and characteristics.

Deepwater (oceanic) dredged material disposal is an attractive potential dredged material disposal alternative. However, research is essential to answer questions regarding biologic effects of pollutants in a largely unknown environment. The potential roles of submarine canyons as natural transport mechanisms should be explored from both the physical and biological aspects.

### 3.2.2 LAND DISPOSAL

There will be more land disposal of dredge material in future years. In the past, decisions concerning land disposal or open water disposal have been based primarily on economic considerations. More recently, land disposal has been recommended by many as the preferred disposal method for polluted dredge material. Until more definitive answers can be provided for questions concerning the environmental impact of open water and land disposal, it is virtually certain that the percentage of land disposal will increase.

Most of the material which will have to be disposed of on land will come from highly developed areas (harbours, estuaries) where land disposal sites will be difficult to obtain. This will require the employment of barge or pipeline systems which can be used to transport the material longer distances and/or the development of techniques which will permit the reuse of disposal areas.

At least four basic problem areas associated with land disposal can be identified. These are: the environmental impact of land disposal, problems related to obligations of local sponsors of a project, problems related to site availability, and technical problems related to design, construction, operation, and utilisation of land disposal sites.

The large majority of environmental research investigations connected with dredging operations have been directed toward the effects of open water disposal, with very few studies conducted to determine the environmental impact of land disposal. Such studies are urgently needed in order that the environmental consequences of land and open water disposal can be evaluated on a case by case basis.

Problems related to local sponsor obligations vary greatly depending upon the type of project (harbour, intercoastal waterway, etc.) and upon the original authorising legislation. These problems are primarily policy questions and would have to be addressed by appropriate legislation after an intensive study.

Site acquisition for land disposal is the principal dredged material disposal problem according to engineers. The problem is difficult nationwide due to differences in dredged material volumes, foundation conditions, material availability, land characteristics, and land use.

Evaluation of sites proposed by local sponsors for confined disposal facilities must be at least as comprehensive as that required for environmental impact statements. A reason for this is a fear that inadequate environmental considerations have resulted from the recent rush to acquire land for confined disposal. Ultimately the engineers will also have to establish site selection criteria that require consideration of regional land use planning and management.

Substantial improvements are necessary in containment area dike design and construction to prevent expensive and environmentally damaging failures. This is particularly true where they are the responsibility of the local sponsors. Contract specifications regarding dikes are frequently inadequate and could benefit from major revision. Subsurface investigations are essential to adequate dike design as is the application of existing soil mechanics principles.

The poorest quality dredged material from the engineering standpoint is being contained on land in increasing quantities and the quality will likely get worse before it gets better. Consequently, problems associated with dredged material drainage, dike stability, containment area management, and subsequent utilisation will become more acute.

It is apparent that most dredge spoils improve with time if drainage is provided, and at some point in time these materials can be used as foundation or building materials. There is a need for research on the characteristics of dredge spoil which will enable it to play a more positive role in urban and regional development projects.

Dewatering techniques must be developed to allow full utilisation of the capacity of diked containment areas and/or the reuse of such areas. Research is needed on both techniques to speed consolidation of the material in the confined area and liquid-solids separation devices that would leave the solid material in a state which would permit its removal to an inland location.

Land disposal sites should in every possible case be selected and developed so that the area can be used for some beneficial purpose (commercial development, recreation area, wildlife habitat) after it has been filled. It is recognised that accomplishment of this objective will require additional regional planning and coordination with the local groups.

There is more potential for the subsequent utilisation of landfills created with dredged material from new work projects than from maintenance dredging projects. Dredged material from maintenance projects is usually more polluted and of poorer quality from the engineering standpoint than that from new work projects and is generated at an undesirably slow rate. Advance land use planning at a more effective level will help achieve more subsequent utilisation of new work project spoil fills.

Dredged material disposal on coastal marshes is decreasing because of adverse environmental consequences and it is desirable that this practice be discontinued whenever feasible. Unconfined disposal on marshes appears to be less damaging to the environment than confined disposal.

Disposal concepts involving large inland facilities serving multiple projects appear to offer certain distinct advantages. Long-distance pipeline transport is technically and economically feasible, particularly when viewed in terms of savings resulting from eliminating separate duplicating containment facilities. Extensive effluent treatment and environmental control are more feasible and economic for larger facilities than for separate smaller ones.

Inland transport of dredged material for disposal in mines and pits might be possible in certain geographic regions. Although long-distance pipeline transport of waste slurries is feasible, mines and pits of adequate size and suitable from the environmental impact standpoint are relatively few. Greatest potential appears to exist in the Great lakes area.

Sandy soils have been substantially improved with no toxic side effects to plants by addition of dredge spoil. However, only extremely limited studies have been made and few extrapolations are possible. The potential for dredged material disposal through agricultural land enhancement is more a matter of agricultural economics than a technical one.

Efforts to make useful products such as building materials from spoil have been few and have met with mixed success. If technical problems can be overcome, production capabilities and economics as well as market potential must still be assessed.

## 3.3 DISPOSAL TECHNIQUES

**3.3.1 Pipeline dredges** These hydraulic dredges discharge either to the side of a channel (open water disposal) or into a confined or unconfined disposal area. In either case the execution and monitoring of the spoil flow are best described as indifferent. A great deal of unnecessary water is pumped into confined and unconfined areas whenever the ladder is raised.

**3.3.2 Hopper dredges and scows** Hopper dredges and scows may discharge by overflow, by bottom dump, and by pump-out. Overflow is a technique designed to increase the economic solids loading but may not necessarily be desirable (even in an economic sense). Bottom dump is a long-established technique; most disposal areas are close inshore in order to minimise turnaround time. Direct pump-out to confined disposal areas has received recent emphasis because of environmental concerns. This has required hopper dredge modification and development of pump-out scow facilities. Unfortunately, the process requires the addition of large quantities of “makeup” water in order to resuspend the thickened slurry and thereby increases disposal area site requirements. A frequent combination involves bottom dump into a rehandling basin and hydraulic pipeline removal to a confined area.

**3.3.3 Beach nourishment** Though technically a "disposal operation," in the case of beach nourishment the dredge spoil is desirable. Pipeline dredges pumping from offshore areas are naturally subject to wind and wave limitations; submerged pipelines and flexible pipeline sections are occasionally employed. Recently a submerged dredge, mounted on crawler tracks, failed to satisfactorily complete such a beach nourishment contract due to mechanical problems. Fortunately, this work is usually limited to clean sands so that its environmental impact is probably minimal. Sand bypassing and offshore disposal of clean sands may have similar effects since the material is retained in the littoral drift.

**3.3.4 Silt curtains** These vertical barriers are polyvinylchloride-type floating "screens" which have effectively prevented the spread of dredge turbidity. They have been used around the spoil operation, the dredge operation, and both operations with success and are not unduly expensive. Their use in currents, however, will present problems proportional to the current and may not be feasible in many cases.

Innovative uses suggest themselves-such as control of current flows anywhere, including use within confined disposal areas to ensure adequate retention time by preventing "short-circuiting" flows, and as silt barriers around an open water disposal site, possibly in conjunction with flocculants or aeration techniques. One such barrier, manufactured by Erosion Control, Inc., is sketched in fig. 7.

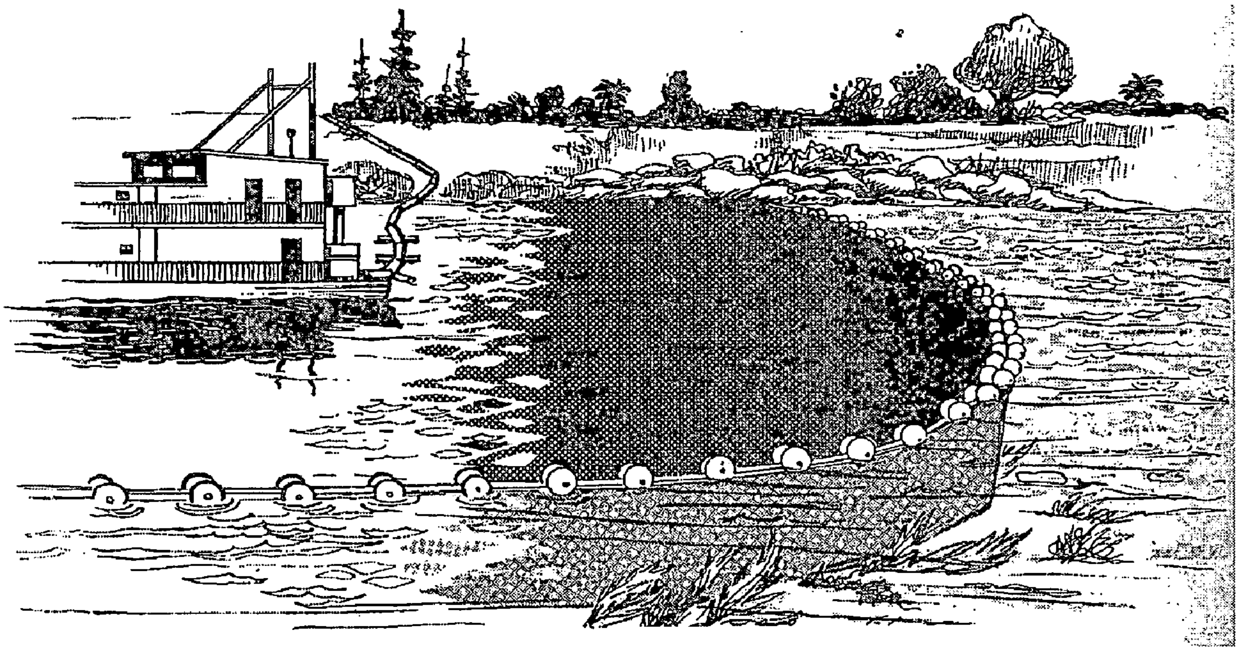


FIG. 7: SILT BARRIER

**3.3.5 Bubble barriers** Pneumatic bubble screens have been considered for use in a wide variety of circumstances involving the creation of a "barrier" to floating or suspended materials. Two facts have become immediately apparent: (a) current velocity must be minimal, and (b) power requirements to supply adequate compressed air are high. The investigators have tested such systems in an attempt to contain oil, and although the method is feasible, power requirements were found to be excessive. It would appear that the technique is not practical at this time.

**3.3.6 Long-distance pipeline transport** Long-distance pipeline disposal has been considered in two general respects. One is to pump the material long distances inland to rehabilitate strip mine areas while another is to pump it to sea. It appears that both the ideas may be economically feasible for certain areas. There are three disadvantages: (a) the large initial investment; (b) the inflexibility of the system; and (c) any failure of such a (unproven) system would entail costly repairs. A bottom discharge line of dredge spoil, either to an underwater confined area or within an area of strong dispersing currents, may find application elsewhere. It seems reasonable to conclude that such long-distance pipeline disposal facilities are feasible but heavily dependent on location, type of material, and existing facilities and equipment.

**3.3.7 Road and rail transport** Road and rail haul of dredge spoil are often submitted as possibilities. Again the nature of the dredged material to be hauled is critical. Haul in slurry form is clearly uneconomical. However, if the dredged material is dewatered sufficiently to be handled by dragline and bucket loader, rail haul or trucking from a temporary storage area to a permanent inland location might become feasible, particularly if distances are not too great. Such a ground transportation system would require a suitable spoil type, dewatering facilities (basins or treatment), rehandling equipment, and final disposal areas accessible in terms of distance and road/track facilities. The requirement for road and railroad access to a final disposal site (often in remote areas) may be critical and the existence of a presently in-place infrastructure is probably necessary to make such a system economically feasible.

**3.3.8 Makeup water requirements** Hopper dredges-and scows in some cases-are required to use direct pump-out into a confined disposal area. The material is usually dredged at a fairly thick consistency (often about the maximum possible without clogging) and settles in the hopper bin. In order to pump out this slightly consolidated dredged material, a great deal of additional water must be added, thereby increasing several fold the volume of dredged material the confined area is required to contain for a given period of time. A significant step toward reduced disposal area requirements and effluent quality problems would result if a means could be found to resuspend, with minimum makeup water, the bin material. "Marconaflo" is a pumped slurry technique to resuspend material with a minimum of makeup water; it is used in the mining industry with some success. The possibility of handling the spoil material in the thickened condition should not be overlooked.

## 3.4 TREATMENT PROCESSES

### 3.4.1 Requirements

Dredged material varies widely in both physical and chemical characteristics. While any material may be defined as "polluted" if it exceeds some arbitrary criteria, major order-of-magnitude problems are generally limited to highly organic, petrochemical-laden silts and clays, and domestic sludge found in waterways bordered by heavy population and industrial concentrations. In many cases, therefore, treatment possibilities parallel conventional domestic and industrial sewage treatment processes.

### 3.4.2 TREATMENT BEFORE AND DURING DREDGING

**3.4.2.1 Aeration** Aeration of bays, harbours, and other areas where organic sludge deposits are responsible for the persistence of noxious, anaerobic conditions could, in some instances, result in the changeover from anaerobic to aerobic decomposition. Thus the long-term result would be the elimination of such aesthetically displeasing nuisances as odour and the reestablishment of aerobic, "healthy" biological communities. Such techniques could be especially effective if combined with the selective removal of the organic bottom sediments by dredging.

**3.4.2.2 Chemical treatments** Chemical treatments to improve spoil prior to dredging are feasible. Chemical oxidisers, such as chlorine, offer the potential for spoil improvement prior to or during dredging. Good possibilities for increasing the slurry density, with chance of both environmental and economic side effects, are "wetting agents"; PO LYOX has already been mentioned as a means of reducing boundary resistance, and actual dredging tests with it have indicated good results.

### 3.4.3 Disposal Treatment

**3.4.3.1 Flocculation** Addition of chemicals to the bins of the hopper dredge Markham were unsuccessful in reducing turbidity during a dump, whereas treatment of the overflows did reduce turbidity to some extent. Flocculation within a diked disposal area was successful both in speeding the natural precipitating process and in clarifying the resultant effluent; however this technique depends on fairly quiescent water, maximum settling prior to addition of chemicals, and efficient mixing. An open water disposal practice of some promise would utilise a silt barrier to enclose a "treatment area" in which dredges could deposit spoil where, after an initial settling period of 15 or 20 min, flocculants would be applied. Such a technique holds promise of limiting possible undesirable effects of dredged material disposal.

**3.4.3.2 Hydrocyclones** Hydrocyclones have been used for some time to separate solids from liquids. The paper industry uses them regularly as liquid-solids separators; some air pollutants are removed by this type of device also. The dredging industry has used them to select and dewater fill material for reclamation work, but as presently constructed and used they do not lend themselves to "pollution control" since the finer polluted particles are passed along with the water and only the larger and relatively clean material remains. Researches indicate that "clarification" that is, separation out of the very fine particles may be possible by use of a series of several types of small, specialised cones. Both concentrating and clarifying functions may find application. Initial dewatering of hydraulic discharges will remove the larger particles and simplify treatment of the remaining spoil. Hopper dredge overflows and diked disposal area effluents can be clarified. The use of hopper bins, confined disposal areas, or other "surge tanks" will probably be required for employing "clarification" equipment whereas "concentration" can be accomplished by direct, high-volume flow-through.

**3.4.3.3 Vacuum filters** Since the dredged material placed in a confined disposal area is so often similar to domestic sewage, the use of vacuum filters for initial dewatering appears feasible. In this manner, the sludge can be separated out for eventual inland disposal (by other means such as rail or road haul). The disposal area could be regarded as a treatment plant, the larger solids being separated out by vacuum filters and the liquid effluent being treated by other processes. Savings on land and dike costs should offset higher operational costs. Such devices would be placed in line with the dredge discharge pipe (preceded only by a small settling basin designed to retain the larger objects) and, in a parallel bank arrangement, would be expected to handle the high flows involved. Related devices, such as "Vari-Nip," are readily available and are illustrated in fig. 8. Pretreatment by chemical aids such as alum or long-chain polymers, a standard sanitary engineering technique may be necessary to aid the dewatering process.

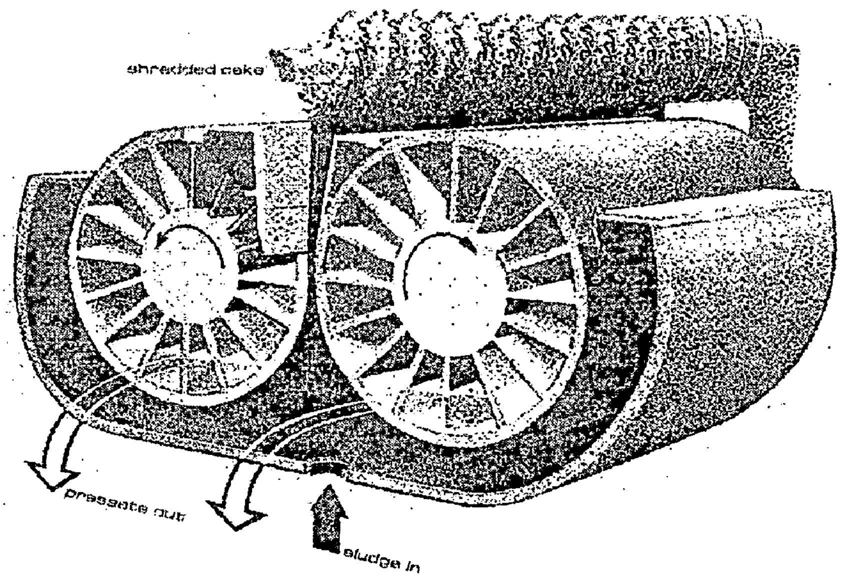


FIG.8: SLUDGE DEWATERING USING SANITARY ENGINEERING TECHNIQUES

**3.4.3.4 Aeration** Aeration can be utilised to stabilise (oxidise) highly organic dredge spoils. Success will depend on proper application of established sanitary engineering principles including sufficient oxygen/water interaction over an adequate time period. Mechanical aerators and pneumatic bubbler systems are presently in widespread use; also, the addition of chemicals, such as chlorine and PURIFAX, will also assist the oxidation of sanitary wastes. Lower cost but similar systems for lake destratification may prove adequate in some cases. Satisfactory aeration by mechanical or bubbler (air or oxygen) systems can be expected within either a confined land disposal site or enclosed open water area (bounded by; a silt curtain). Fig. 9 illustrates a procedure whereby organic spoils could be treated during disposal. Basically, the concept would involve spraying (by side casting or similar method) the material into a sufficient volume of water surrounded by a silt barrier. The dredged material would then be subjected to extended aeration in an effort to satisfy the associated oxygen demand. It is conceivable that aeration could be followed by coagulation. As mentioned earlier in the discussion of the environmental aspects of open water disposal, there is some question as to whether polluted spoil should be dispersed, thereby allowing a maximum of spoil-water contact, or disposed of in such a manner as to minimise this interaction. The above technique would maximise spoil-water contact while limiting the area over which this action occurs. If this system proves practical, dredging could be used to both improve the area from which the spoil was removed (by virtue of removing unwanted organic spoil) and improve overall water quality (by satisfying the oxygen demand associated with organic materials). Aeration offers the potential to deal with highly polluted dredged material in a very progressive, environmentally compatible manner and may give some flexibility with regard to location.

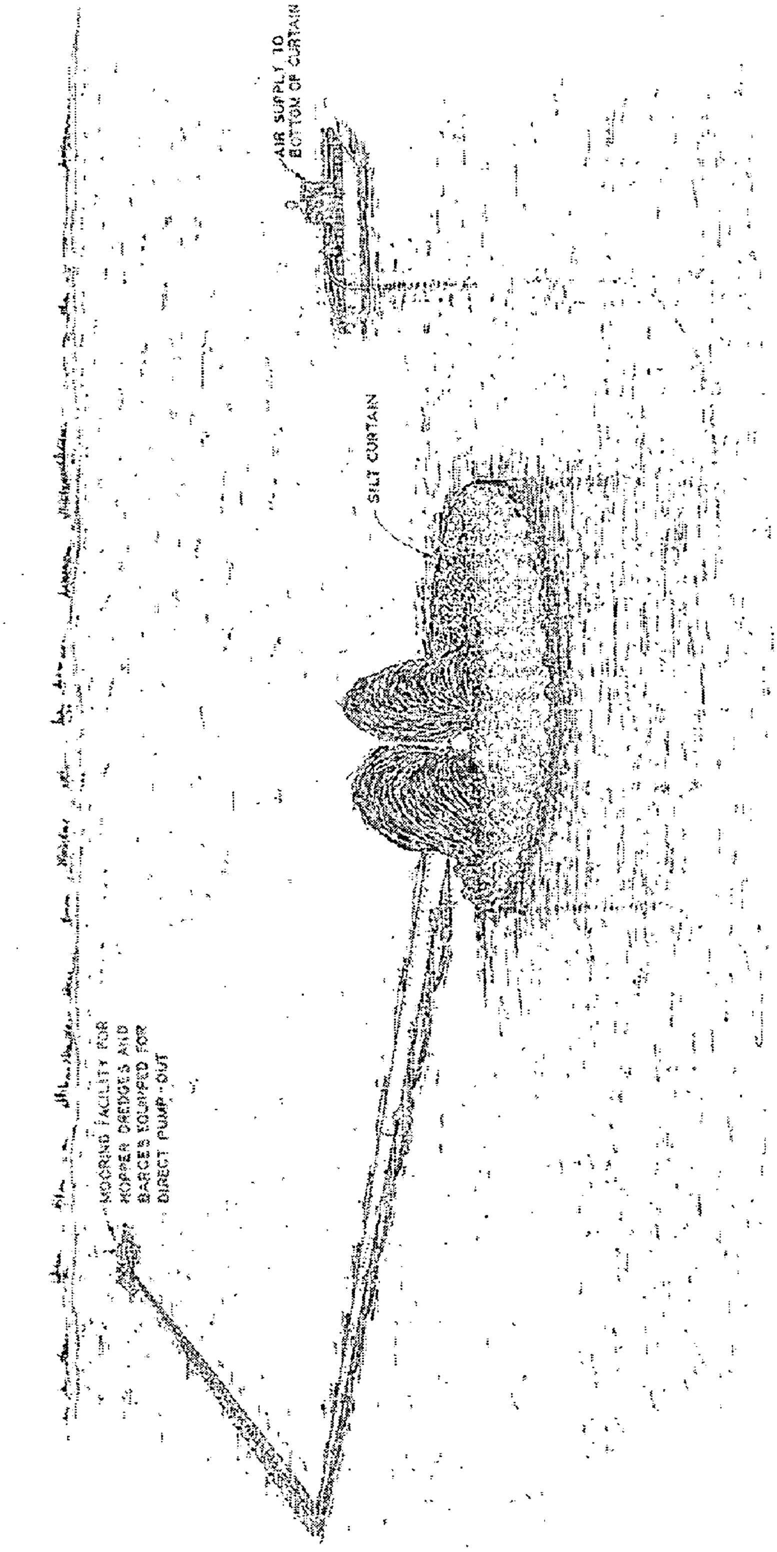


FIG. 9: OPEN WATER EXTENDED AERATION TREATMENT/DISPOSAL

**3.4.3.5 Incineration** Much as in a municipal sanitary system, the treatment of highly organic dredged materials will require a primary (solid) and secondary (liquid) phase. Incineration is a proven technique that can be expected to handle solids disposal. Multiple-hearth incineration as the most economical treatment process, but noted that there also were other suitable disposal alternatives at reasonable cost. Sludge with sufficiently high volatile solids content is readily available in a number of harbour areas but would require preliminary dewatering through natural settling, vacuum filtration, or some other technique. Other incineration techniques include wet oxidation and fluid bed incineration. The danger of air pollution must be investigated in all cases.

**3.4.3.6 Filters** The use of filters of various types is a possibility. If the dredged material were of sufficient size a screening or centrifuge process could perform a fairly efficient water-solids separation. Aggregate dredges do this, of course. In the case of finer materials, sand bed filters, as used in municipal water treatment plants, can find application in effluent treatment. Such filters could be built as integral parts of a diked area to either replace or supplement existing weirs. A recently developed tubular cloth filter requiring only occasional back-flushing is another possible effluent treatment device whose potential has not yet been adequately investigated.

**3.4.3.7Sewage treatment plants** Disposal of highly organic dredged material from waterways into a city interceptor-treatment plant system has been determined to be practical in some cases, but expensive and requiring long periods of time to dispose of large quantities of solids. The nature and volume of this spoil material simply overwhelms the capacity of a typical treatment facility to process and dispose of additional sludge-already a major sanitary engineering headache. One major limitation inherent in such a system is the requirement to cease dredge operations during high sewage flow, such as following a rainstorm. Dredged material can only be, handled in modern treatment facilities on a limited, intermittent, and costly basis. For large projects such a scheme is, therefore, unworkable; smaller projects may find it a viable alternative, particularly if temporary storage facilities are available to hold the dredged material effluent for further processing.

**3.4.3.8 Miscellaneous** Other possible treatment techniques for dealing with spoil material continue to make their appearances, often through sanitary engineering research. Heating of sludge, for example, or freezing of the sludge are both possibilities although freezing appears much too expensive even for municipal sewage treatment applications. Electro osmotic pumping might hold some promise even though it may not be able to handle the quantities required. In any case, the sanitary engineering and water treatment fields will have to be monitored for developments which might affect the handling, treatment, and disposal of dredge material.

### 3.4.4 Disposal Systems

It is apparent that few of the one-element processes noted above will solve the problem. Although each technique offers a reasonable chance of accomplishing a given function, combinations of these needs to be placed in a "systems" context in order to attack the entire dredged material disposal problem. Several such systems are suggested below:

a. Hydrocyclone or filter clarifiers for hopper dredge overflows.
b. Hydrocyclone, filter, or flocculent clarification of diked disposal area effluent.
c. Initial vacuum filter dewatering of solids, and subsequent mechanical removal (rail or truck); liquid disposal into confined area; and final clarification by hydrocyclone, flocculants, or filters (sand, tube, etc.)
d. Disposal of dewatered solids (via vacuum filtration) by incineration.
e. Aeration by air, bubbler, or chemicals within a diked area or a confined open water area.
f. Flocculation within an open water confined disposal area.
g. Removal of solids (by dewatering, settling, or other means); treatment of remaining effluent by local sewage treatment plant.

The treatment and disposal concepts noted offer environmentally compatible means for dealing with undesirable dredged materials. Since each of these processes can be expected to increase the cost of disposal, treatment should be reserved for the most appropriate cases. This decision should include consideration of several factors:

a. The pollution status of the material. If the dredge material is highly polluted and men able to treatment, it's physical, chemical, and biological characteristics can be improved through an appropriate treatment process. Material high in organic content can be treated using sanitary engineering methods, while other pollutants can best be handled by diked containment and clarification of effluent.

b. The physical and chemical characteristics of the dredged material. Some separation techniques will only deal with particles of a certain size, density, and chemical state; design decisions will have to take this into account. Invariably, the nature of the dredged material and local facilities will determine whether there is a significant solids disposal problem, an effluent disposal problem, or both.

# ENVIRONMENTAL IMPACT OF DISPOSAL OF DREDGED MATERIAL

## 4.1 Environmental Considerations

The environmental considerations discussed here also apply to all agitation dredging techniques. The properties of sediments affect the fate of contaminants, and the short and long-term physical and chemical conditions of the sediments at the agitation dredging site influence the environmental consequences of contaminants. These factors should be considered in evaluating the environmental risk of a proposed agitation dredging technique.

## 4.2 Disposal Alternatives

The major considerations in selecting disposal alternatives are the environmental impact and the economics of the disposal operation. The major objectives of the Dredged Material Research Program DMRP were to provide definitive information on the environmental impact of dredging and dredged material disposal operations and to develop new or improved dredged material disposal practices. The research was conducted on a national basis, excluding no major types of dredging activity or region or environmental setting. It produced methods for evaluating the physical, chemical, and biological impacts of a variety of disposal alternatives in water, on land, or in wetland areas, as well as tested viable, cost-effective methods and guidelines for reducing the impacts of conventional disposal alternatives.

Two fundamental conclusions were drawn from the results of the DMRP concerning disposal of dredged material: (1) no single disposal alternative can be presumed most suitable for a region, a type of dredged material, or a group of projects before it has been tested, and (2) environmental considerations make necessary long-range regional planning for lasting, effective solutions to disposal concerns. There is no inherent effect or characteristic of a disposal alternative that can rule it out of consideration from an environmental standpoint before specific on-site evaluation. This holds true for open-water disposal, confined upland disposal, habitat development, or any other alternative. Case-by-Case project evaluations are time-consuming and expensive and may seriously complicate advanced planning and funding requests. Nevertheless, from a technical point of view, situations can be envisioned where tens of millions of dollars may have been or could be spent for disposal alternatives that contribute to adverse environmental effects rather than reduce them. Also, easily obtained beneficial impacts should not be overlooked. No category of disposal alternative is without environmental risk or offers the soundest environmental protection or reflects the best management practice; therefore, all disposal alternatives should be fully investigated during the planning process and treated on an equal basis until a final decision can be made based on all available facts. It is hypothesized that all alternatives could be considered to dispose of even the most highly contaminated dredged material if a plan could be devised for management that was adequate and legally acceptable under domestic regulations and international treaty.

## 4.3 ENVIRONMENTAL IMPACTS IN THE WATER COLUMN

### a. Contaminants

Although the vast majority of heavy metals, nutrients, and petroleum and chlorinated hydrocarbons are usually associated with the fine-grained and organic components of the sediment, there is no biologically significant release of these chemical constituents from typical dredged material to the water column during or after dredging or disposal operations. Levels of manganese, iron, ammonium nitrogen, orthophosphate, and reactive silica in the water column may be increased somewhat for a matter of minutes over background conditions during open-water disposal operations; however, there are no persistent well-defined plumes of dissolved metals or nutrients at levels significantly greater than background concentrations.

### b. Turbidity

There are now ample research results indicating that the traditional fears of water-quality degradation resulting from the resuspension of dredged material during dredging and disposal operations are for the most part unfounded. The possible impact of depressed levels of dissolved oxygen has also been of some concern, due to the very high oxygen demand associated with fine-grained dredged material slurry. However, even at open-water pipeline disposal operations where the dissolved oxygen decrease should theoretically be greatest, near-surface dissolved oxygen levels of 8 to 9 ppm will be depressed during the operation by only 2 to 3 ppm at distances of 75 to 150 ft from the discharge point. The degree of oxygen depletion generally increases with depth and increasing concentration of total suspended solids; near-bottom levels may be less than 2 ppm. However, dissolved oxygen levels usually increase with increasing distance from the discharge point, due to dilution and settling of the suspended material.

(1) It has been demonstrated that elevated suspended solids concentrations are generally confined to the immediate vicinity of the dredge or discharge point and dissipate rapidly at the completion of the operation. If turbidity is used as a basis for evaluating the environmental impact of a dredging or disposal operation, it is essential that the predicted turbidity levels are evaluated in light of background conditions. Average turbidity levels, as well as the occasional relatively high levels that are often associated with naturally occurring storms, high wave conditions, and floods, should be considered.

(2) Other activities of man may also be responsible for generating as much or more turbidity than dredging and disposal operations. For example, each year shrimp trawlers in Corpus Christi Bay, Texas, suspend 16 to 131 times the amount of sediment that is dredged annually from the main ship channel. In addition, suspended solids levels of 0.1 to 0.5 ppt generated behind the trawlers are comparable to those levels measured in the turbidity plumes around open-water pipeline disposal operations. Resuspension of bottom sediment in the wake of large ships, tugboats, and tows can also be considerable. In fact, where bottom clearance is 3 ft or less, there may be scour to a depth of 3 ft if the sediment is easily resuspended.

## 4.4 ENVIRONMENTAL IMPACTS ON THE BENTHOS

**a. Physical.** Whereas the impact associated with water-column turbidity around dredging and disposal operations is for the most part insignificant, the dispersal of fluid mud dredged material appears to have a relatively significant short-term impact on the benthic organisms within open-water disposal areas. Open-water pipeline disposal of fine-grained dredged material slurry may result in a substantial reduction in the average abundance of organisms and a decrease in the community diversity in the area covered by fluid mud. Despite this immediate impact, recovery of the community apparently begins soon after the disposal operation ceases.

(1) Disposal operations will blanket established bottom communities at the site with dredged material which may or may not resemble bottom sediments at the disposal site. Recolonization of animals on the new substrate and the vertical migration of benthic organisms in newly deposited sediments can be important recovery mechanisms. The first organisms to recolonize dredged material usually are not the same as those which had originally occupied the site; they consist of opportunistic species whose environmental requirements are flexible enough to allow them to occupy the disturbed areas. Trends toward reestablishment of the original community are often noted within several months of disturbance, and complete recovery approached within a year or two. The general recolonization pattern is often dependent upon the nature of the adjacent undisturbed community, which provides a pool of replacement organisms capable of recolonizing the site by adult migration or larval recruitment.

(2) Organisms have various capabilities for moving upward through newly deposited sediments, such as dredged material, to reoccupy positions relative to the sediment-water interface similar to those maintained prior to burial by the disposal activity. Vertical migration ability is greatest in dredged material similar to that in which the animals normally occur and is minimal in sediments of dissimilar particle-size distribution. Bottom dwelling organisms having morphological and physiological adaptations for crawling through sediments are able to migrate vertically through several inches of overlying sediment. However, physiological status and environmental variables are of great importance to vertical migration ability. Organisms of similar life-style and morphology react similarly when covered with an overburden. For example, most surface-dwelling forms are generally killed if trapped under dredged material overburdens, while subsurface dwellers migrate to varying degrees. Laboratory studies suggest vertical migration may very well occur at disposal sites, although field evidence is not available. Literature review (WES TR DS-78-1)[1] indicates the vertical migration phenomenon is highly variable among species.

(3) Dredging and disposal operations have immediate localized effects on the bottom life. The recovery of the affected sites occurs over periods of weeks, months, or

years, depending on the type of environment and the biology of the animals and plants affected. The more naturally variable the physical environment, especially in relation to shifting substrate due to waves or currents, the less effect dredging and disposal will have. Animals and plants common to such areas of unstable sediments are adapted to physically stressful conditions and have life cycles which allow them to withstand the stresses imposed by dredging and disposal. Exotic sediments (those in or on which the species in question does not normally live) are likely to have more severe effects when organisms are buried than sediments similar to those of the disposal site. Generally, physical impacts are minimized when sand is placed on a sandy bottom and are maximized when mud is deposited over a sand bottom. When disposed sediments are dissimilar to bottom sediments at the sites, recolonization of the dredged material will probably be slow and carried out by organisms whose life habits are adapted to the new sediment. The new community may be different from that originally occurring at the site.

(4) Dredged material discharged at disposal sites which have a naturally unstable or shifting substrate due to wave or current action is rather quickly dispersed and does not cover the area to substantial depths. This natural dispersion, which usually occurs most rapidly and effectively during the stormy winter season, can be assisted by conducting the disposal operation so as to maximize the spread of dredged material, producing the thinnest possible overburden. The thinner the layer of overburden, the easier it is for mobile organisms to survive burial by vertical migration through dredged material. The desirability of minimizing physical impacts by dispersion can be overridden by other considerations, however. For example, dredged material shown by biological or chemical testing to have a potential for adverse environmental impacts might best be placed in an area of retention, rather than dispersion. This would maximize habitat disruption in a restricted area, but would confine potentially more important chemical impacts to the same small area.

(5) Since larval recruitment and migration of adults are primary mechanisms of recolonization, recovery from physical impacts will generally be most rapid if disposal operations are completed shortly before the seasonal increase in biological activity and larval abundance in the area. The possibility of impacts can also be reduced by locating disposal sites in the least sensitive or critical habitats. This can sometimes be done on a seasonal basis. Known fish migratory routes and spawning beds

should be avoided just before and during use, but might be acceptable for disposal during other periods of the year. However, care must be taken to ensure that the area returns to an acceptable condition before the next intensive use by the fish. Clam or oyster beds, municipal or industrial water intakes, highly productive backwater areas, etc., should be avoided in selecting disposal sites.

(6) All the above factors should be evaluated in selecting a disposal site, method, and season in order to minimize the habitat disruption of disposal operations. All require evaluations on a case-by-case basis by persons familiar with the ecological principles involved, as well as the characteristics of the proposed disposal operations and the local environment.

**b. Contaminants.**

(1) Dredging and disposal do not introduce new contaminants to the aquatic environment, but simply redistribute the sediments which are the natural depository of contaminants introduced from other sources. The potential for accumulation of a metal in the tissues of an organism (bioaccumulation) may be affected by several factors such as duration of exposure, salinity, water hardness, exposure concentration, temperature, the chemical form of the metal, and the particular organism under study. The relative importance of these factors varies from metal to metal, but there is a trend toward greater uptake at lower salinities. Elevated concentrations of heavy metals in tissues of benthic invertebrates are not always indicative of high levels of metals in the ambient medium or associated sediments. Although a few instances of uptake of possible ecological significance have been shown, the diversity of results among species, different metals, types of exposure, and salinity regimes strongly argues that bulk analysis of sediments for metal content cannot be used as a reliable index of metal availability and potential ecological impact of dredged material, but only as an indicator of total metal context. Bioaccumulation of most metals from sediments is generally minor. Levels often vary from one sample period to another and are quantitatively marginal, usually being less than one order of magnitude greater than levels in the control organisms, even after one month of exposure. Animals in undisturbed environments may naturally have high and fluctuating metal levels. Therefore, in order to evaluate bioaccumulation, comparisons should be made between control and experimental organisms at the same point in time.

(2) Organochlorine compounds such as DDT, dieldrin, and polychlorinated biphenyls (PCB's) are environmental contaminants of worldwide significance which are manmade and, therefore, do not exist naturally in the earth's crust. Organochlorine compounds are generally not soluble in surface waters at concentrations higher than approximately 20 ppb, and most of the amount present in waterways is associated with either biological organisms or suspended solids. Organochlorine compounds are released from sediment until some equilibrium concentration is achieved between the aqueous and the solid phases and then readsorbed by other suspended solids or biological organisms in the water column. The concentration of organochlorines in the water column is reduced to background levels within a matter of hours as the organochlorine compounds not taken up by aquatic organisms eventually settle with the particulate matter and become incorporated into the bottom deposits in aquatic ecosystems. Most of these compounds are stable and may accumulate to relatively high concentrations in the sediments. The manufacture and/or disposal of most of these compounds is now severely limited; however, sediments that have already been contaminated with organochlorine compounds will probably continue to have elevated levels of these compounds for several decades. The low concentrations of chlorinated hydrocarbons in sediment interstitial water indicate that during dredging operations, the release of the interstitial water and contaminants to the surrounding environment would not create environmental problems. Bioaccumulation of chlorinated hydrocarbons from deposited sediments does occur. However, the sediments greatly reduce the bioavailability of these contaminants, and tissue concentrations may range from less than one to several times the sediment concentration. Unreasonable degradation of the aquatic environment due to the routine maintenance dredging and disposal of sediment contaminated with chlorinated hydrocarbons has never been demonstrated.

(3) The term "oil and grease" is used collectively to describe all components of sediments of natural and contaminant origin which are primarily fat soluble. There is a broad variety of possible oil and grease components in sediment, the analytical quantification of which is dependent on the type of solvent and method used to extract these residues. Trace contaminants, such as PCB's and chlorinated hydrocarbons, often occur in the oil and grease'. Large amounts of contaminant oil and grease find their way into the sediments of the Nation's waterways either by

spillage or as chronic inputs in municipal and industrial effluents, particularly near urban areas with major waste outfalls. The literature suggests long-term retention of oil and grease residues in sediments, with minor biodegradation occurring. Where oily residues of known toxicity became associated with sediments, these sediments retained toxic properties over periods of years, affecting local biota. Spilled oils are known to readily become adsorbed to naturally occurring suspended particulates, and oil residues in municipal and industrial effluents are commonly found adsorbed to particles. These particulates are deposited in sediments and are subject to suspension during disposal. Even so, there is only slight desorption, and the amount of oil released during the elutriate test is less than 0.01 percent of the sediment-associated hydrocarbons under worst-case conditions. Selected estuarine and freshwater organisms exposed for periods up to 30 days to dredged material that is contaminated with thousands of parts per million of oil and grease experience minor mortality. Uptake of hydrocarbons from heavily contaminated sediments appears minor when compared with the hydrocarbon content of the test sediments.

(4) Ammonia is one of the potentially toxic materials known to be released from sediments during disposal; it is routinely found in evaluations of sediments using the elutriate test and in the water near a disposal area where concentrations rapidly return to baseline levels. Similar temporary increases in ammonia at marine, estuarine, and freshwater disposal sites have been documented in several DMRP field studies, but concentrations and durations are usually well below levels causing concern.

(5) The potential environmental impact of contaminants associated with sediments must be evaluated in light of chemical and biological data describing the availability of contaminants to organisms. Information must then be gained as to the effects of specific substances on organism survival and function. Many contaminants are not readily released from sediment attachment and are thus less toxic than contaminants in the free or soluble state on which most toxicity data are based.

(6) There are now cogent reasons for rejecting many of the conceptualized impacts of disposed dredged material based on classical bulk analysis determinations. It is invalid to use total sediment concentration to estimate contaminant levels in organisms since only a variable and undetermined amount of sediment-associated contaminant is biologically available. Although a few instances of toxicity and

bioaccumulation of possible ecological consequence have been seen, the fact that the degree of effect depends on species, contaminants, salinity, sediment type, etc., argues strongly that bulk analysis does not provide a reliable index of contaminant availability and potential ecological impact of dredged material.

### 4.5 Overview of Open-Water Disposal

a. Prediction of physical effects of dredging and disposal is fairly straightforward. Physical effects include removal of organisms at dredging sites and burial of organisms at disposal sites. Physical effects are restricted to the immediate areas of dredging or disposal. Recolonization of sites occurs in periods of months to 1-2 years in case studies. Disturbed sites may be recolonized by opportunistic species which are not normally the dominant species occurring at the site.

b. Many organisms are very resistant to the effects of sediment suspensions in the water; aside from natural systems requiring clear water, such as coral reefs and some aquatic plant beds, dredging or disposal induced turbidity is not of major ecological concern. The formation of fluid mud due to disposal is not fully understood and is of probable environmental concern in some situations.

c. Release of sediment-associated heavy metals and chlorinated hydrocarbons to the water column by dredging and disposal has been found to be the exception, rather than the rule. Metals are rarely bio accumulated from sediments and then only to low levels. Chlorinated hydrocarbons may be bio accumulated from sediments, but only very highly contaminated sediments might result in tissue concentrations of potential concern. There is little or no correlation between bulk analysis of sediments for contaminants and their environmental impact.

d. Oil and grease residues, like heavy metals, are tightly bound to sediment particles, and there appears to be minimal uptake of the residues into organism tissues. Of the thousands of chemicals constituting the oil and grease fraction, very few can be considered significant threats to aquatic life when associated with dredged material.

e. Many laboratory studies describe worst-case experimental conditions where relatively short-term exposures to high concentrations of sediments and contaminants are investigated. Although limited in scope, experimental results showing the lack of effects under these worst-case conditions support the conclusion that the indirect long-term and sub lethal effects of dredging and disposal will be minimal. An integrated, whole-sediment bioassay using sensitive test organisms should be used to determine potential sediment impacts at a particular site. Appropriate chemical testing and biological evaluation of the dredged material can be used to resolve any site-specific problems which may occur.

CHAPTER – 5

# DISPOSAL- DISPERSION PROCESS OF DREDGED MATERIAL

## 5.1 GENERAL

A variety of methods are available for the disposal of dredged material in estuarine and coastal marine environments, including instantaneous, continuous, and mixed (i.e., somewhere between instantaneous and continuous).

Much of the material dredged in India is presently discharged by either bottom dump barges or hopper dredges. These vessels usually are partitioned into compartments, each having a set of hinged bottom doors that open downward. The compartments are opened sequentially. The time required to discharge each compartment is commonly a fraction of a minute, although the time to discharge all of the compartments is roughly the number of compartments times 1 min per compartment (Tetra Tech 1982)[2]. An increasingly popular method of disposal is by the use of split-hull or clamshell barges. The split-hull barge is opened by gradually widening the two halves of the barge hydraulically. Depending on the width of the opening, the barge can discharge material in as little as a few seconds to much longer times if desired. The material discharged from these barges commonly have a water content not appreciably different from in situ sediments, although in some instances water is mixed with the dredged material prior to discharge in an attempt to break up cohesive silt-clay mixtures. Another method of disposing of dredged material is by continuous discharge from an open pipe, commonly from a barge. This material usually is hydraulically dredged, using a cutterhead dredge for instance, and therefore contains a higher percentage of water than in situ material.

## 5.2 PHYSICAL PROCESSES

The physical processes that occur in the discharge of dredged material have been investigated, and some of the knowledge gained has been incorporated into numerical models. The processes are commonly divided into three phases: convective descent, dynamic collapse, and passive transport diffusion. During convective descent, which begins immediately on discharge, the descent of the discharge is caused by its negative buoyancy and discharge conditions. As the discharge descends, it entrains seawater, and as a result the bulk density of the discharge mixture decreases. If the water depth is sufficiently large and the seawater density stratification is sufficiently strong, then the bulk density of the discharge may equal the density of the seawater at a depth called the neutral density depth. If this occurs, then the discharge tends to stabilize near this depth and collapse. If the water depth is not great enough, the discharge mixture will impact the seafloor and form a bottom surge.

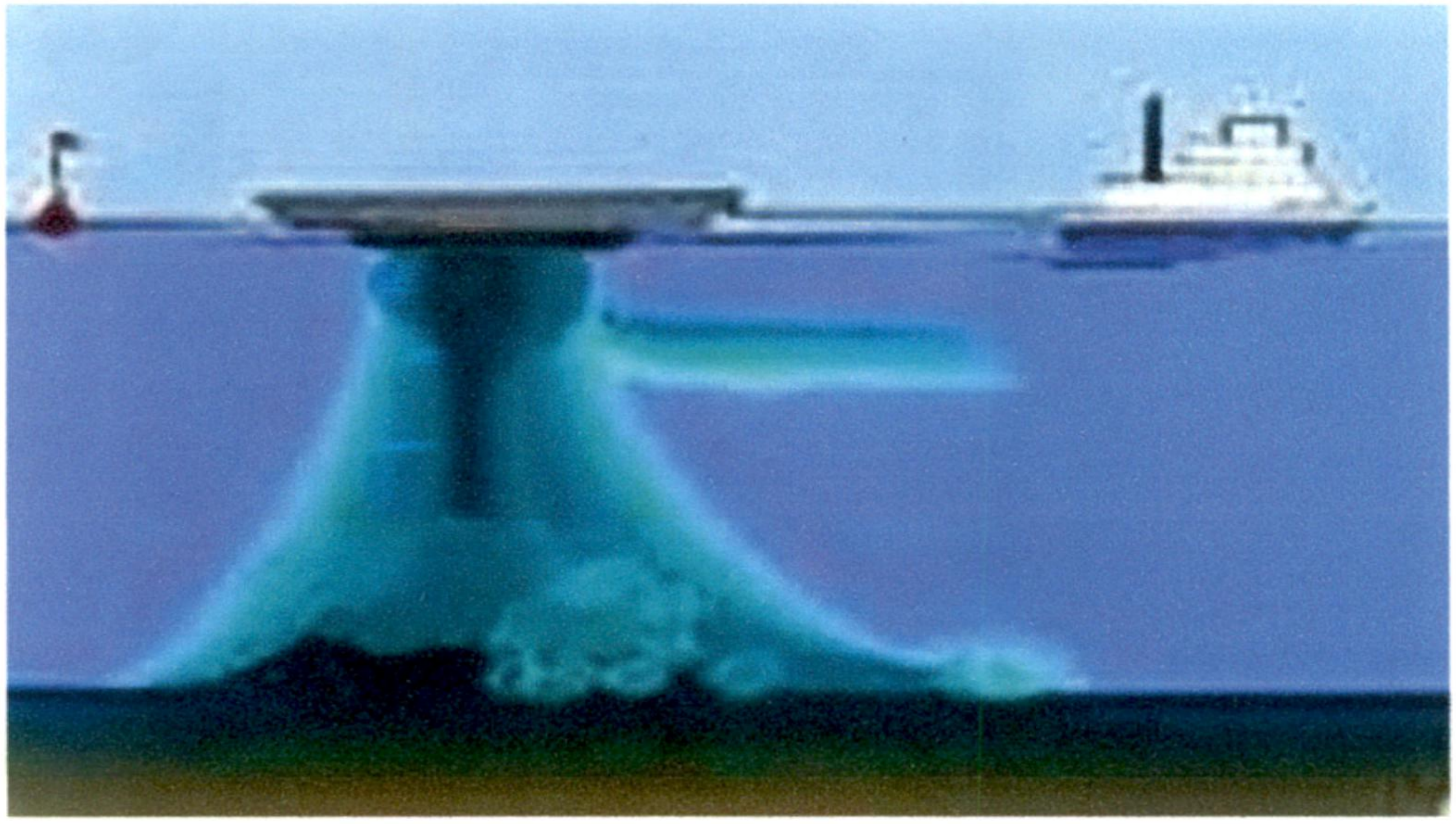


**FIG. 10 : SCHEMATIC REPRESENTATION OF DISPOSAL-DISPERSION PROCESSES**

The collapse of the discharge mixture either in the water column or on the seafloor is termed the dynamic collapse phase. As the disposal cloud goes through the convective descent phase, it gains mass and momentum by entrainment. The horizontal velocity of the cloud tends to approach that of the ambient fluid. Coincidently, the disposed material concentration is greatly reduced and the vorticity becomes insignificant because of dissipation by ambient stratification and turbulence. If the cloud reaches the depth of neutral buoyancy, its momentum will tend to make it overshoot beyond the neutrally buoyant point while the buoyancy force will tend to bring it back to the neutrally buoyant point. The combined action of these forces will make the cloud undergo a decaying vertical oscillation. As the vertical motion of the cloud is being suppressed, the cloud tends to collapse vertically and spread out horizontally, seeking hydrostatic equilibrium within the stratified ambient fluid.

This phase ends when the momentum of the discharge is spent. Thereafter, i.e., during the passive transport-diffusion phase, the motions of material remaining in the water column are caused by processes independent of the method of discharge. This distribution is governed by different mass transport mechanisms which act in the water body and which are a function of the discharge characteristics and of the ambient hydrologic and meteorological conditions prevailing in the disposal area. In principle, the governing equations of fluid motion and mass conservation can be stated accurately for a differential volume of water. However, difficulties usually arise in the integration of these equations, as one is interested in the concentration distribution of disposed dredged material over a large region.

At most disposal sites, the convective descent and dynamic collapse phases only last on the order of a few minutes. When the rate of spreading of the collapsing cloud becomes less than an estimated rate of spreading due to turbulent diffusion, the collapse phase is terminated and the "longer" term transport-diffusion phase is initiated. In this phase, material in suspension is transported and diffused by the ambient current while undergoing settling.

### 5.2.1 Ambient and Discharge Condition

The mixing behaviour of any disposed material is governed by the interplay of ambient conditions in the receiving water body and by the discharge characteristics.

The ambient condition in an estuary or coastal water body are described by geometric parameters - such as plan shape of the estuary, vertical cross-sections, and bathymetry, especially in the discharge vicinity and by its dynamic characteristics. The latter are given by the velocity and density distribution in the estuary, again primarily in the discharge vicinity.

Many estuaries and coastal areas are highly energetic water bodies and their velocity field with its vertical and temporal variability may be influenced by many factors. Usually the most significant velocity component is controlled by tidal influences, but freshwater inflows, wind-driven currents and wave-induced currents may also play important roles and, in some cases, may even dominate the flow. Furthermore the mean velocity field is often superposed by secondary currents due to topographic effects or due to baroclinic influences giving rise to complicated three-dimensional flow fields.

The density distribution in such water bodies is usually strongly coupled with the velocity field. Density differences are mostly caused by the freshwater inflow and lighter, less saline, water tends to overflow the more saline ocean water. Estuaries are sometimes classified on the basis of their density structure into well-stratified, partially-stratified and vertically mixed estuaries (Fischer et al. 1979)[3]. Well stratified estuaries, usually those with weak tidal effects, exhibit a two-layer structure with an upper predominantly fresh water layer flowing over a lower saline layer (the so-called salt wedge). The dominant vertical velocity distribution in that instance is a seaward flow in the upper layer and a reversed landward flow in the lower layer. The other end of the spectrum is given by vertically well mixed estuaries with strong tidal energetic leading to nearly complete vertical mixing but density gradients may still exist in the horizontal direction (i.e. along the axis of the estuary or tidal bay).

Clearly, a major feature of estuarine ambient conditions is their time variability. For tidally controlled currents this is given by a time scale equal to the tidal period. Other time scales, usually also of the order of several hours, describe wind driven currents and seiche motions. However, the time scale for initial mixing processes of effluent discharges is usually much shorter (of the order of minutes to tens of minutes) so that it usually suffices to analyse certain flow and density conditions under a steady state assumption.

Similar conservation laws are used for predicting the behaviour of the discharge cloud formed by an instantaneous discharge or for the jet formed by a continuous discharge from a submerged pipe. In addition, constants must be specified for the density gradient inside the discharge at commencement of dynamic collapse, and for the friction between the seafloor and the discharge. Accurate predictions from the models depend on proper knowledge of the coefficients, assuming that the formulations of the physical processes used in the model are adequate. If the formulations are not sufficiently detailed, however, then determination of the coefficients based on extensive experiments is not likely to produce accurate model estimates.

### 5.2.2 Hydrodynamic Mixing Processes

The hydrodynamics of an effluent continuously discharging into a receiving body of water can be conceptualized as a mixing process occurring in two separate regions. In the first region, the initial jet characteristics of momentum flux, buoyancy flux, and outfall geometry influence the jet trajectory and mixing. This region will be referred to as the "near-field", and encompasses the buoyant jet subsurface flow and any surface or bottom interaction, or in the case of a stratified ambient, terminal layer interaction. In this region, designers of the outfall can usually affect the initial mixing characteristics through appropriate manipulation of design variables.

As the turbulent plume travels further away from the source, the source characteristics become less important. Conditions existing in the ambient environment will control trajectory and dilution of the turbulent plume through buoyant spreading motions and passive diffusion due to ambient turbulence. This region will be referred to here as the "far-field".

It is stressed at this point that the distinction between near-field and far-field is made purely on hydrodynamic grounds. It is unrelated to any regulatory mixing zone definitions that address prescribed water quality standards. For example in the United States the regulatory mixing zone in coastal waters is often specified by a horizontal length equal to the water depth. Depending on the individual case, the whole gamut of mixing processes ranging from the near-field to the far-field may have to be considered for individual mixing zone analyses.

### 5.2.3 Near-Field Processes

Three important types of near-field processes are submerged buoyant jet mixing, boundary interactions and surface buoyant jet mixing as described in the following paragraphs.

**5.2.3.1 Disposed Dredged Material Mixing:** The disposed dredged material from a hopper provides a velocity discontinuity between the discharged fluid and the ambient fluid causing an intense shearing action. The shearing flow breaks rapidly down into a turbulent action. The width of the zone of high turbulence intensity increases in the direction of the flow by incorporating (entraining) more of the outside, less turbulent fluid into this zone. In this manner, any internal concentrations (e.g. fluid momentum or pollutants} of the discharge flow become diluted by the entrainment of ambient water. Inversely, one can speak of the fact that both fluid momentum and pollutants become gradually diffused into the ambient field.

The, initial velocity discontinuity may arise in different fashions. In a *"pure jet"* (also called "momentum jet" or "non-buoyant jet"), the initial momentum flux in the form of a high-velocity injection causes the turbulent mixing. In a *"pure plume"*, the initial buoyancy flux leads to local vertical accelerations which then lead to turbulent mixing. In the general case of a *"buoyant jet"* (also called a "forced plume"), a combination of initial momentum flux and buoyancy flux is responsible.

Dispersion of disposed dredged material is further affected by ambient currents and density stratification. The role of *ambient currents* is to gradually deflect the disposed dredged material into the current direction and thereby induce additional mixing. The role of ambient *density stratification* is to counteract the vertical acceleration within the disposed dredged material leading ultimately to trapping of the flow at a certain level.

**5.2.3.2 Boundary Interaction Processes and Near-Field Stability:** Ambient water bodies always have vertical boundaries. These include the water surface and the bottom, but in addition, "internal boundaries" may exist at pycnoclines. *Pycnoclines* are layers of rapid density change.

In essence, boundary interaction processes provide a transition between the disposals mixing process in the near-field, and between dredged material spreading and passive diffusion in the far-field. They can be gradual and mild, or abrupt leading to vigorous transition and mixing processes.

### 5.2.4 Far-Field Processes

Far-field mixing processes are characterised by the longitudinal advection of the disposed material by the ambient current velocity.

**5.2.4.1 Spreading Processes:** These are defined as the horizontally transverse spreading of the disposed material flow while it is being advected downstream by the ambient current. Such spreading processes arise due to the buoyant forces caused by the density difference of the mixed flow relative to the ambient density. They can be effective transport mechanisms that can quickly spread a mixed material laterally over large distances in the transverse direction, particularly in cases of strong ambient stratification. In this situation, effluent of considerable vertical thickness at the terminal level can collapse into a thin but very wide layer unless this is prevented by lateral boundaries. If the discharge is non-buoyant, or weakly buoyant, and the ambient is unstratified, there is no buoyant spreading region in the far-field, only a passive diffusion region.

The laterally spreading flow behaves like a density current and entrains some ambient fluid in the "head region" of the current. During this phase, the mixing rate is usually relatively small, the layer thickness may decrease, and a subsequent interaction with a shoreline or bank can impact the spreading and mixing processes.

**5.2.4.2 Passive Ambient Diffusion Processes:** The existing turbulence in the ambient environment becomes the dominating mixing mechanism at sufficiently large distances from the discharge point. In general, the passively diffusing flow grows in width and in thickness until it interacts with the channel bottom. The strength of the ambient diffusion mechanism depends on a number of factors relating mainly to the geometry of the ambient shear flow and the amount of ambient stratification. In the context of classical diffusion theory, gradient diffusion processes in the bounded flows of rivers or narrow estuaries can be described by constant diffusivities in the vertical and horizontal direction that depend on turbulent intensity and on channel depth or width as the length scales. In contrast, wide "unbounded" channels or open coastal areas are characterised by plume size dependent diffusivities leading to accelerating plume growth described, for example, by the "4/3 law" of diffusion. In the presence of a stable ambient stratification, the vertical diffusive mixing is generally strongly damped.

## 5.3 DREDGED MATERIAL DISPOSAL CHARACTERISTICS

The characteristics of dredged material vary substantially. The material ranges from gravel to clays with particle size distributions depending on the site. The sediment particle densities usually range from 2.6 to 2.7 g/cm$^3$. In situ bulk densities commonly range from 1.4 to 1.7 g/cm$^3$ or more. Clamshell dredging tends not to disturb the in situ properties (i.e., the degree of compaction and clumping of clay-silt mixtures) of the dredged material. In contrast, hydraulic dredging tends to destroy the in situ properties of the material and mixes the sediments with water, the addition of which lowers the bulk density of the water-sediment mixture (compared to its in situ value). In lieu of site-specific information, the voids ratio of both dredged material particles and bulk material is commonly assumed to be 0.8. The particle fall velocities of sand and gravel particles are normally computed using Stokes' law based on particle density and diameter. Clay and silt particles are usually cohesive, and thus their particle fall velocities are usually a function of sediment concentration. Commonly, fall velocities for dilute clay-silt mixtures are dependent on the concentration raised to a power, usually 4/3. If the particles are bound together in clumps, then the fall velocity of the clump is calculable as a noncohesive particle.

Discharge of dredged materials is usually into estuarine waters or on the continental shelf. Occasionally, material is discharged off the shelf; however, this practice is not used in many locations due to excessive transportation costs. Dredged material discharges usually occur in water depths of less than 200m, with continuous discharges usually in relatively shallow water. The volume of dredged material discharged from barges and/or hopper dredges ranges approximately from 15 to 120 m$^3$. The speed of the barge during discharge operations usually does-not exceed 2 m/sec.

## 5.4 GOVERNING EQUATIONS:

The spatial and temporal distribution of mass concentration c is given by the equation of mass conservation. For a turbulent flow, this equation can be written in time-averaged form as

$$\underbrace{\frac{\partial c}{\partial t}}_{\text{storage}} + \underbrace{\frac{\partial (u_i c)}{\partial x_i}}_{\substack{\text{convective}\\ \text{transport}}} = \underbrace{D \frac{\partial^2 c}{\partial x_i \partial x_j}}_{\substack{\text{molecular}\\ \text{diffusive}\\ \text{transport}}} + \underbrace{\frac{\partial}{\partial x_i}\left(\overline{u'_i c'}\right)}_{\substack{\text{turbulent}\\ \text{diffusive}\\ \text{transport}}} + \underbrace{R}_{\substack{\text{mass}\\ \text{source}\\ \text{or sink}}} \qquad (1)$$

where

$c$ = concentration

$t$ = time

$x_i$ = coordinate axes ($i = 1,2,3$)

$u_i$ = velocities in direction $x_i$

$D$ = coefficient of molecular diffusion

$R$ = rate of mass production or loss (decay)

$\overline{u'_i c'}$ = time-averaged turbulent mass transport into direction $x_i$

$u_i'$ = velocity fluctuation

$c'$ = concentration fluctuation.

In the above equation, the mass transport by convection, $u_i'c'$, and by turbulent diffusion, $\overline{u_i'c'}$, depend on the state of the flow and, in principle, need to be evaluated by simultaneous solution of the hydrodynamic equations. Mass transport by molecular diffusion is usually negligible in comparison to turbulent diffusion. Internal mass sources are given by physical, chemical, or biological reaction processes (growth or decay) within the water body.

The hydrodynamic equations are the <u>continuity equation</u> (for an incompressible fluid)

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad (2)$$

and the three turbulent, time-averaged <u>momentum equations</u> (j = 1,2,3)

$$\rho \frac{\partial u_j}{\partial t} + \rho \frac{\partial}{\partial x_i}\left(u_i u_j\right) = -\frac{\partial p}{\partial x_j} - \rho g K_j + \rho \nu \frac{\partial^2 u_j}{\partial x_i \partial x_j} - \rho \frac{\partial}{\partial x_i}\left(\overline{u_i' u_j'}\right) \qquad (3)$$

| | | | | | |
|---|---|---|---|---|---|
| local accel. | convective acceleration | pressure gradient | gravity accel. | molecular shear | turbulent shear |

where

$p$ = pressure

$g$ = gravitational acceleration

$K_j$ = unit vector in the direction of g

$\nu$ = kinematic molecular viscosity

$\rho\overline{u_i'u_j'}$ = time-averaged turbulent eddy transport of momentum

In the general case, the concentration measure c in Eq.(1) applies to any property or material that may be transported by the flow. Thus, c may describe a pollutant concentration, or salinity S, or temperature T, or a density deficit relative to some ambient density. In fact, Eq.(1) may represent a series of equations for these diverse parameters. It should be remembered, however, that these parameters may link (the mass conservation Eq. (1) to the momentum Eq.(3) via an equation of state that may be written in general form

$$\rho = \rho\ (S,T,c) \qquad (4)$$

The dependence of density on salinity, of course, is of crucial importance for freshwater discharges into the ocean. The dependence on pollutant concentration is usually negligible if pollutants occur in low concentration, dilute solutions.

Eq. (1) to (4) represent a set of six equations for the six variables $u_i$, p, $\rho$, and c. Initial and boundary conditions have to be specified for these variables. Also the turbulent eddy transport terms $\rho\overline{u_i' u_j'}$ and $\overline{u_i' c_j}$, are essentially unknowns at this point and need to be related to the mean parameters, $u_i$ and c. This constitutes the "turbulence closure" assumption and is discussed further below.

## 5.5 SOLUTION APPROACHES:

No general solution to the above system of governing equations can be formulated. The equation system is highly complex due to its time-dependent and three-dimensional nature and because of significant coupling between the mass transport and hydrodynamic equations. Sources of this coupling are the density change due to admixtures, as expressed by the equation of state and the convective transport term in the mass conservation equation.

In principle, one can conceive of two approaches to the prediction of effluent discharges in the water environment: complete models or zone models.

**5.5.1 Complete models**: These are three-dimensional numerical models that directly solve a finite difference or finite element approximation for the full dynamic and mass conservation equations with various assumptions for the turbulent shear and mass transport terms. In principle, with the advent of powerful computing facilities, even on the desktop, such a complete modelling approach that encompasses the entire fluid domain of interest with all individual mixing processes appears feasible. However, successful applications to date have been limited. Apparent reasons for the present shortcomings include (1) lack of fully workable turbulence closure techniques under the influence of buoyancy while considering the full range of jet-induced to geophysical turbulence; (2) the difficult trade-off of modelling a large enough domain while providing sufficient resolution in a three-dimensional model (computer capacity and costs); and 3) the unknown nature of the open fluid boundary conditions which need to be specified as part of the elliptic equation system. These boundaries may, in general, contain a combination of stratified inflow and outflow that is inherently difficult to specify. For these reasons, complete numerical models are usually not used in routine mixing zone analyses of effluent discharges and this is expected to remain so for at least the next decade.

**5.5.2 Zone Models**: Instead of attempting to integrate the general governing equations over the whole region of interest it is frequently useful to divide the region into several zones with distinct behaviour (such as individual mixing processes in the near-field and in the far-field). Within these zones it is then possible to simplify the governing equations by dropping unimportant terms. This gives a considerable advantage in the mathematical treatment and improved accuracy in the solution. However, a challenge remains because the solutions are restricted to specific zones. Thus, criteria need to be established for a meaningful division of the whole region into zones, and to provide transition conditions between zones.

Current practice in disposal analyses relies on zone models. Such models that deal with individual flow processes are described in the specialized research literature' as well as in several monographs (e.g. Fischer et al., 1979, Holley and Jirka, 1986)[4]. However, a problem arises because there is limited guidance to the model user on the limits of applicability of each model, and on how to combine the individual models for an overall prediction of the entire flow process. The use of an integrated expert system framework (e.g. Jirka et al, 1991)[5] promises to alleviate this problem.

CHAPTER – 6

# RADIO ACTIVE TRACER (RAT) STUDIES BY BARC AT NMPT

## 6.1 GENERAL

Two radiotracer investigations were carried out by BARC at New Mangalore Port Trust, Mangalore during pre south-west and post south-west monsoon periods to examine the suitability of a dumping site for dredged sediment located at north of shipping channel. The brief description about the technique and studies are given below.

## 6.2 RADIO ACTIVE TRACER TECHNIQUE

The radiotracer technique involves preparation of a radioactive particulate tracer having similar physicochemical properties as the bed material, injection of the tracer at the desired point, tracking of the tracer with underwater nuclear detectors and finally interpretation of iso-activity contours to evaluate the different parameters. Two kinds of tracer preparations are in common use. In the first method, the tracer is prepared by incorporating an activable element like scandium or iridium in glass, ground the glass and mix the different grain size fractions to have the grain size distribution as that of the bed material of interest and activate the powder in a nuclear reactor to produce the radiotracer (incorporating Scandium-46 or Irridium-192). In second method, normally used for fine sediment and short duration studies, a suitable radioisotope is labeled on the surface of the natural sediment and used as a tracer. Some of the important aspects of the techniques are discussed below.

### 6.2.2 Selection of grain size distribution

In order to track the sediment movement on the seabed it is necessary that the injected radiotracer should have identical physical properties (density and particle size distribution) as that of natural sediment. Usually very fines i.e. less than 60 microns are avoided as they have tendency to go into suspension and get washed away. Similarly, the coarser particles may move very slowly than the bulk sediment and thus are avoided. Therefore, for the present study a glass mixture of grain size distribution ranging from 60-100 μm was used as a tracer.

### 6.2.3 Selection and Preparation of radiotracer

A radioisotope to be used as a radiotracer for an investigation is selected on the basis of its half-life, type and energy of emitted radiations, to be produced in sufficient quantity in the desired form and radiotoxicity. For present investigation, scandium-46 (half-life: 84 days, gamma energies: 0.887 MeV (100%), 1.12 MeV (100%) in the form of scandium glass powder was selected to be used as a tracer. The tracer in the form of glass matrix was prepared as per the following composition:

$SiO_2$ : 64.5%
$CaO$ : 15.9%
$Na_2O_3$ : 18.6%
$Sc_2O_3$ : 1%.

Appropriate quantity of the mixture as per the above composition and was kept overnight in a furnace at a temperature of $1300^0$ C to produce glass of desired specific density i.e. ~2.62 gm/cm$^3$.

The prepared glass is crushed to obtain different desired size fractions and irradiated in a nuclear reactor to produce scandium-46 radioisotope. About 100 gms of scandium glass powder containing two desired size fractions i.e. 60-80 microns (20%), 80-100 (80%) and 1% scandium as $Sc_2O_3$ was used in present study. The produced radiotracer (8 Ci) was transferred to a brass container and shipped to the experimental site in Mangalore in a 7-inch lead pot weighing about 700 kg.

### 6.2.4 Background Survey

Prior to conducting the radiotracer experiment BARC people need to know the natural background radiation in the study area. Extensive background survey was carried out by them using a waterproof scintillation detector connected to a scaler/ratemeter and mounted on a sledge. The sledge mounted with the detector is dragged on the seabed and the natural radiation intensity is recorded at discrete locations. Natural background radiation level in the experimental area was observed to be in the range of 1500-2,000 cpm (counts/minute). The position of the detector at any time was fixed by a computerized positioning system available on board.

### 6.2.5 Tracer injection

The lead pot containing radiotracer was boarded onto a vessel VARAHI and shipped to the experimental site. In both the investigations, the radiotracer was injected at location $12^0$ 57.567' N and $74^0$ 41.685' E. The activities used in first and second investigations were 8 and 5 Ci, respectively. The tracer was transferred to the injection system mixed with 2-3 kg of sand, lowered onto the seabed using a crane and derrick and released onto the seabed. After injection, the injection system was disposed off by dumping at a location about 3 km away from the injection site.

### 6.2.6 Post injection trackings for First Investigation

The vessel VARAI was used for post injection trackings. The waterproof detector mounted on the sledge is lowered at the injection point and dragged on the seabed with a speed about 1.0-1.5 knots. At higher vessel speed the sledge gets lifted up resulting in non-detection of tracer. Other end of the detector is connected to a ratemeter kept in the deck near the Global Positioning System (GPS). The vessel dragging the sledge is navigated along predefined tracks and radiation intensity on seabed is manually noted at an interval of every 50-100 meters. The corresponding position i.e. latitude and longitude are also noted. The tracking on a particular track is continued till the background radiation levels are reached. Tracking is continued till the entire area around injection point is covered. Four trackings over a period of 3 months (90) days were carried out and the schedule of the trackings is given in Table1.

**Table 1: Schedule of post injection trackings**

| Tracking No. | Post injection Trackings | |
|---|---|---|
| | First Investigation | Second Investigation |
| Tracer injection | October 24, 2007 | January 20,2009 |
| 1st Tracking | October 25, 2007 | January 21-22,2009 |
| 2nd Tracking | November 14, 2007 | February 24-25, 2009 |
| 3rd Tracking | December 18, 2007 | April 15-16,2009 |
| 4th Tracking | January 23, 2008 | - |

### 6.3 Data Analysis

The tracer concentration recorded at discrete locations during each tracking is corrected for natural background level and radiation decay and the isocount contours were plotted. The isocount contours plotted for two different investigations are shown in Fig. 12, Fig. 13, Fig. 14, Fig. 15, Fig. 18, Fig 19and Fig 20.

### 6.3.1. Transport diagram and Velocity

For estimating the transport velocity, the cumulative of counts multiplied by the lateral distance of spread (cpm x m), at regular interval perpendicular to the general axis of transport is plotted for each tracking. These diagrams are called transport diagrams and each is characterized by its center of gravity (C.G). Center of gravity is determined by the following formula:

$$\overline{X} = \frac{\int Cxdx}{\int Cdx} \tag{1}$$

The transport diagrams with centre of gravity of each tracking are shown in Fig16 and Fig 17. The zero on x-axis indicates injection point. From the shift in centers of gravity of consecutive trackings, the mean velocity of transport for each tracking is calculated and is given in Table 2.

### 6.3.2. Transport Thickness

The determination of transport thickness is based on the count rate balance. As bed-load moves, the tracer gets mixed within the thickness of the moving bed. This depth of tracer burial is called "transport-thickness". The total integrated count rate N (cpm x $m^2$) over the whole surface area of tracer patch for each tracking is related to the transport thickness by,

$$N = \frac{\beta KA}{E\alpha(1-e^{-\alpha E})} \tag{2}$$

where, K is the calibration factor of the detector (4000 cpm/µCi/$m^2$), A is the total activity injected (8 Ci), $\alpha$ is the attenuation coefficient, (characteristic of the isotope, bed material and geometry of detector (0.15/cm for Scandium-46), E is the transport thickness (cm), $\beta$ is a function of transport thickness and the shape of distribution of tracer concentration with depth. Table 2 gives the value of E calculated using equation 2.

### 6.3.3. Transport Rate

The bed load transport rate Q (tonnes / day) can be expressed as:

$$Q = \rho . l . \ V . E \qquad (3)$$

where, ρ is the sediment bulk density (1.5 t/m$^3$), l is the width of transport (m), V is the mean velocity of transport (m/d). Table 2 also gives bed load transport rate per meter width.

**Table 2: Parameters of bed-load transport**

| Tracking No. | Days after injection | Location of C.G (m) | Activity spread N (cpm.m$^2$) | % Activity recovered | V (m/d) | E(cm) | Q (T/d/m) |
|---|---|---|---|---|---|---|---|
| **First Investigation** | | | | | | | |
| 1 | 1 | 182 | $2.92 \times 10^{10}$ | 91 % (7.3 Ci) | 182 | 1.2 | 3.27 |
| 2 | 20 | 665 | $2.8 \times 10^{10}$ | 87 % (7.0 Ci) | 25 | 1.7 | 0.63 |
| 3 | 53 | 611 | $2.8 \times 10^{10}$ | 87 % (7.0 Ci) | 8.2 | 1.7 | 0.21 |
| 4 | 90 | 802 | $2.6 \times 10^{10}$ | 81 % (6.5 Ci) | 6.8 | 2.5 | 0.26 |
| **Second Investigation** | | | | | | | |
| 1 | 1 | 170 | $1.80 \times 10^{10}$ | 90 % (4.5 Ci) | 170 | 1.35 | 3.39 |
| 2 | 33 | 495 | $1.38 \times 10^{10}$ | 72 % (3.6 Ci) | 10 | 4.2 | 0.63 |
| 3 | 84 | 487 | $1.36 \times 10^{10}$ | 52% (2.59Ci) | 3.8 | 6.4 | 0.36 |

### 6.4. Results and Discussion

#### 6.4.1. First Investigation

***1$^{st}$ Post Injection Tracking***

Radiotracer was injected on October 24, 2007 at location 12$^0$ 57.567" N and 74$^0$ 41.685" E at 12:30 hours and the first tracking was carried out on October 25, 2007. The isocount contours and transport diagram for first post injection tracking are shown in Fig. 12 and Fig. 16, respectively. The isocount contours clearly indicate that the general direction of movement of tracer is towards west i.e. away from the shipping channel. The movement of tracer towards west was about 600 meters from injection point, whereas towards east the tracer moved only about 200 meters. The maximum transverse distance covered by tracer in a period of one day was about 400 meters. During first tracking about 91% of injected activity was recovered indicating loss of small fraction of radiotracer due saturation limit of radiation detector.

### *2$^{nd}$ Post Injection Tracking*

The isocount contours and transport diagram for second post injection tracking are shown in Fig. 13 and Fig. 16 respectively. The isocount contour indicates that the tracer predominantly moves towards north-west direction. The longitudinal distances covered by tracer towards west and east from injection point were about 800 meters and 400 meters respectively. Similarly, the maximum spread in north-south direction was about 2100 meters with 1400 towards north and 700 meters towards south from injection point. During second tracking about 87% of injected activity was recovered indicating loss of negligibly small fraction of radiotracer due to burial. Thus the thickness of the moving sediment layer and rate of bed-load transport were also negligibly small as shown in Table 2. The velocity of sediment transport was about 25 meters/day calculated over a period of 20 days.

### *3$^{rd}$ Post Injection Tracking*

The isocount contours and transport diagram for third post injection tracking are shown in Fig. 14 and Fig. 16 respectively. The spread pattern in third tracking was found almost similar to that of the second tracking. The longitudinal distances covered by tracer towards west and east from injection point were about 600 meters and 300 meters respectively. Similarly, the maximum spread in north-south direction was about 2000 meters with 1500 towards north and 500 meters towards south from injection point. During third tracking about 87% activity was recovered indicating significant burial of radiotracer. Thus the thickness of the moving sediment layer was calculated to be about 1.7 cm. The velocity and bed-load transport rate were calculated to be thickness of moving sediment layer was 8.2 meter/day and 0.21 tons/day/meter.

### *4th Post Injection Tracking*

The isocount contours and transport diagram for fourth post injection tracking are shown in Fig. 15 and Fig. 16 respectively. During 4th tracking carried out after a period of 90 days, the tracer movement was predominantly towards north-west. However, the maximum concentration of tracer was confined to about 700 meters around the injection point. The maximum longitudinal distance covered by tracer was about 1100 meters with 700 meters towards west and about 400 meters towards east. Similarly, the maximum spread in north-south direction was about 1700 meters with1200 towards north and 500 meters towards south from injection point. During fourth tracking about 81% activity was recovered and the thickness of moving sediment layer and bed-load transport rate was calculated to be 2.5 cm and 0.26 ton/day/meter, respectively.

## *6.4.2. Second Investigation*

### *1st Post Injection Tracking*

The radiotracer was injected on January 20, 2009 at location $12^0$ 57.567" N and $74^0$ 41.685" E at 12:30 hours and the first tracking was carried out during January 21-22, 2009. The transport diagram and isocount contours for first post injection tracking are shown in Fig. 17 and Fig. 18, respectively. The isocount contours clearly indicate that the general direction of movement of tracer was predominantly towards north-west. The movement of tracer towards north was about 900 meters from injection point, whereas towards west the tracer moved only about 500 meters. Similarly, the maximum spread in east-west direction was about 650 meters with 500 towards west and 150 meters towards east from injection point. During first tracking about 90% of injected activity was recovered indicating loss of small fraction of radiotracer due saturation limit of radiation detector.

### *2nd Post Injection Tracking*

The transport diagram and isocount contours for second post injection tracking are shown in Fig. 17 and Fig. 19, respectively. The isocount contour indicates that the tracer predominantly moves towards north-west and south-east direction. The longitudinal distances covered by tracer towards east and west from injection point were about 500 meters and 600 meters respectively. Similarly, the maximum spread in north-west direction was about 900 meters, however spread in south-east direction was about 600 metes from injection point. During second tracking about 72% of injected activity was recovered indicating loss of small fraction of radiotracer due to burial. Thus the thickness of the moving sediment layer and rate of bed-load transport were also negligibly small as shown in Table 2. The thickness of the moving sediment layer was calculated to be about 4.2 cm. The velocity and bed-load transport rate were calculated to be thickness of moving sediment layer was 4.2 meter/day and 0.63 tons/day/meter respectively.

### *3rd Post Injection Tracking*

The transport diagram and isocount contours for third post injection tracking are shown in Fig. 17 and Fig. 20 respectively. The spread pattern in third tracking was found slightly different to that of the second tracking. The isocount contour indicates that the tracer predominantly moves towards north-west and south-east direction. The longitudinal distances covered by tracer towards north and west from injection point were about 600 meters and 500 meters respectively. Similarly, the maximum spread in north-south direction was about 1200 meters with 600 meter towards north and 600 meters towards south from injection point. During third tracking about 52% activity was recovered indicating significant burial of radiotracer. Another reason for this low recovery of tracer was inadequate tracking due to bad weather conditions. Based on the recovered activity (tracer) the thickness of the moving sediment layer was estimated to be about 6.4 cm. The velocity and bed-load transport rate were calculated to be thickness of moving sediment layer was 3.8 meter/day and 0.36 tons/day/meter respectively.

## 6.5 Conclusions

### *6.5.1 First Investigation*

From the results following conclusions were drawn.

1. The sediment predominantly moves towards north-west direction during all the four trackings. The movement towards south and east direction was relatively much less.
2. After a period of 90 days the maximum longitudinal distance moved by sediment along west-east direction was about 1000 meters. Similarly maximum transverse movement along north-south direction was about 1600 meters.
3. The average velocity of sediment transport over a period of 3 months (90 days)

was found to be 7.5 meters/day during the last two trackings.

4. Based on the investigations, it is found that the proposed site is suitable for dumping the dredged material during post south-west monsoon period (October-January), as the movement of sediment is away form the shipping channel.

### *6.5.2 Second Investigation*

From the results following conclusions were drawn.

1. The sediment predominantly moves towards north-west during the first post injection tracking.
2. The sediment predominantly moves towards north-west and south-east during the second and third trackings.
3. After a period of 84 days maximum longitudinal distance moved by sediment along east-west direction was about 700 meters. Similarly maximum transverse movement along north-south direction was about 1000 meters.
4. The average velocity of sediment transport over a period of about 3 months (84 days) was found to be 7 meters/day.
5. The movement of sediments is significant in north-west direction during January. However, during February-April it was noticed that the sediments moved towards south-east direction. Therefore it is suggested that a periodic bathymetry survey should be carried out in the dumping area over a long period of time to monitor the sediment build up.

## 6.6 Concluding remarks

The radiotracer investigation was successfully carried out to investigate the dispersion of sediments during two different periods. The results of both the investigations indicated that the present dumping site is suitable for dumping the dredged sediment during both the periods i.e. pre and post south-west monsoon period. The results of the investigations will help the port authorities to plan and optimize the dredging and dumping operations.

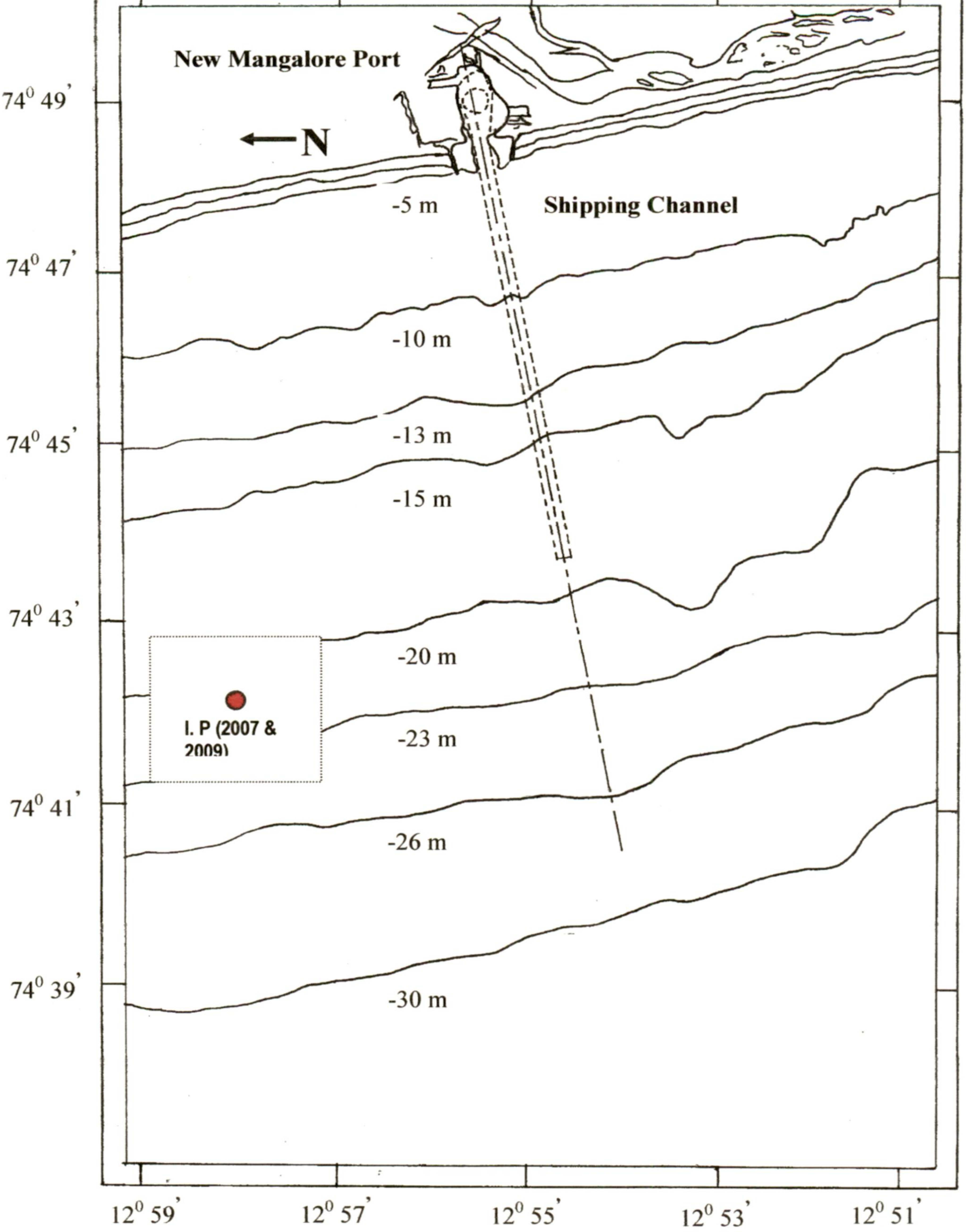


Fig. 11. PLAN OF NEW MANGALORE PORT AND STUDY AREA

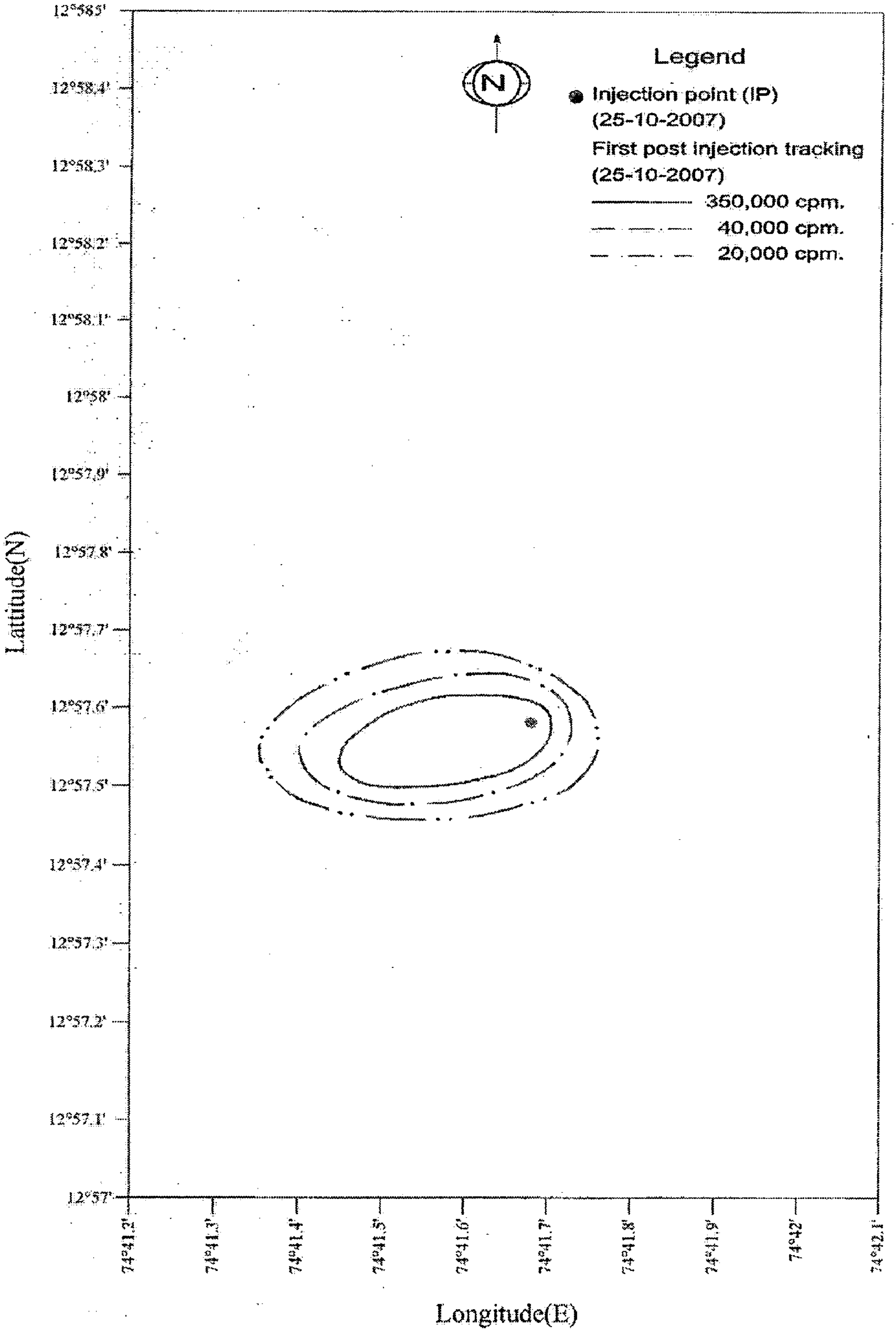


FIG. 12 : ISOCOUNT CONTOURS OF FIRST POST INJECTION TRACKING (FIRST INVESTIGATION)

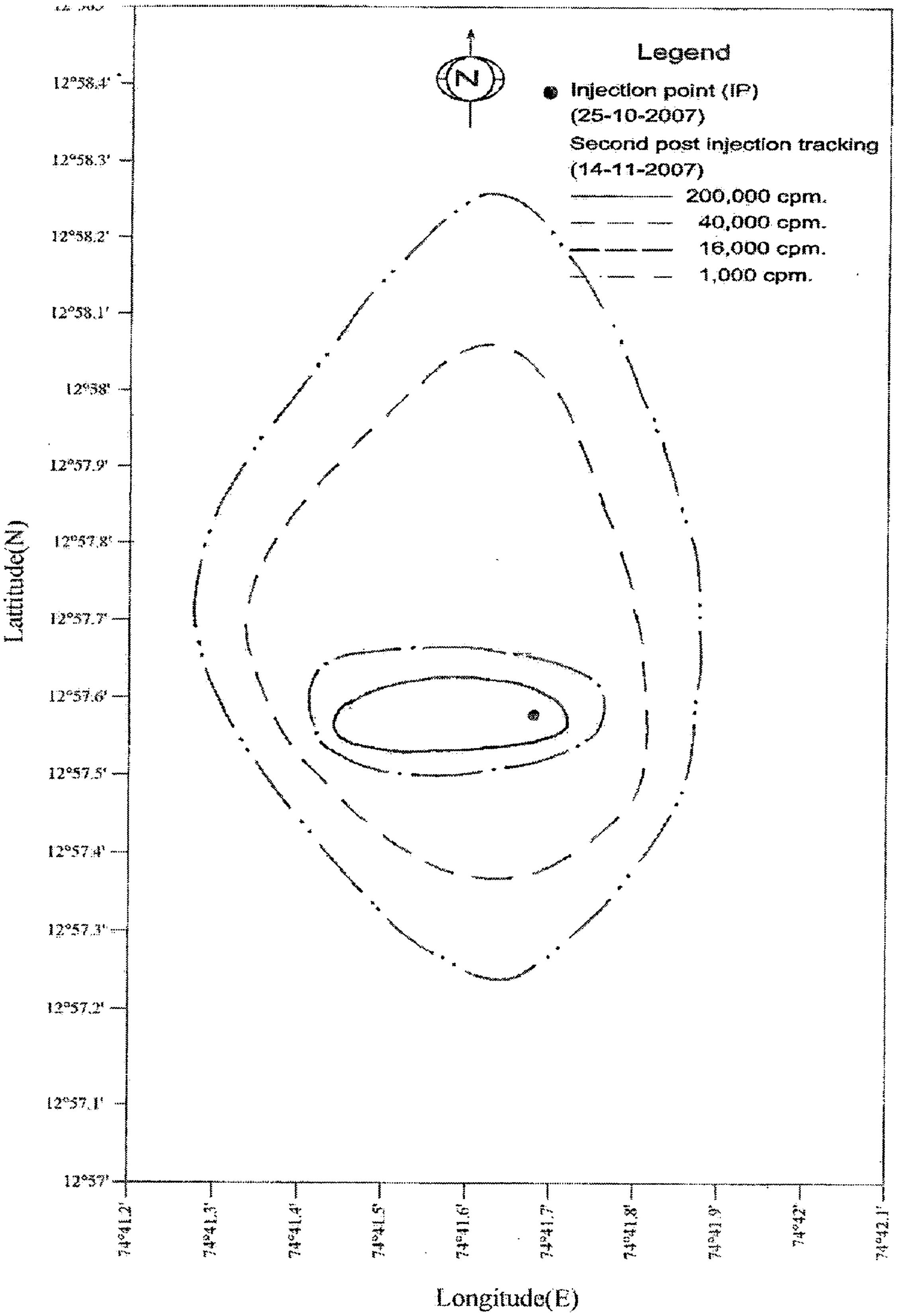


FIG. 13: ISOCOUNT CONTOURS OF SECOND POST INJECTION TRACKING (FIRST INVESTIGATION)

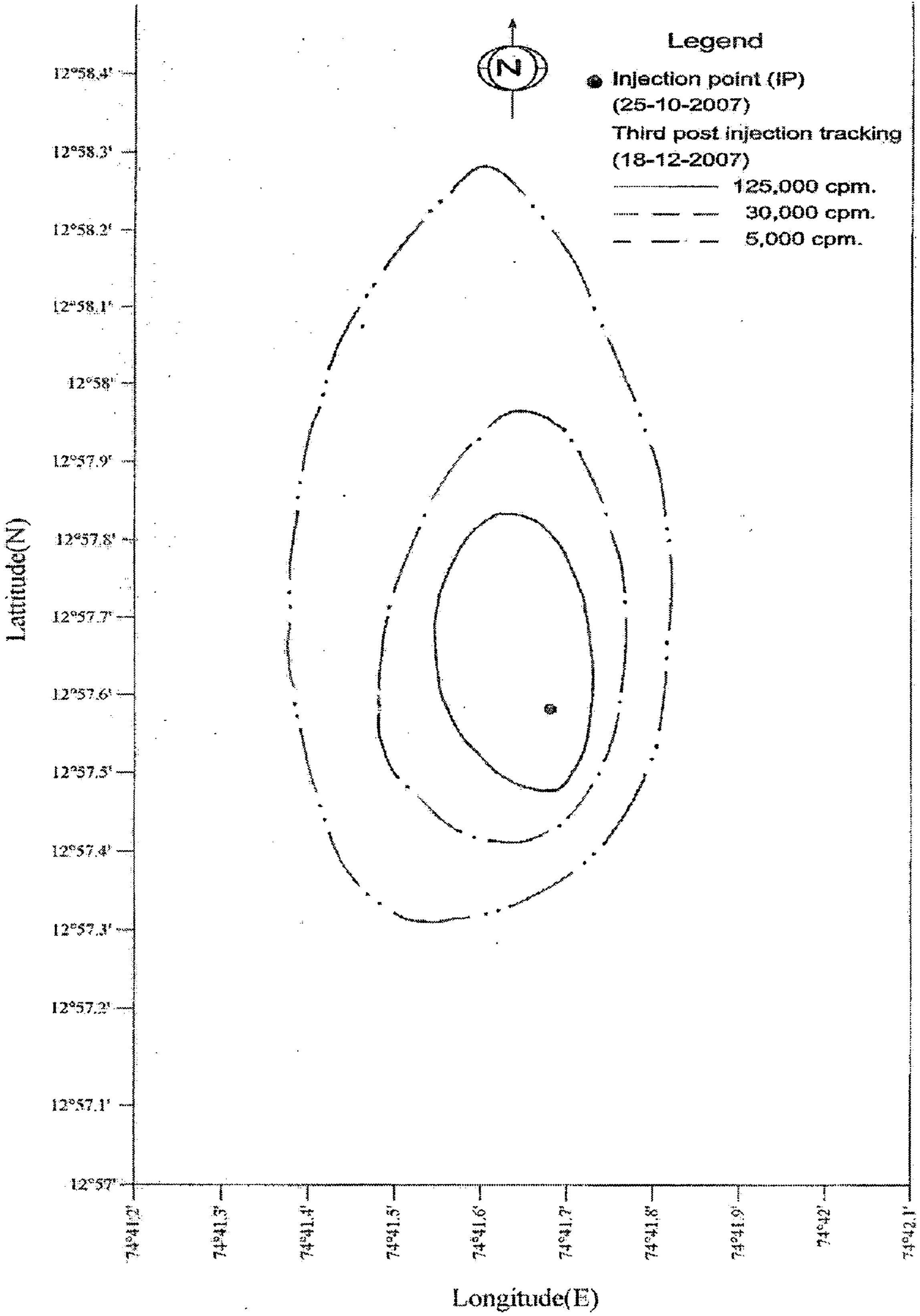


**FIG. 14: ISOCOUNT CONTOURS OF THIRD POST INJECTION TRACKING (FIRST INVESTIGATION)**

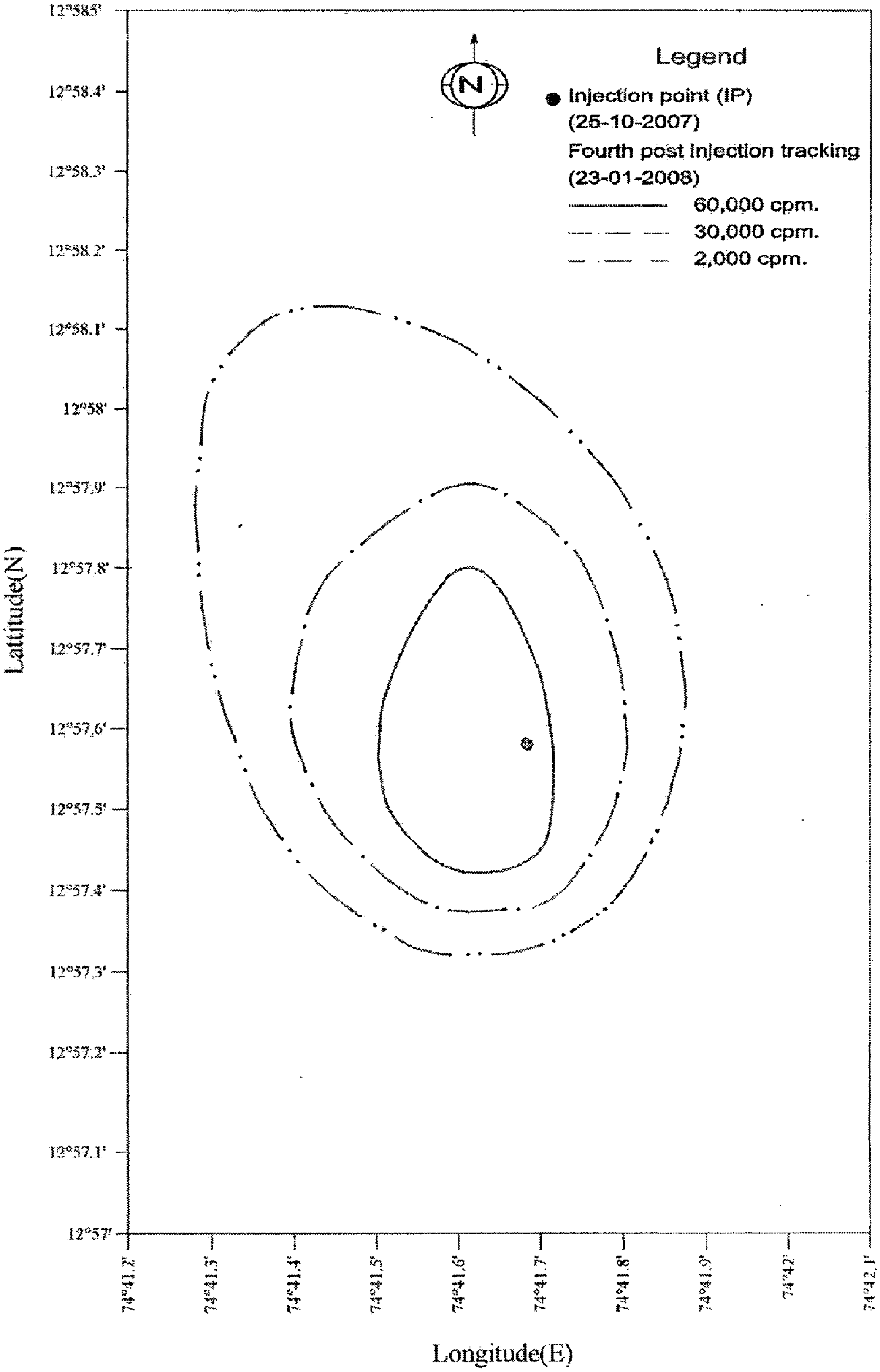


FIG. 15: ISOCOUNT CONTOURS OF FOURTH POST INJECTION TRACKING (FIRST INVESTIGATION)

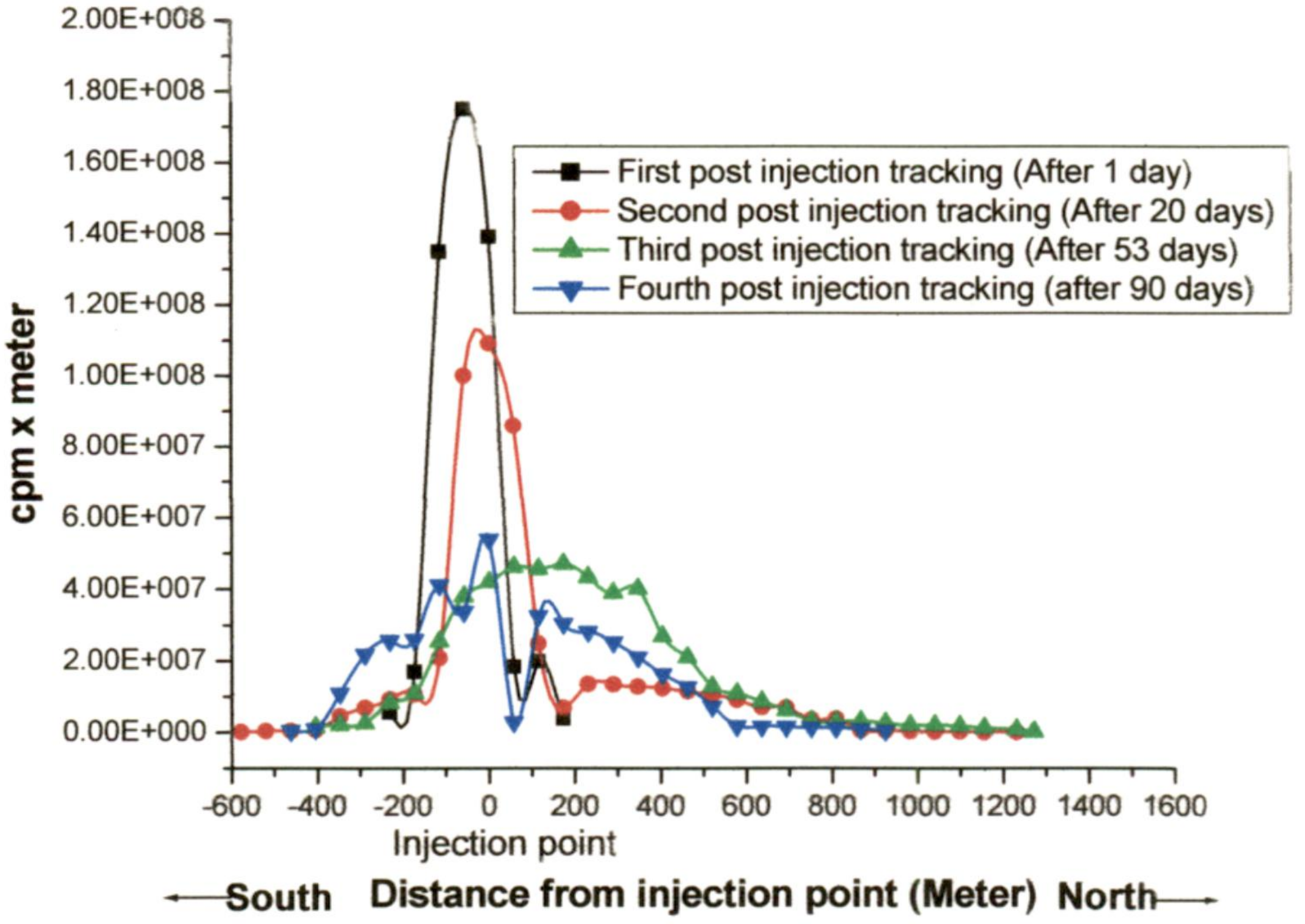


FIG. 16: TRANSPORT DIAGRAMS FOR POST INJECTION TRACKINGS (FIRST INVESTIGATION)

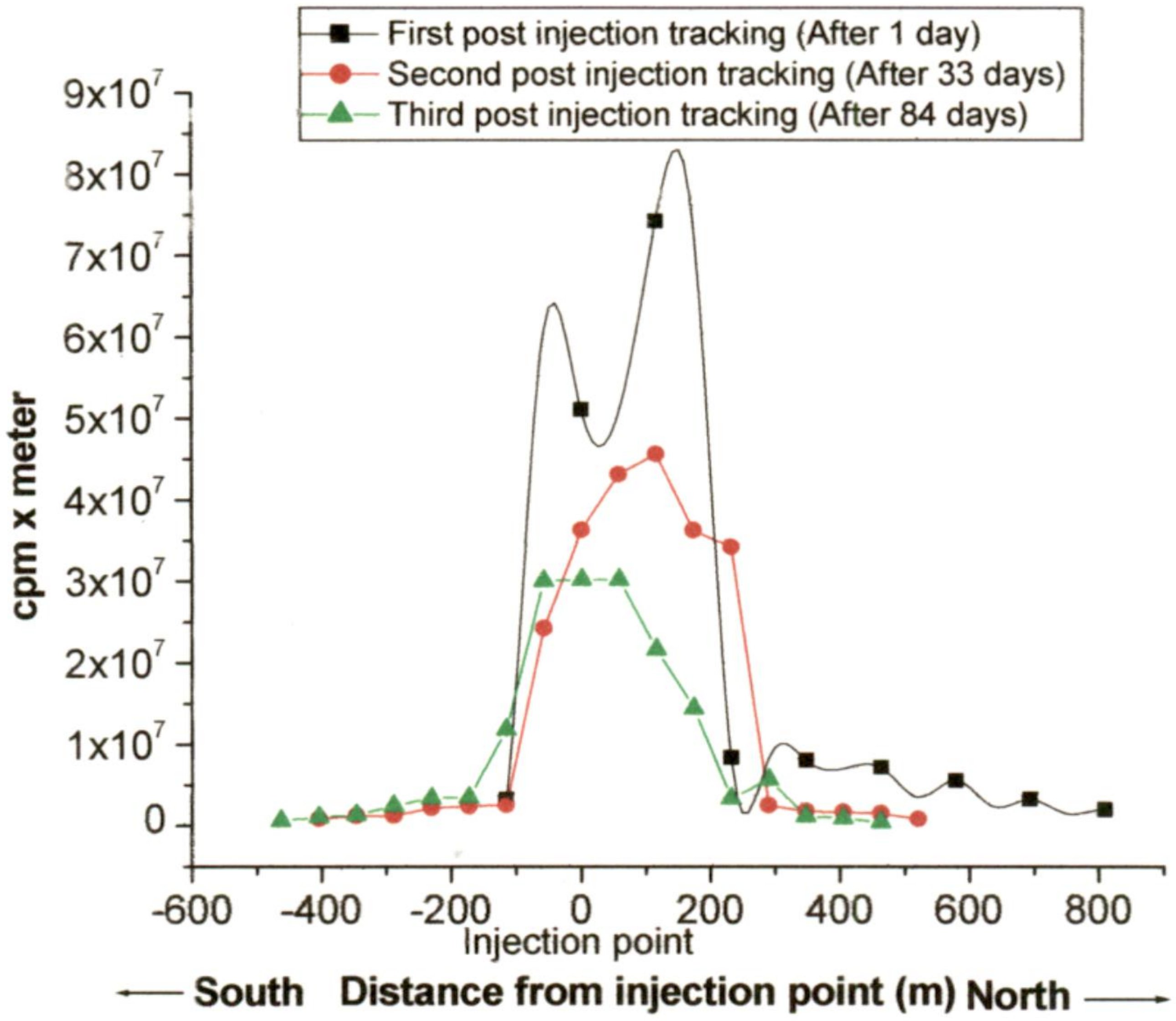


FIG. 17: TRANSPORT DIAGRAMS FOR POST INJECTION TRACKINGS (SECOND INVESTIGATION)

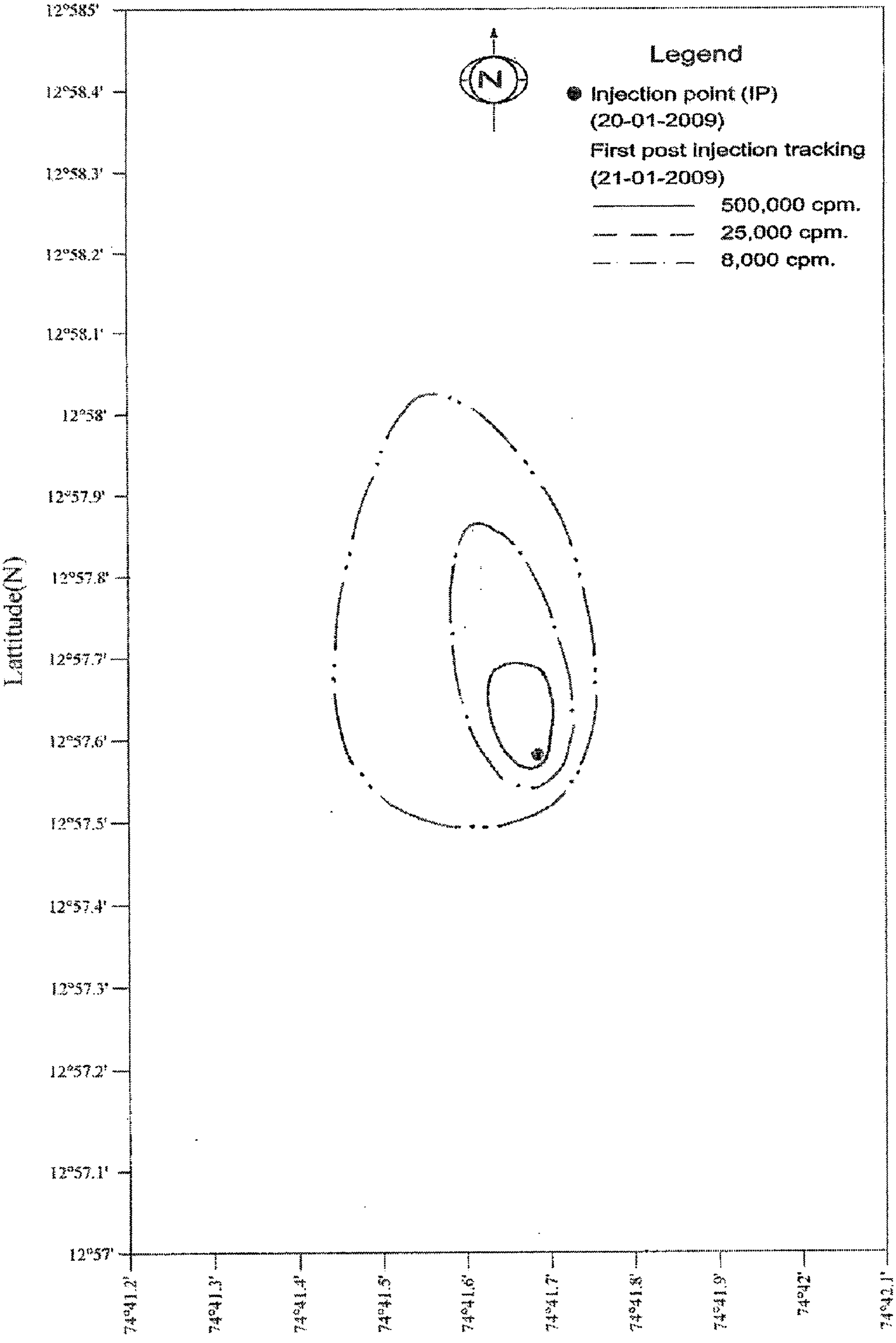


FIG. 18: ISOCOUNT CONTOURS OF FIRST POST INJECTION TRACKING (SECOND INVESTIGATION)

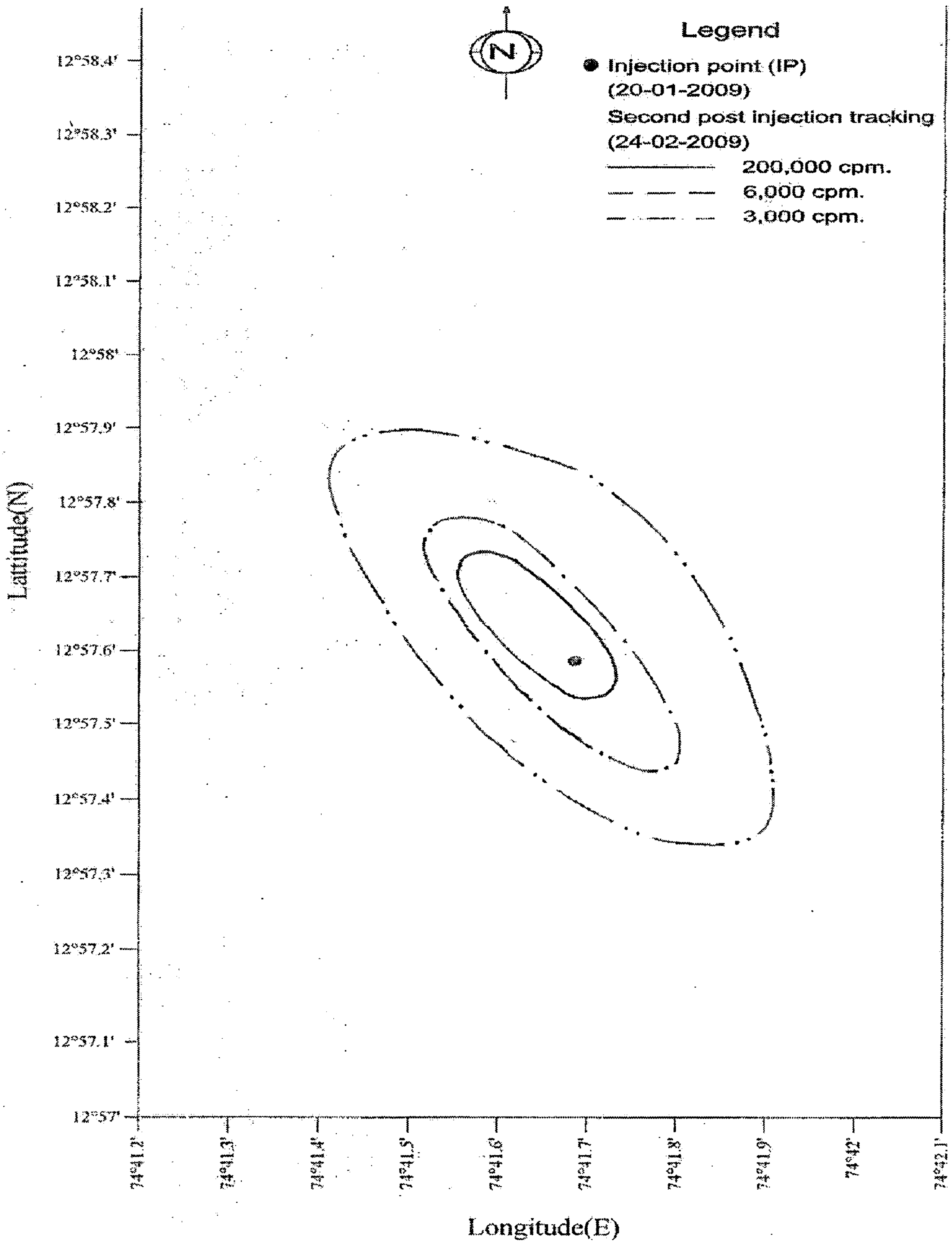


FIG. 19: ISOCOUNT CONTOURS OF SECOND POST INJECTION TRACKING (SECOND INVESTIGATION)

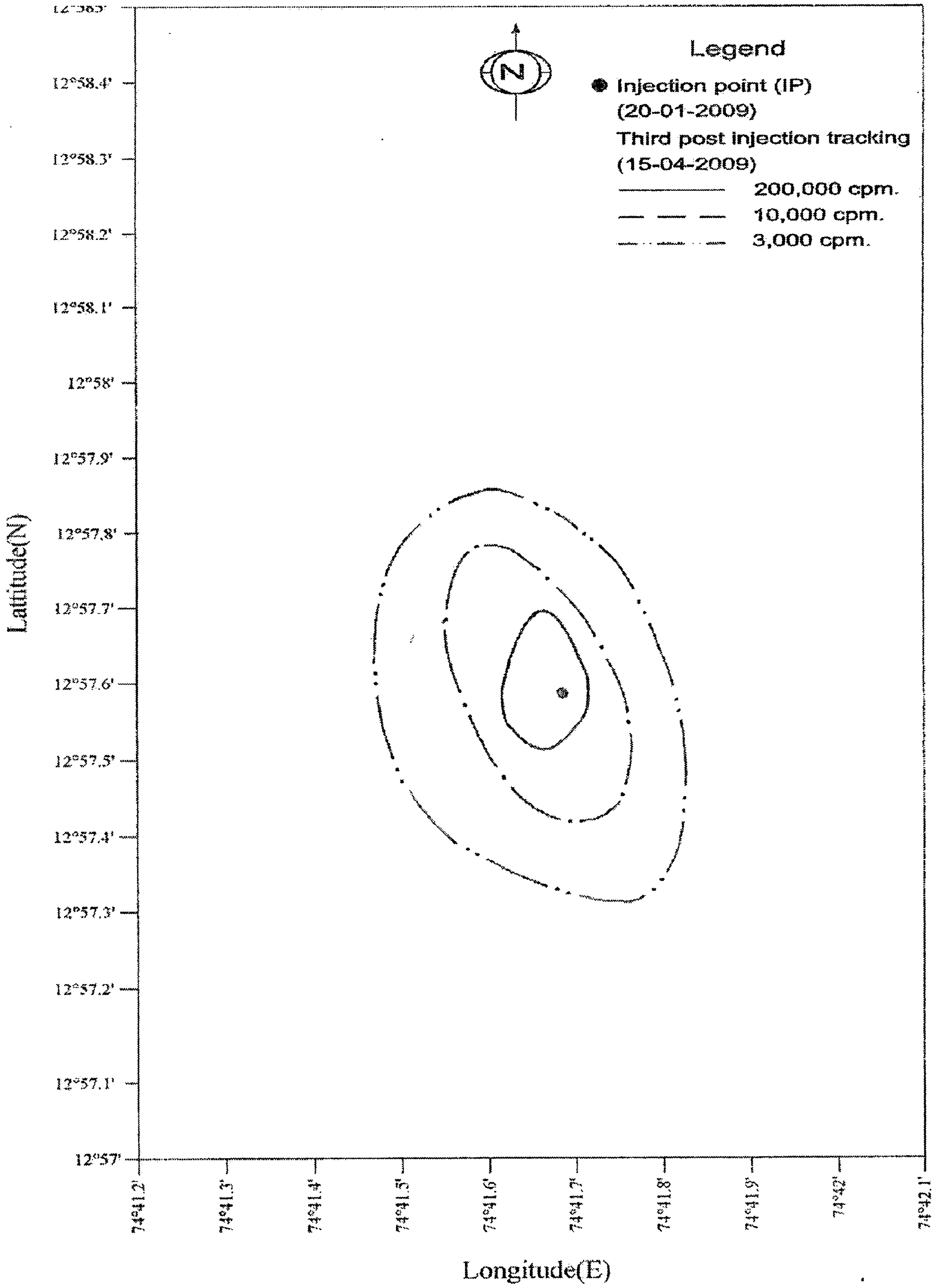


FIG. 20: ISOCOUNT CONTOURS OF THIRD POST INJECTION TRACKING (SECOND INVESTIGATION)

## CHAPTER – 7

# METHODOLOGY OF SIMULATING DISPERSION BY USING MIKE 21

## 7.1 GENERAL DESCRIPTION

MIKE 21 Flow Model is a modelling system for 2D free-surface flows. MIKE 21 Flow Model is applicable to the simulation of hydraulic and environmental phenomena in lakes, estuaries, bays, coastal areas and seas. It may be applied wherever stratification can be neglected.

## 7.2 INTRODUCTION TO HYDRODYNAMIC MODELLING

The hydrodynamic (HD) module is the basic module in the MIKE 21 Flow Model. It provides the hydrodynamic basis for the computations performed in the Environmental Hydraulics modules.

The hydrodynamic module simulates water level variations and flows in response to a variety of forcing functions in lakes, estuaries and coastal regions. The effects and facilities include:

- bottom shear stress
- wind shear stress
- barometric pressure gradients
- Coriolis force
- momentum dispersion
- sources and sinks
- evaporation
- flooding and drying
- wave radiation stresses

### 7.2.1 Application Areas

MIKE 21 Flow Model, Hydrodynamic Module, can be applied to a wide range of hydraulic and related phenomena. This includes:

- modelling of tidal hydraulics
- wind and wave generated currents
- storm surges

The MIKE 21 HD output results are also used as input for many of the other MIKE 21 modules such as the Advection-Dispersion module (AD), the Sediment

Transport (ST, MT), the Particle tracking (PA) and the Environment module (ECOLab). As MIKE 21 HD is a very general hydraulic model, it can easily be set up to describe specific hydraulic phenomena. Examples of such applications are:

- secondary circulations, eddies and vortices
- harbour seiching
- dam-break
- Tsunamis

### 7.2.2 Hydrodynamic Model

2-Dimensional Hydrodynamic model MIKE-21 was used to simulate the flow field at NMPT offshore area under different tidal conditions. In order to simulate water borne transport process, it is necessary to know dynamics of the water body in terms of velocity and water level fluctuations beforehand. The appropriate governing equations for studying water movement in tidal areas are the two dimensional shallow water equations. These are obtained by vertically integrating the Navier-Stokes equations of motion making the following simplified assumptions -

- The flow is incompressible
- The flow is well mixed (no variation in density)
- Vertical accelerations are negligible
- Bed stress can be modelled using a quadratic friction law

Continuity equation:

$$\frac{\partial z}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=0 \qquad (1)$$

Equation of *motion* in x-direction

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial z}{\partial x}+\tau_{bx}-C_f v-E_c\nabla^2 u = 0 \qquad (2)$$

Equation of motion in y-direction :

$$\frac{\partial u}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial z}{\partial x}+\tau_{by}-C_f u-E_c\nabla^2 v = 0 \qquad (3)$$

where,

u : velocity in x co-ordinate direction;
v : velocity in y co-ordinate direction;
z : surface elevation of water;
$C_f$ : Coriolis force;
x,y : co-ordinate directions;
$E_c$ : Eddy viscosity coefficient;
t : time;
g : acceleration due to gravity

The governing equations arc solved using alternating directions implicit (ADI) finite difference technique based on Crank-Nicholson scheme. This entails covering the estuary with a mesh or grid and discretising elevations and velocities in space and time to fit on this grid in a discretised manner. Having discretised the variables, derivatives are approximated by simple differences divided by the distance between consecutive grid points. The space differences involve variables at the unknown time level being calculated; thus a system of equations involving the boundary conditions has to be solved before the value of the variables at the next time step can be obtained. They are thus known implicitly. Alternating directions implicit scheme (ADI) implies that in one time step, there are two half time steps. In one half time step, the scheme is implicit in the east-west direction and explicit in the north- south direction. In the next half time step, computations are implicit in the north-south direction and explicit in the east-west direction. ADI scheme is computationally efficient and widely used in solving shallow water equations. Thus all the three variables water level and velocity components along co-ordinate directions can be computed at each time step.

### 7.2.3 Defining the Hydrodynamic Model

The northern part of NMPT Port including the injection site is shown in Figure 21. The currents are governed mainly by the tide due to non-monsoon season.

The model area was chosen based on the following considerations:

- The model is turned 77 degrees relative to true north so that the y-axis lies parallel to the flow in the main channel running from NMPT towards the Arabian Sea. This rotation of the model also reduces the number of grid points in the model and makes the main flow direction at the boundary perpendicular to it.

- The boundary is situated not too close to the approach channel. This ensures a uniform flow pattern at the boundary. Furthermore, the boundary cannot be situated in the approach channel itself, as flooding and drying are not allowed on an open boundary.

As the area required to be simulated is very large, hence a grid spacing of 90 meters was chosen to keep the number of grid points in the optimum range. The total no. of grids in x-direction are 196 (0 to 195) i.e. 17.55 km and total no. of grids in y-direction are 224 (0 to 223) i.e. 20.07 km.

The time step was chosen to be 20 seconds to keep the maximum Courant number in the area of the order of 3.87.

### 7.2.4 Collecting Data

The digitised bathymetry was based on Admiralty Charts No. 2052. Tidal level observations and current measurements were provided by the port authority. Tidal levels used for model is shown in fig. 22.

### 7.2.5 Setting Up the Model

The digitised model bathymetry in 3-D is shown in fig. 23. Much effort was spent in its preparation especially in the approach channel and offshore area including the injection site, where the dredged material to be disposed.

Simultaneous measurements of the water level close to the disposed site had been made for a period of a little more than one tidal cycle. This period was therefore selected as the calibration period. A tidal range of 1.68 meters with a period of 12.5 hours was measured at the boundary.

### 7.2.6 Calibrating and Verifying the Model

The model was calibrated so that the simulated and measured water level variation near disposed site showed a satisfactory agreement. The simulated and measured current speeds and water levels are shown in fig. 24 and fig. 25.

For the whole model a Manning number of 32 $m^{1/3}/s$ and a constant eddy viscosity of 4 $m^2/s$ was used. A simulation period of 3 months for both the investigations was selected. Simulation period of more than two tidal cycles have been kept as the warm up period for the model, while the second onward could then be used for comparisons.

### 7.2.7 Running the Hydrodynamic Simulations

We run the hydrodynamic model for simulation period of 3 months for both the investigations.

### 7.2.8 Presenting the Results

Model results are presented in the plots showing the flow pattern and currents for various tidal levels (as in figures 26 to 34).

## 7.3 INTRODUCTION TO MUD TRANSPORT MODELLING

### 7.3.1 What is Mud

Mud is a term generally used for fine-grained and cohesive sediment with grain-sizes less than 63 microns. Mud is typically found in sheltered areas protected from strong wave and current activity. Examples are the upper and mid reaches of estuaries, lagoons and coastal bays. The sources of the fine-grained sediments may be both fluvial and marine.

Fine-grained suspended sediment plays an important role in the estuarine environment. Fine sediment is brought in suspension and transported by current and wave actions. In estuaries, the transport mechanisms (settling and scour lag) acting on the fine-grained material tend to concentrate and deposit the fine-grained material in the inner sheltered parts of the area (Postma, 1967; Pejrup, 1988)[6]. A zone of high concentration suspension is called a turbidity maximum and will change its position within the estuary depending on the tidal cycle and the input of fresh-water from rivers, etc. (Dyer, 1986)[7].

Fine sediments are characterised by slow settling velocities. Therefore, they may be transported over long distances by the water flow before settling. The cohesive properties of fine sediments allow them to stick together and form larger aggregates or flocs with settling velocities much higher than the individual particles within the floc (Krone, 1986; Burt, 1986)[8]. In this way they are able to deposit in areas where the individual fine particles would never settle. The formation and destruction of flocs are depending on the amount of sediment in suspension as well as the turbulence properties of the flow. This is in contrast to non-cohesive sediment, where the particles are transported as single grains.

Fine sediment is classified according to grain-size as shown in the table 3 below.

**Table 3: Classification of fine sediment**

| Sediment type | Grain size |
|---|---|
| Clay | < 4 µm |
| Silt | 4-63 µm |
| Fine sand | 63-125 µm |

### 7.3.2 General Model Description

In order to include the transport and deposition processes of fine-grained material in the modelling system, it is necessary to integrate the description with the advection-diffusion equation caused by the water flow.

MIKE 21 is a depth-integrated, two-dimensional flow model. This means that the simulation of the transport of fine-grained material must be averaged over depth and appropriate parameterisations of the sediment processes must be applied.

In the MIKE 21 model complex, the transport of fine-grained material (mud) has been included in the Mud Transport module (MT), linked to the Hydrodynamic module (HD) and the Advection-Dispersion (AD) module, as indicated in Figure 35.

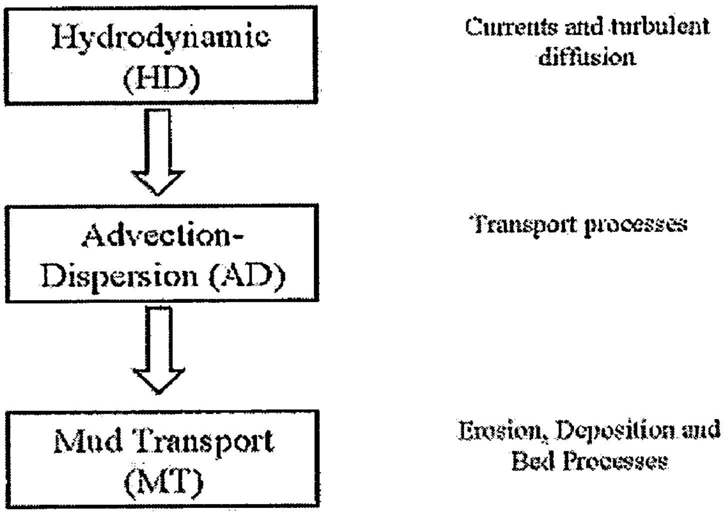


FIG. 35: DATA FLOW AND PHYSICAL PROCESSES FOR MIKE - 21

The combination of the Multi-Fraction and Multi-Layer models is an extension compared to the earlier versions of MIKE 21 MT, where these models were independent.

The MIKE 21 Flow Model, Mud Transport Module (MT) describes erosion, transport and deposition of mud or sand/mud mixtures under the action of currents and waves. The processes included in the MT module are kept as general as possible.

The MT module includes the following processes:

- Multiple mud fractions
- Multiple bed layers
- Wave-current interaction
- Flocculation
- Hindered settling
- Inclusion of a sand fraction
- Sliding
- Consolidation of layers
- Simple morphological calculations

The above possibilities cover most cases appropriate for 2D modelling.

In the MT-module, the settling velocity varies, according to the salinity, if included, and the concentration taking into account flocculation in the water column. Furthermore, hindered settling and consolidation in the fluid mud and under consolidated bed are included in the model. Bed erosion can be either non-uniform i.e. the erosion of soft and partly consolidated bed, or uniform, i.e. the erosion of a dense and consolidated bed. The bed is described as layered and characterised by the density and shear strength.

### 7.3.3 Application Areas

The Mud Transport Module can be applied to the study of engineering problems such as:

- Sediment transport studies for fine cohesive materials or sand/mud
- mixtures in estuaries and coastal areas in which environmental aspects are involved and degradation of water quality may occur.
- Siltation in harbours, navigational fairways, canals, rivers and reservoirs
- Dredging studies.

### 7.3.4 The AD module

The sediment transport formulations are built into the advection-dispersion module, MIKE 21 AD.

The Advection-Dispersion Module solves the so-called advection-dispersion equation for dissolved or suspended substances in two dimensions. This is in fact the mass-conservation equation. Discharge quantities and compound concentrations at source and sink points are
included together with a decay rate.

$$\frac{\partial}{\partial t}(hc)+\frac{\partial}{\partial x}(uhc)+\frac{\partial}{\partial x}(vhc)=\frac{\partial}{\partial x}\left(h.Dx.\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(h.Dy.\frac{\partial c}{\partial y}\right)-F.h.c+S$$

where,

$c$ : compound concentration (arbitrary units)
$u$, $v$ : horizontal velocity components in the x ,y directions (m/s)
$h$ : water depth (m)
$D_x$, $D_y$: dispersion coefficients in the x, y directions ($m^2/s$)
$F$ : linear decay coefficient ($sec^{-1}$)
$S$ : $Q_s.(c_s-c)$
$Q_s$ : source/sink discharge ($m^3/s/m^2$)
$C_s$ : concentration of compound in the source/sink discharge.

Information on u, v and h at each time step is provided by the hydrodynamic module.

In cases of multiple sediment fractions, the equation is extended to include several fractions while the deposition and erosion processes are connected to the number of fractions.

The advection-dispersion equation is solved using an explicit, third-order finite difference scheme, known as the ULTIMATE scheme, Leonard (1991)[9]. This scheme is based on the well-known QUICKEST scheme, Leonard (1979), Ekebjærg et al. (1991)[10].

This scheme has been described in various papers dealing with turbulence modelling, environmental modelling and other problems involving the advection-dispersion equation. It has several advantages over other schemes, especially which it avoids the "wiggle" instability problem associated with central differentiation of the advection terms. At the same time it greatly reduces the numerical damping, which is characteristic of first order up-winding methods.

The scheme itself is a Lax-Wendroff or Leith-like scheme in the sense that it cancels out the truncation error terms due to time differentiation up to a certain order by using the basic equation itself. In the case of QUICKEST, truncation error terms up to third-order are cancelled for both space and time derivatives.

The solution of the erosion and the deposition equations are straightforward and do not require special numerical methods.

Firstly is outlined the scientific background for the fine-grained sediment < 63 µm followed by the sand fraction.

### 7.3.5 Cohesive Sediments

The mud transport module of MIKE 21 describes the erosion, transport and deposition of fine-grained material < 63 µm (silt and clay) under the action of currents and waves. For a correct solution of the erosion processes, the consolidation of sediment deposited on the bed is also included.

The model is essentially based on the principles in Mehta et al. (1989)[11] with the innovation of including the bed shear stresses due to waves. Clay particles have a plate-like structure and an overall negative ionic charge due to broken mineral bonds on their faces. In saline water, the negative charges on the particles attract positively charged cations and a diffuse cloud of cations is formed around the particles. In this way the particles tend to repel each other (Van Olphen, 1963)[12]. Still, particles in saline water flocculate and form large aggregates or flocs in spite of the repulsive forces. This is because in saline water, the electrical double layer is compressed and the attractive van der Waals force acting upon the atom pairs in the particles becomes active. Flocculation is governed by increasing concentration, because more particles in the water enhance meetings between individual particles. Turbulence also plays an important role for flocculation both for the forming and breaking up of flocs depending on the turbulent shear (Dyer, 1986)[13].

A deterministic physically based description of the behaviour of cohesive sediment has not yet been developed, because the numerous forces included in their behaviour tend to complicate matters. Consequently, the mathematical descriptions of erosion and deposition are essentially empirical, although they are based on sound physical principles.

The lack of a universally applicable, physically based formulation for cohesive sediment behaviour means that any model of this phenomenon is heavily dependent on field data (Andersen & Pejrup, 2001; Andersen, 2001; Edelvang & Austen, 1997; Pejrup et al., 1997)[14]. Extensive data over the entire area to be modelled is required such as:

- bed sedimentology
- bed erodibility
- biology
- settling velocities
- suspended sediment concentrations
- current velocities
- vertical velocity and suspended sediment concentration profiles
- compaction of bed layers
- effect of wave action
- critical shear stresses for deposition and erosion

Naturally, the dynamic variation of water depth and flow velocities must also be known along with boundary values of suspended sediment concentration.

The MIKE 21 MT module consists of a 'water-column' and an 'in-the-bed' module. The link between these two modules is source/sink terms in an advection-dispersion model.

The transport and deposition of fine-grained material is governed by the fact that settling velocities are generally slow compared to sand. Hence, the concentration of suspended material does not adjust immediately to changes in the hydraulic conditions. In other words, the sediment concentration at a given time and location is dependent on the conditions upstream of this location at an earlier time. Postma (1967)[15] first described this process, called settling- and scour-lag. This is the main factor for the concentration of fine material in estuaries often resulting in a turbidity maximum. In order to describe this process, the sediment computation has been built into the advection-dispersion module, MIKE 21 AD.

The source and sink term S in the advection-dispersion equation depends on whether the local hydrodynamic conditions cause the bed to become eroded or allow deposition to occur. Empirical relations are used, and possible formulations for evaluating S are given below.

The mobile suspended sediment is transported by long-period waves only, which are tidal currents, whereas the wind-waves are considered as "shakers". Combined they are able to re-entrain or re-suspend the deposited or consolidated sediment.

The processes in the bed are described in a multi-layer bed (max. 8); each described by a critical shear stress, erosion coefficient , power of erosion, density of dry sediment and erosion function. The bed layers can be dense and consolidated or soft and partly consolidated.

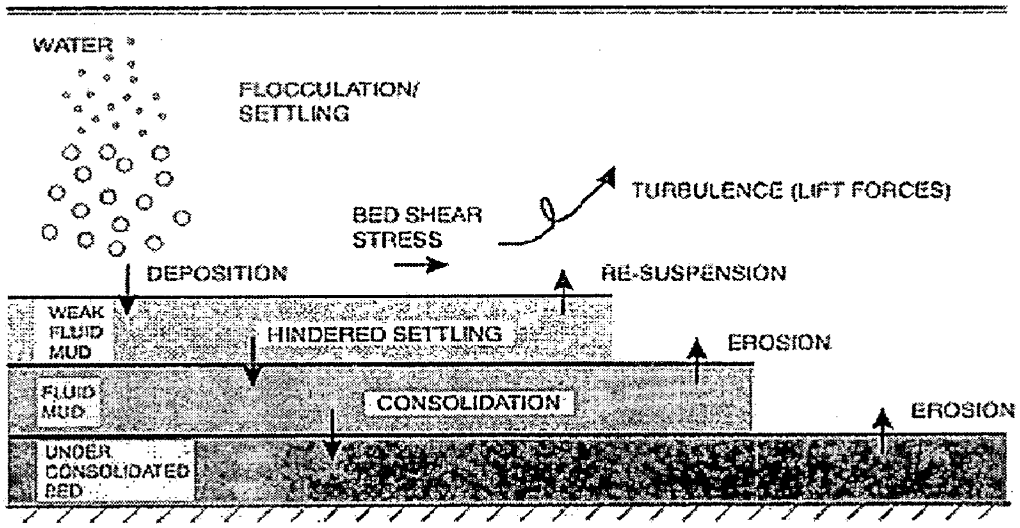
Liquefaction by waves is included as a weakening of the bed due to breakdown of the bed structure.

Consolidation is included between the layers as a transition rate of sediment between the layers.

In areas with deep channels or large variations in water depths it is possible to include a sliding process, which allows sediment to slide down to deeper areas due to gravity and current motion. This is described by a dispersion equation.

### 7.3.6 Model description

The physical processes are modelled by a "multi bed layer approach". An example with 3 bed layers is shown in Figure 36.



**Processes**

- flocculation
- settling
- deposition
- consolidation
- re-suspension by currents and waves
- erosion by currents and waves
- liquefaction by waves
- sliding

FIG. 36: MULTI-LAYER MODEL AND PHYSICAL PROCESSES

### 7.3.7 Deposition

In the MT model, a stochastic model for flow and sediment interaction is applied. This approach was first developed by Krone (1962)[16].

Krone suggests that the deposition rate can be expressed by

Deposition: $S_D = w_s c_b p_d$

$w_s$ settling velocity (m/s)

$c_b$ near bed concentration (kg/m$^3$)

$p_d$ probability of deposition

$= 1 - \frac{\tau_b}{\tau_{cd}}, \tau b \leq \tau cd$

$\tau_b$ the bed shear stress (N/m$^2$)

$\tau_{cd}$ critical bed shear stress for deposition (N/m$^2$)

### 7.3.8 Settling velocity and flocculation

The settling velocity of the fine sediment depends on the particle/floc size, temperature, concentration of suspended matter and content of organic material.

Usually one distinguishes between a regime where the settling velocity increases with increasing concentration (flocculation) and a regime where the settling velocity decreases with increasing concentration. The latter is referred to as hindered settling. The first is the more common of the two in the estuary.

Following Rijn (1989)[17] the settling velocity in saline water (>5 ppt) can be expressed by:

$$w_s = kc^{\gamma} \text{ for } c \leq 10 \text{ kg/m}^3$$

where

| | |
|---|---|
| $w_s$ | settling velocity of flocs (m/s) |
| c | mass concentration |
| k,γ | coefficients |
| γ | 1 to 2 |

The relation c ≤ 10kg/m3 for describes the flocculation of particles based on particle collisions. The higher concentration the higher possibility for the particles to flocculate.

c > 10kg/m3 corresponds to "hindered" settling, where particles are in contact with each other and do not fall freely through the water.

Alternative settling formulations are also available:

The formulation of Richardson and Zaki (1954)[18] is the classical equation for hindered settling.

$$w_s = w_{s,r}\left(1 - \frac{c}{c_{gel}}\right)^{w_{s,n}}$$

Where $w_{s,r}$ is a reference value, $w_{s,n}$ a coefficient and $c_{gel}$ the concentration at which the flocs start to form a real self-supported matrix (referred to as the gel point). Flocculation is enhanced by high organic matter content including organic coatings, etc. (Van Leussen, 1988; Eisma, 1993)[19]. In fresh water, flocculation is dependent on organic matter content, whereas in saline waters salt flocculation also occurs. The influence of salt on flocculation is primarily important in areas where fresh water meets salt water such as estuaries.

The following expression is used to express the variation of settling velocity with salinity. Notice that the reference value $w_s$ is the value representative for saline water.

$$w_s = w_s(1 - C_1 e^{C_2})$$

where C1 and C2 are calibration parameters.

Figure 37 shows an example of $C_1 = \{0 , 0.5 , 1\}$ and $C_2 = -1/3$.

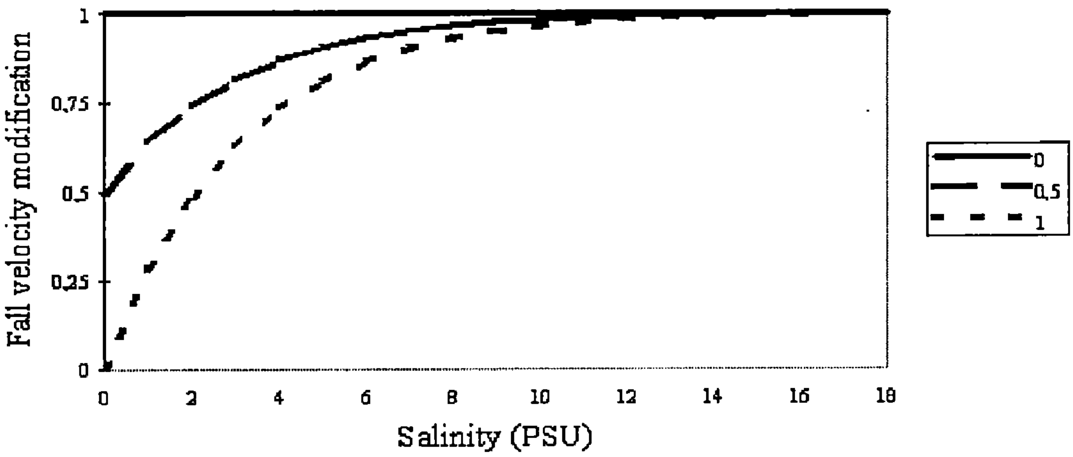


FIG. 37: SETTLING VELOCITY AND SALINITY DEPENDENCY

The description of salt flocculation is based on Krone's experimental research, Krone (1962), Whitehouse et al.,(1960)[20] studied the effect of varying salinities on flocculation of different clay minerals in the laboratory.

Gibbs (1985)[21] showed that in the natural environment, flocculation is more dependent on organic coating. Therefore, the effect of mineral constitution of the sediment is not taken is not account in the model. Furthermore, information on mineralogy of bed sediments is rarely available.

### 7.3.9 Sediment concentration profiles

Two expressions for the sediment concentration profile can be applied. Either an expression that is based on an approximate solution to the vertical sediment fluxes during deposition (Teeter) or an expression that assumes equilibrium between upward and downward sediment fluxes (Rouse).

**Teeter 1986 profile**

The near bed concentration cb is proportional to the depth averaged mass concentration and is related to the vertical transport, i.e. a ratio of the vertical convective and diffusive transport represented by the Peclet number:

$$P_e = \frac{C_{rc}}{C_{rd}}$$

where

| | |
|---|---|
| $C_{rc}$ | convective Courant number= $w_s \frac{\Delta t}{h}$ |
| $C_{rd}$ | diffusive Courant number = $\overline{D_z} \frac{\Delta t}{h^2}$ |
| $\overline{D_z}$ | depth mean eddy diffusivity |
| $C_b$ | near bed concentration and is related to the depth averaged Concentration $\bar{c}$, Teeter (1986)[22]. |

$$\beta = \frac{C_b}{\bar{C}}$$

Where $\beta = 1 + \frac{P_e}{1.25+4.75P_d^{2.5}}$

$P_e$ – Peclet number = $\frac{w_s h}{\overline{D_z}} = \frac{6w_s}{kU_f}$

| | |
|---|---|
| $p_d$ | probability of deposition |

**Rouse profile**

The suspended sediment is affected by turbulent diffusion, which results in an upward motion. This is balanced by settling of the grains. The balance between diffusion and settling can be expressed:

$$-\varepsilon \frac{dC}{dz} = wC$$

Symbol list

| | |
|---|---|
| ε | diffusion coefficient |
| $C$ | concentration as function of z |
| z | vertical Cartesian coordinate |
| w | mean settling velocity of the sediment |

### 7.3.10 Erosion

Erosion can be described in two ways depending upon whether the bed is dense and consolidated or soft and partly consolidated, Mehta et al.(1989)[23].

Dense, consolidated bed:

Erosion: $S_E = E(\frac{\tau_b}{\tau_{ce}} - 1)^n, \tau_b > \tau_{ce}$

Where

$E$ erodibility of bed (kg/m$^2$/s)

$\tau_{ce}$ critical bed shear stress for erosion (N/m$^2$)

$n$ power of erosion

Soft, partly consolidated bed:

Erosion: $S_E = E exp\ [\alpha(\tau_b - \tau_{ce})^{1/2}],\ \tau_b > \tau_{ce}$

where

$\alpha$ coefficient (m/N$^{1/2}$)

**7.3.11 Bed description**

It is possible to describe the bed as having more than one layer. Each layer is described by the critical shear stress for erosion, $\tau_{ce,j}$, power of erosion, $n_j$, density of dry bed material, $\rho_i$, erosion coefficient, $E_j$, and $\alpha_j$-coefficient. The deposited sediment is first included in the top layer. The layers represent weak fluid mud, fluid mud and under-consolidated bed, Mehta et al. (1989)[23] and are associated with different time scales.

The model requires an initial thickness of each layer to be defined.

The consolidation process is described as the transition of sediment between the layers, Teisson (1991)[24].

The influence of waves is taken into account as liquefaction resulting in a weakening of the bed due to breakdown of bed structure. This may cause increased surface erosion, because of the reduced strength of the bed top layer (Delo and Ockenden, 1992)[25].

In areas where large bathymetry gradients are present, i.e. in navigational channels, it is possible to invoke a process describing the sliding of sediment from shallow parts into the channels. This will especially be possible in the top bed layers, where weak mud often will be present. The initiation of the sliding process depends on the slope of the bathymetry, and the dry density of the actual bed layer, $\rho_i$ (Unit: g/m3), which corresponds to an equilibrium slope ($\alpha_e$) of the bed. The relation is where

Sliding $\alpha \geq \alpha_e$

No sliding $\alpha < \alpha_e$

where

$\alpha$ actual slope of bathymetry

$$\alpha_e = arc\tan[2.5.10^{-13}\left(\frac{P_l}{1000}\right)^{4.7}]$$

The sliding process is modelled by a dispersion equation, see Teisson(1991)[24].

$$\frac{\partial z_b}{\partial t} = K_{sx}\frac{\partial^2 z_b}{\partial x^2} + K_{sy}\frac{\partial^2 z_b}{\partial y^2}$$

where

| | |
|---|---|
| $z_b$ | bed level |
| $K_{sx}$, $K_{sy}$ | dispersion coefficients in x, y directions |

The dispersion coefficients, $K_{sx}$, $K_{sy}$ may be either constant or related to some model parameters, Grishanin and Lavygin (1987)[26].

$$\overrightarrow{K_s} = \frac{9.8.10^{-8}}{1-\varepsilon}\sqrt{(s-1)gd_{50}}\left(\frac{h}{d_{50}}\right)^{1/6}\frac{h\vec{v}}{(g\nu)^{2/3}}$$

where

| | |
|---|---|
| $\overrightarrow{K_s}$ | ($K_{sx}$, $K_{sy}$) |
| $\varepsilon$ | medium porosity factor |
| $s$ | relative density of bed layer material |
| $d_{50}$ | mean diameter of bed layer |
| $h$ | water depth |
| $\vec{v}$ | ($V_x$,$V_y$) - components of depth-averaged flow velocities |
| $\nu$ | kinematic viscosity of water |
| $g$ | gravity acceleration |

All other parameters besides the $K_{sx}$, $K_{sy}$ are explicitly calculated by the model. The lack of proper sediment characteristics (ε,s) prevents a satisfactory calibration of the sliding process.

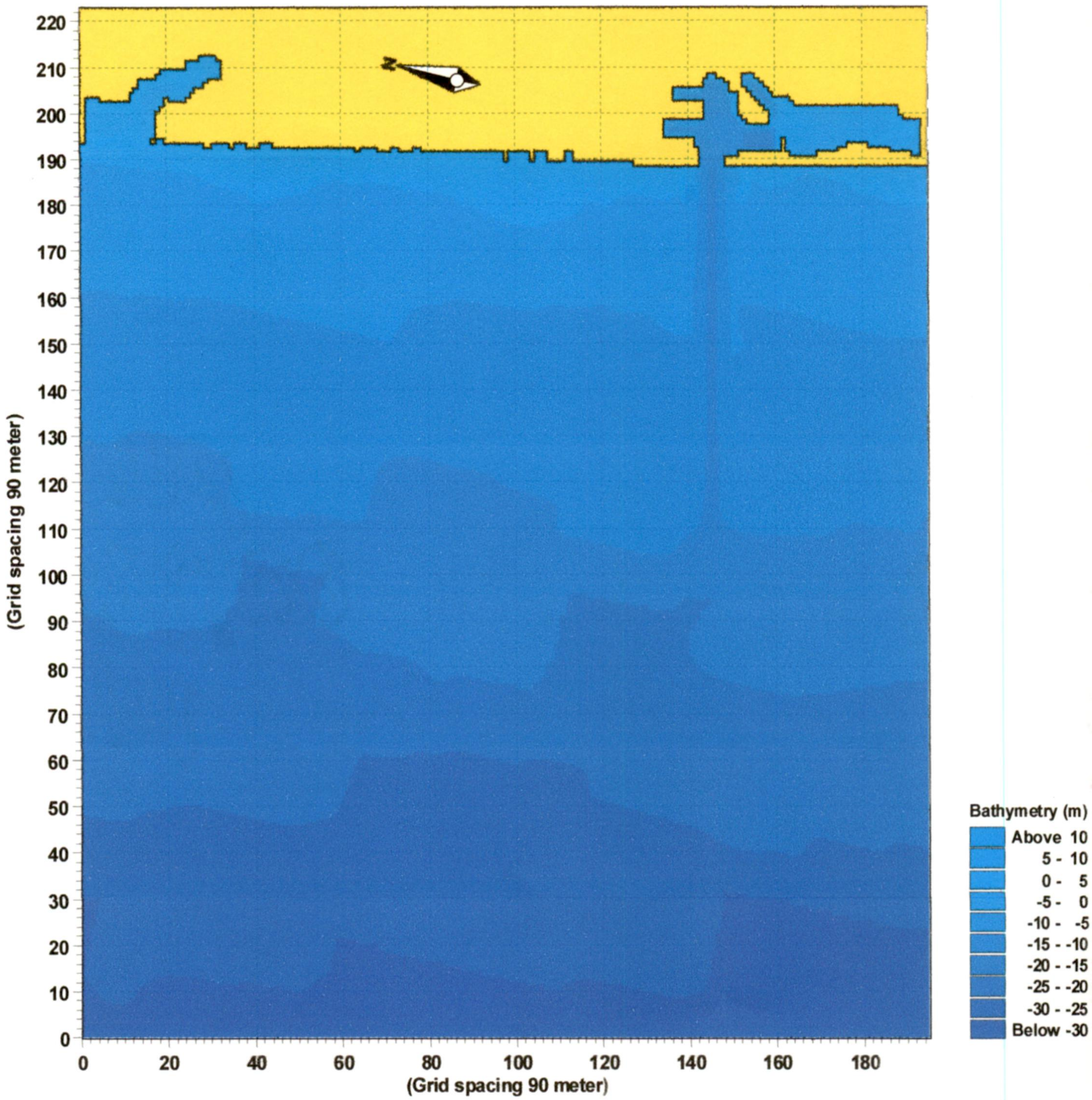
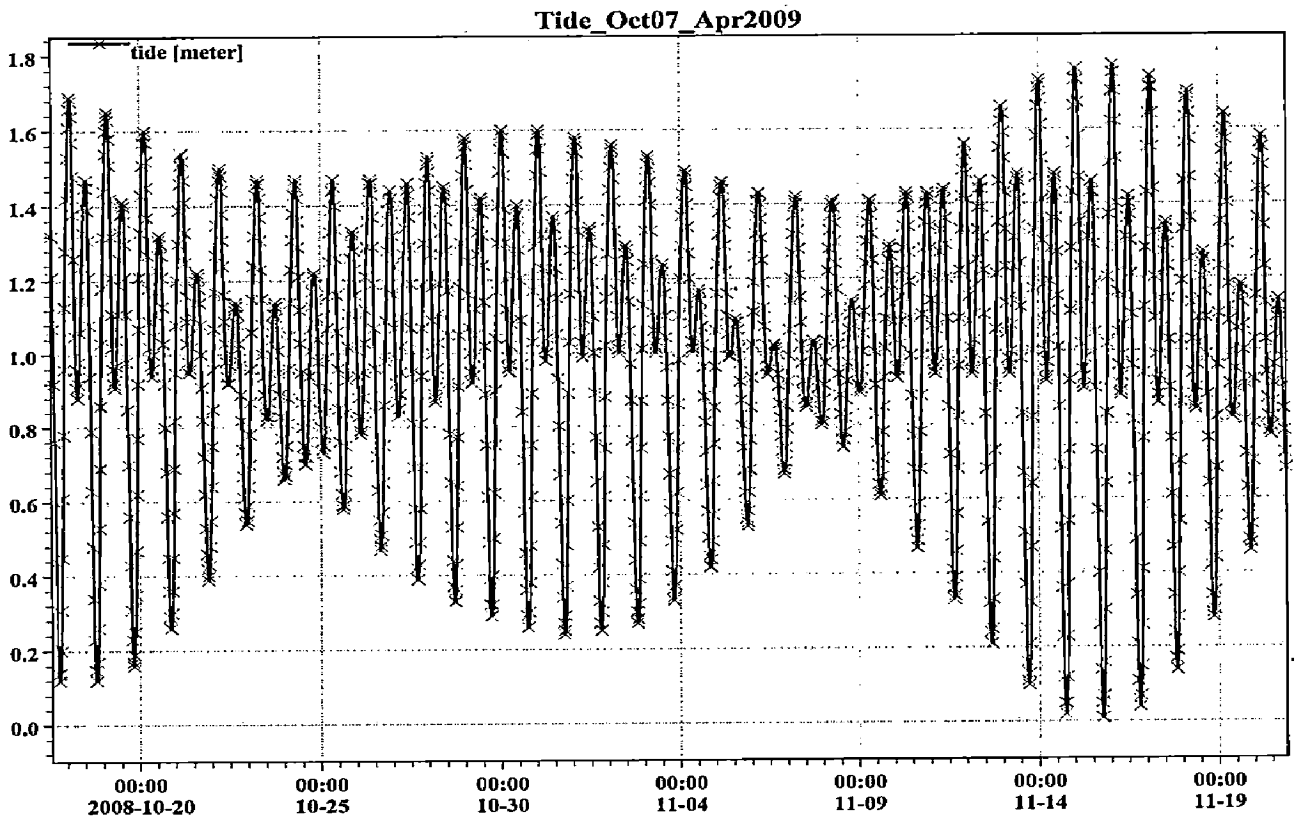


FIG. 21: 2-D VIEW OF COMPUTATIONAL MODEL GRID



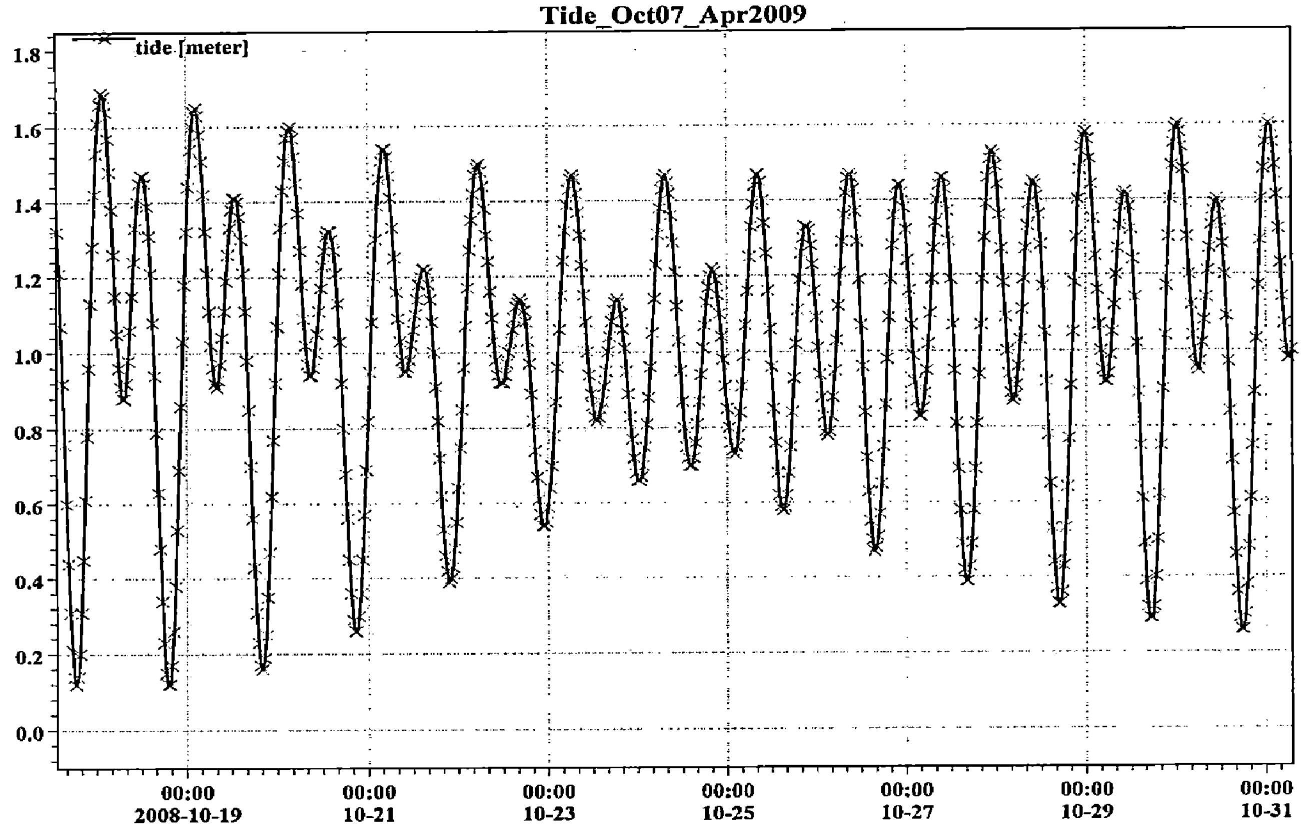


FIG. 22: BOUNDARY TIDE AND IT'S ENLARGED VIEW

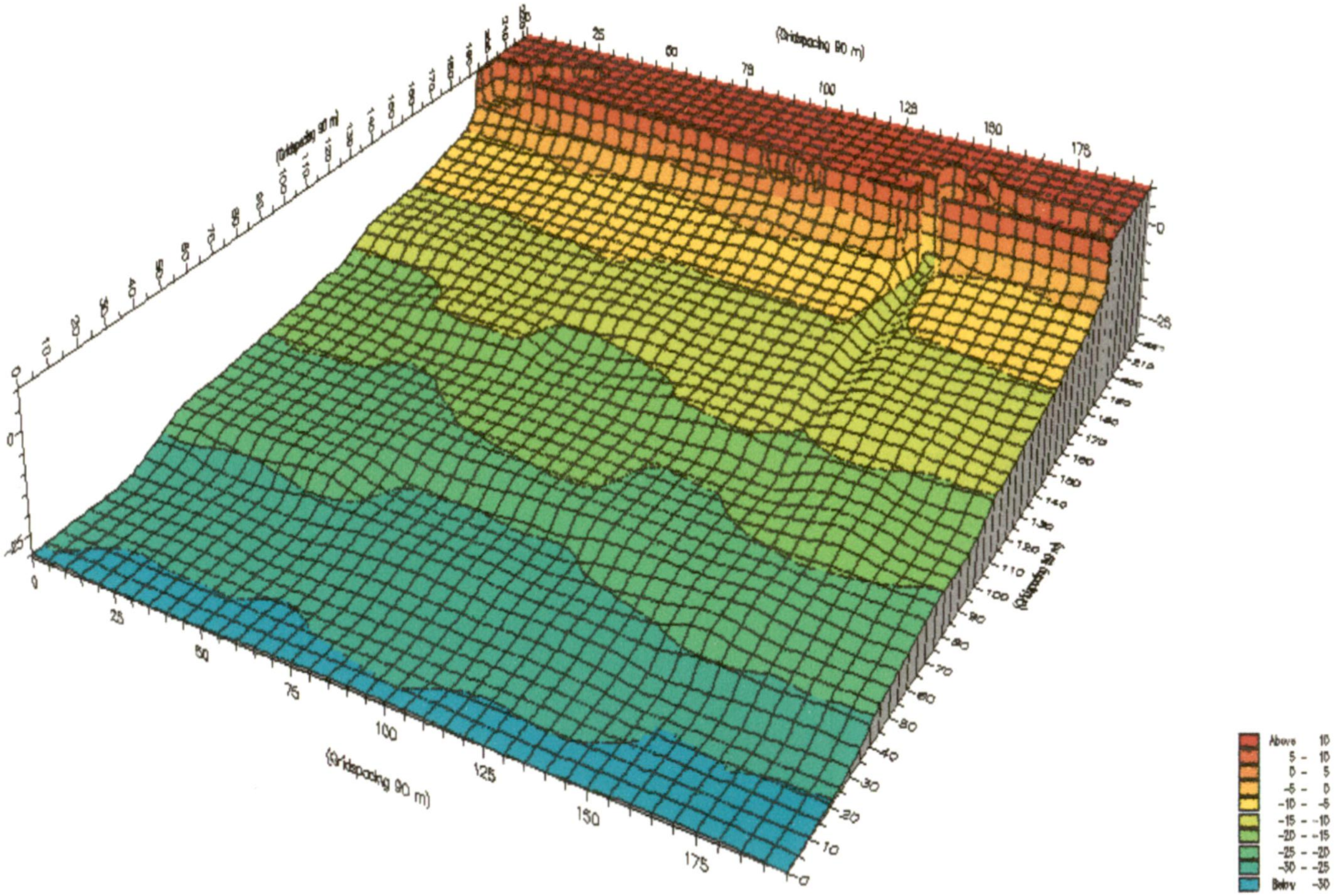


FIG. 23: 3-D VIEW OF COMPUTATIONAL MODEL GRID SHOWING BATHYMETRY OF NMPT PORT AND OUTER SEA

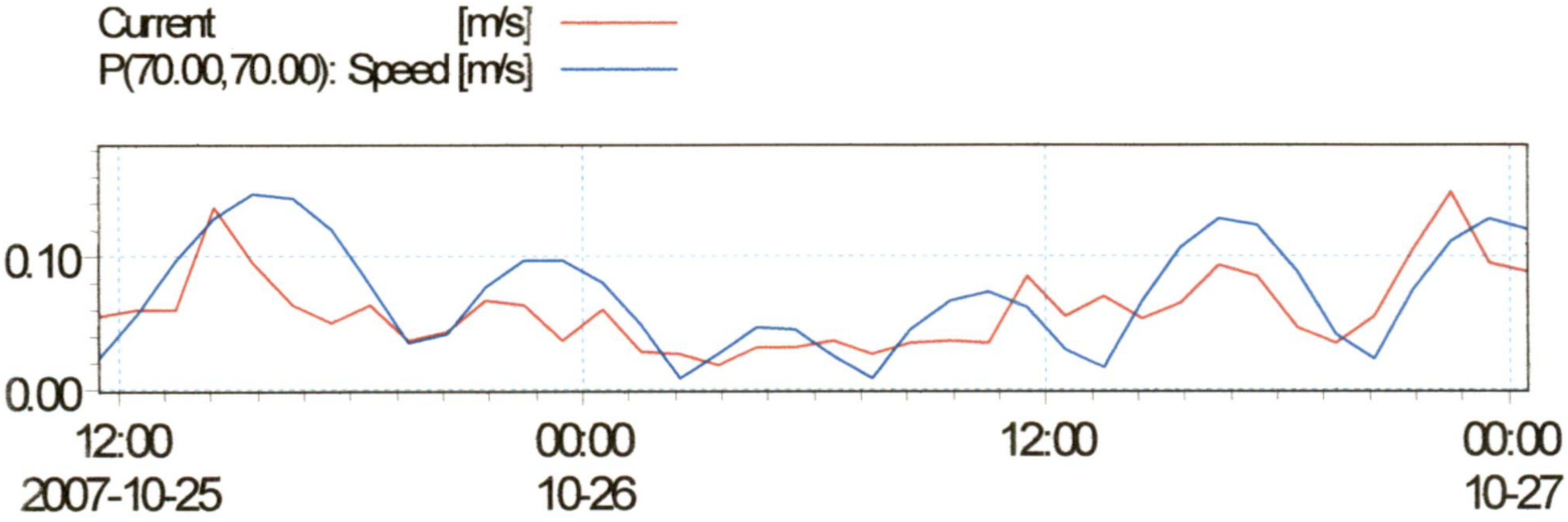


FIG. 24 : OBSERVED VELOCITY V/S EXTRACTED VELOCITY FROM HYDRODYNAMIC MODEL

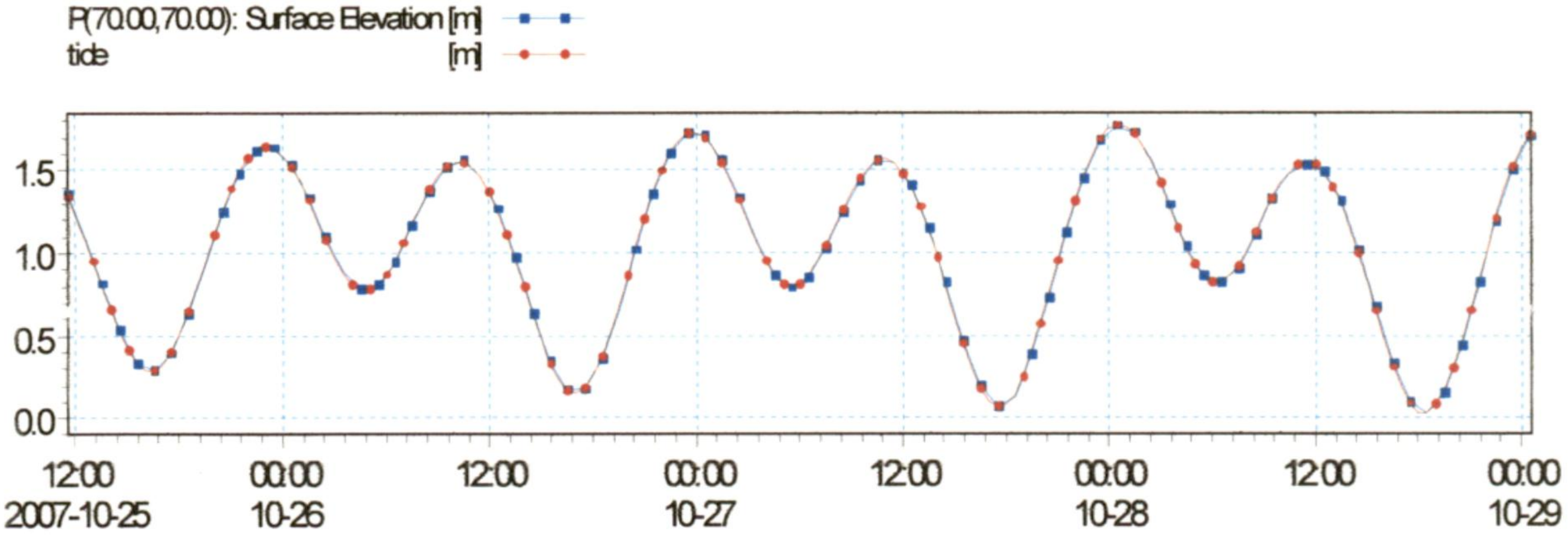


FIG. 25: OBSERVED TIDE V/S EXTRACTED WATER LEVEL FROM HYDRODYNAMIC MODEL

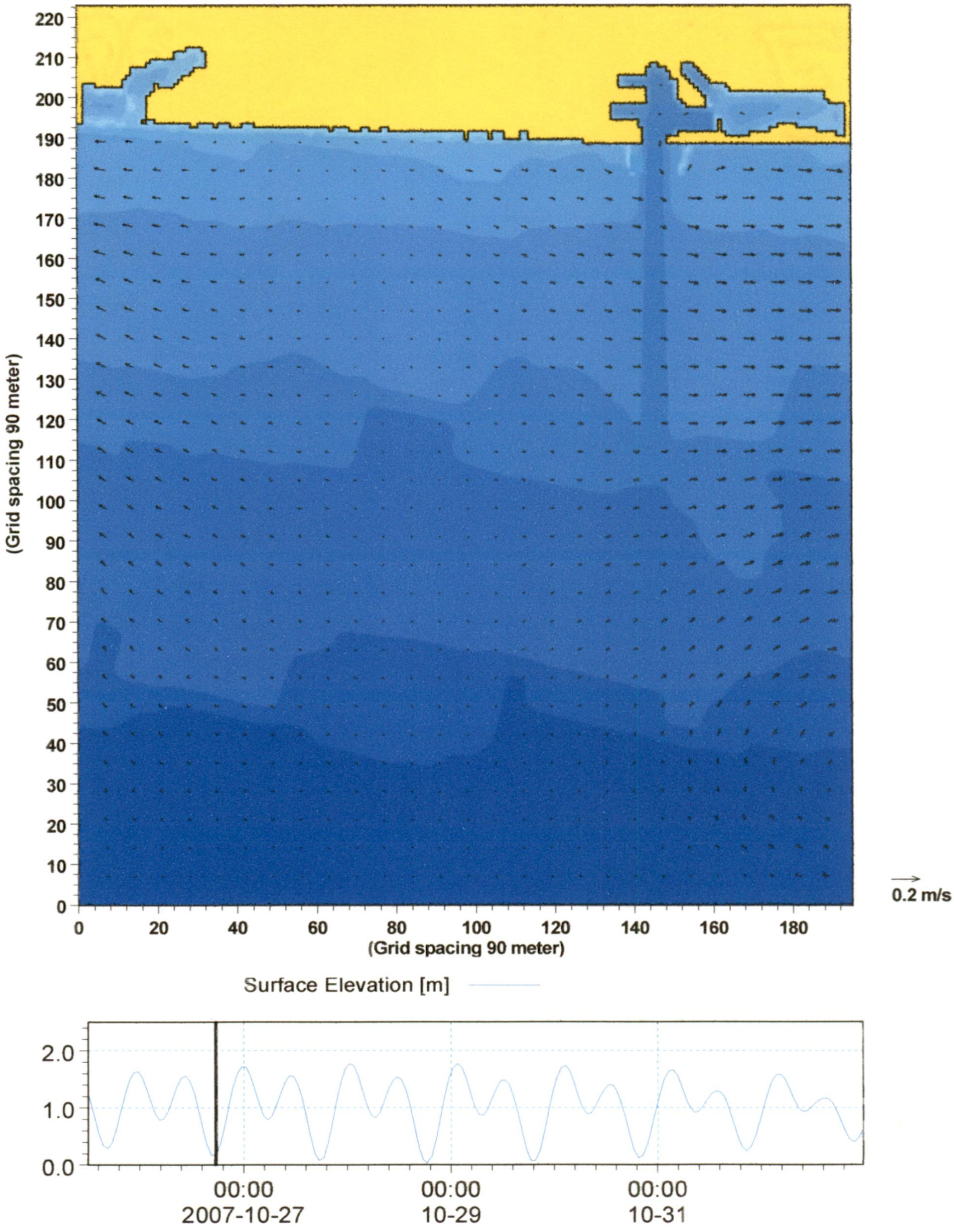


FIG. 26: FLOW FIELD DURING LOW WATER AT THE START OF TIDE

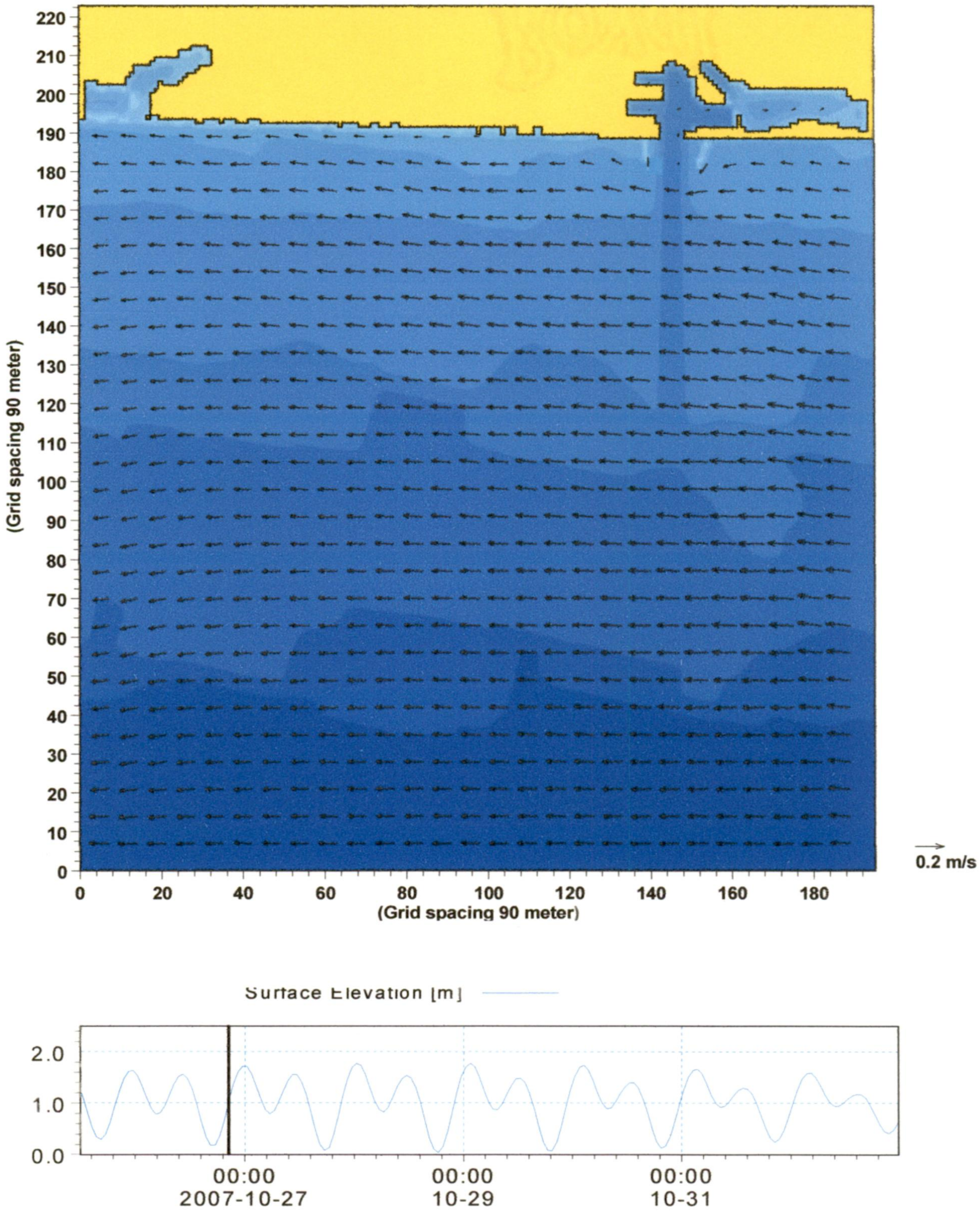


FIG. 27: FLOW FIELD DURING PEAK FLOOD FLOW FROM FIRST LOW WATER

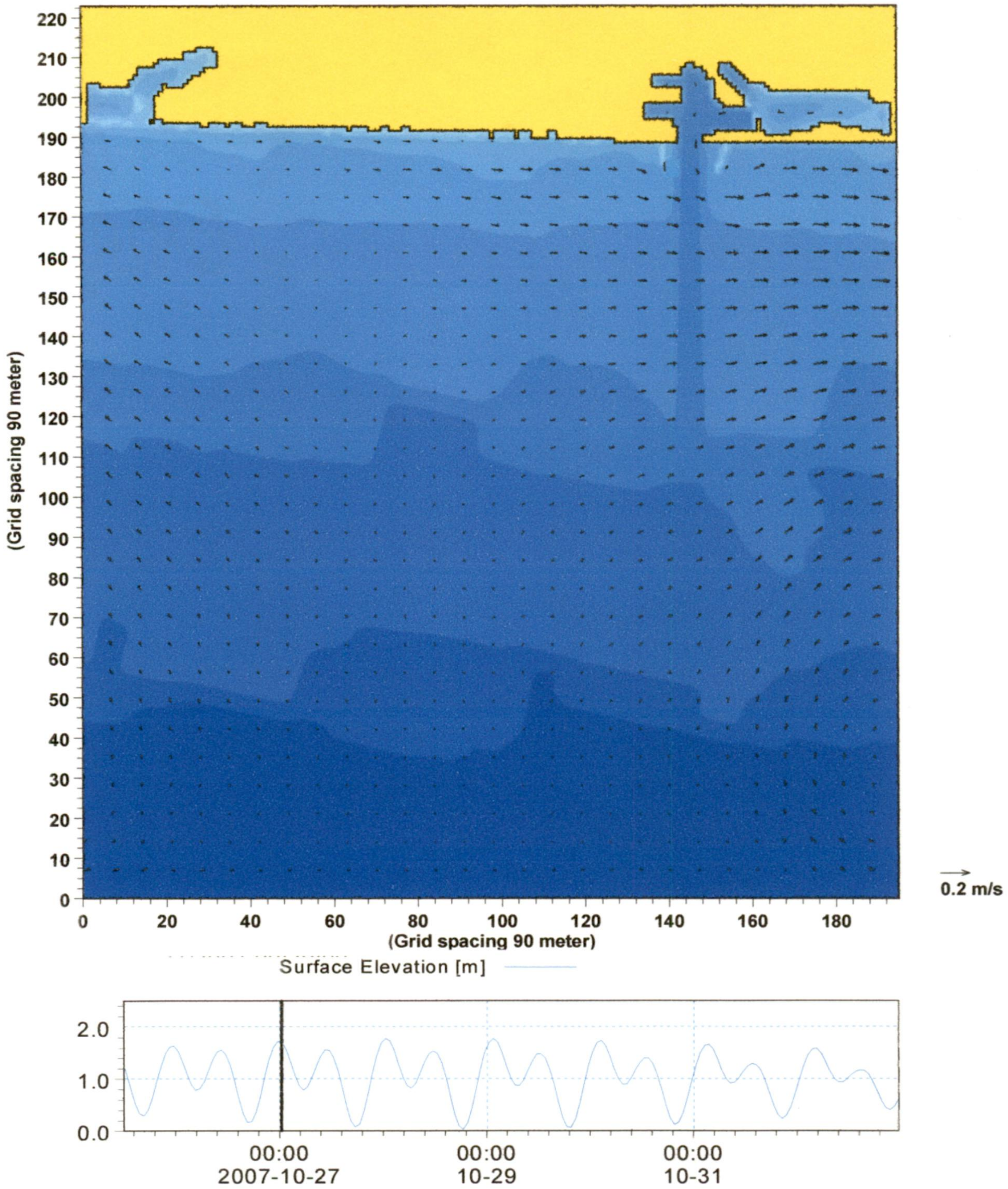


FIG. 28: FLOW FIELD DURING FIRST HIGH WATER OF TIDE

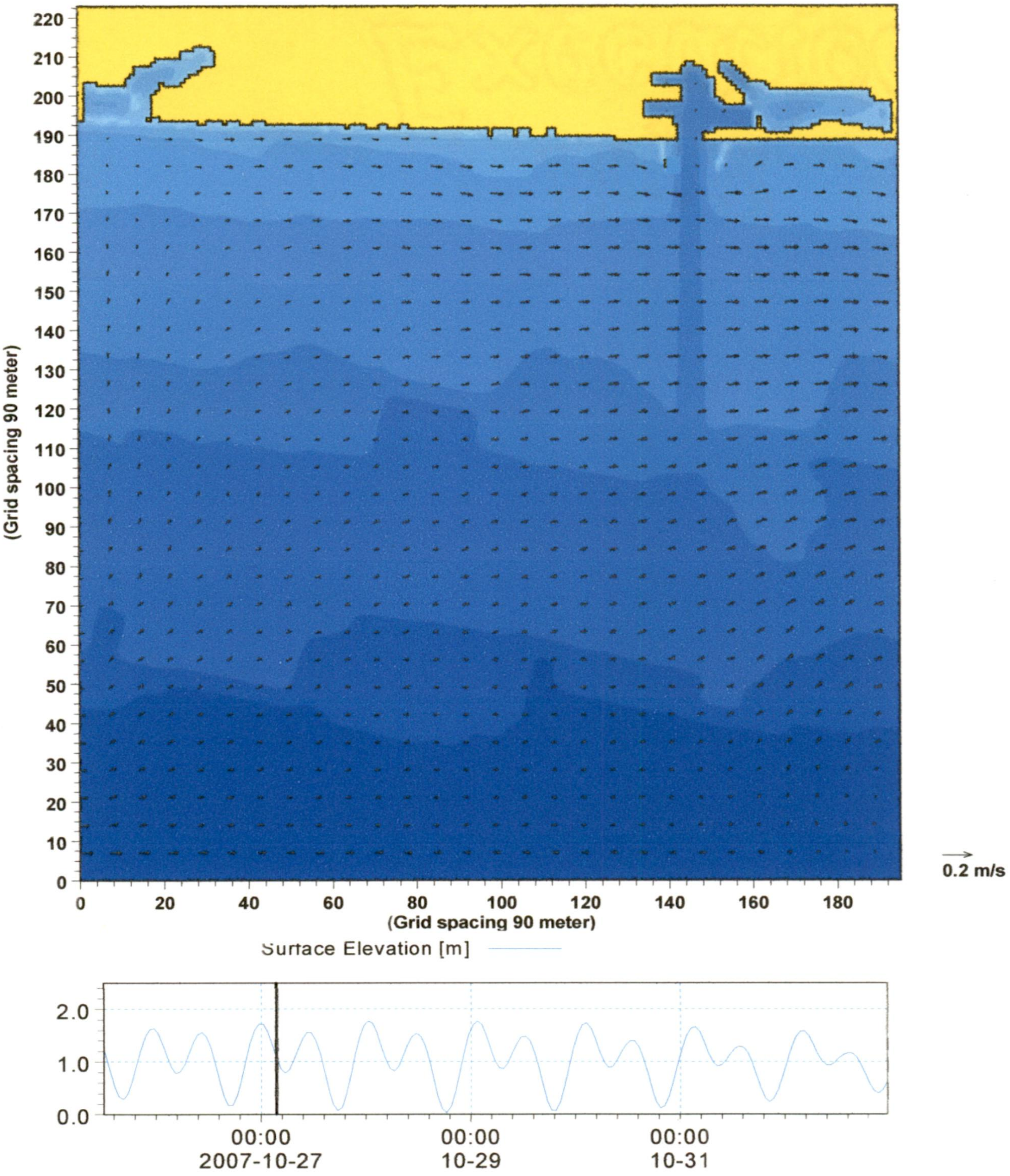


FIG. 29: FLOW FIELD DURING MID OF EBB FROM FIRST HIGH WATER

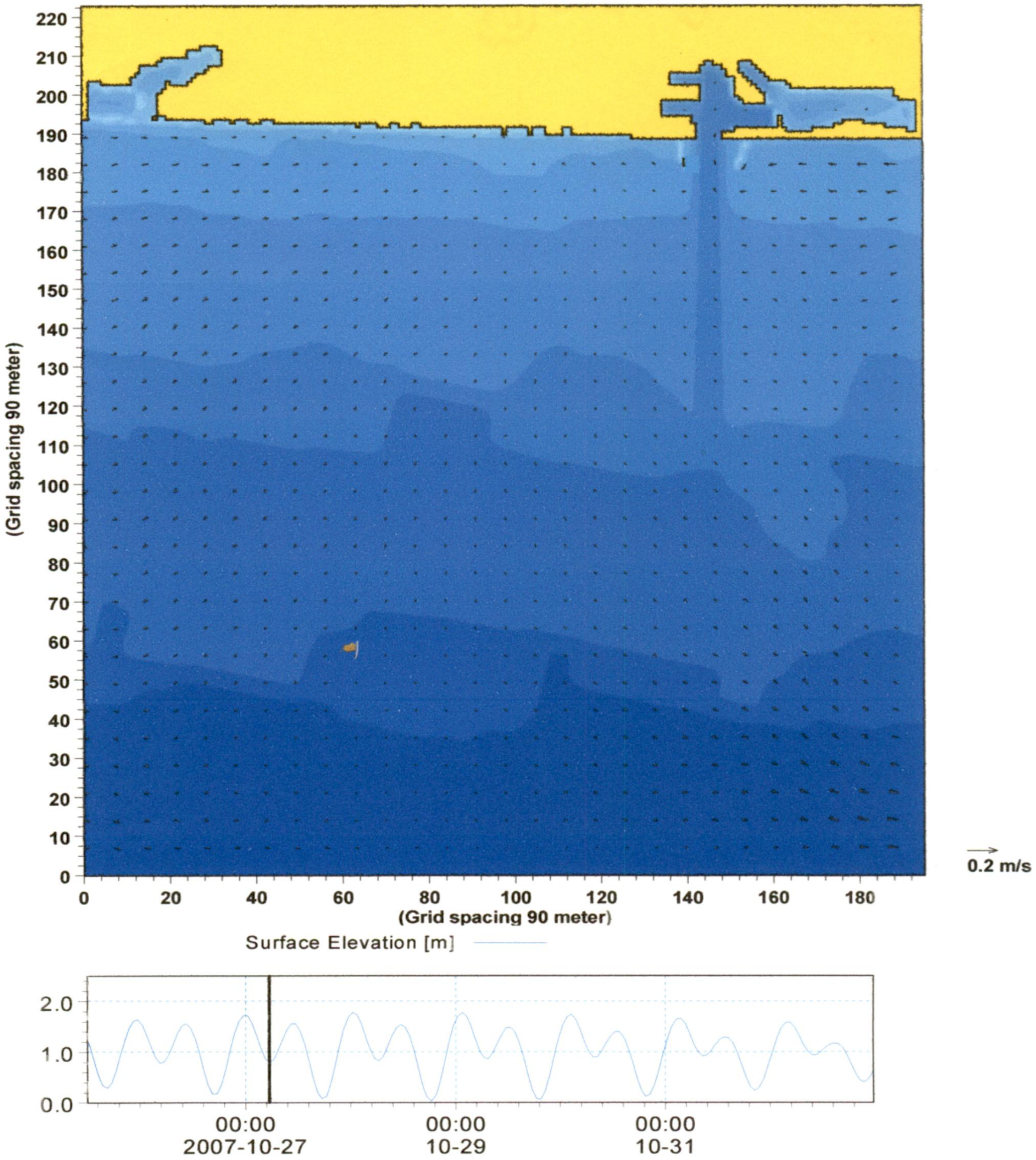


FIG. 30: FLOW FIELD DURING SECOND LOW WATER FROM THE START OF TIDE

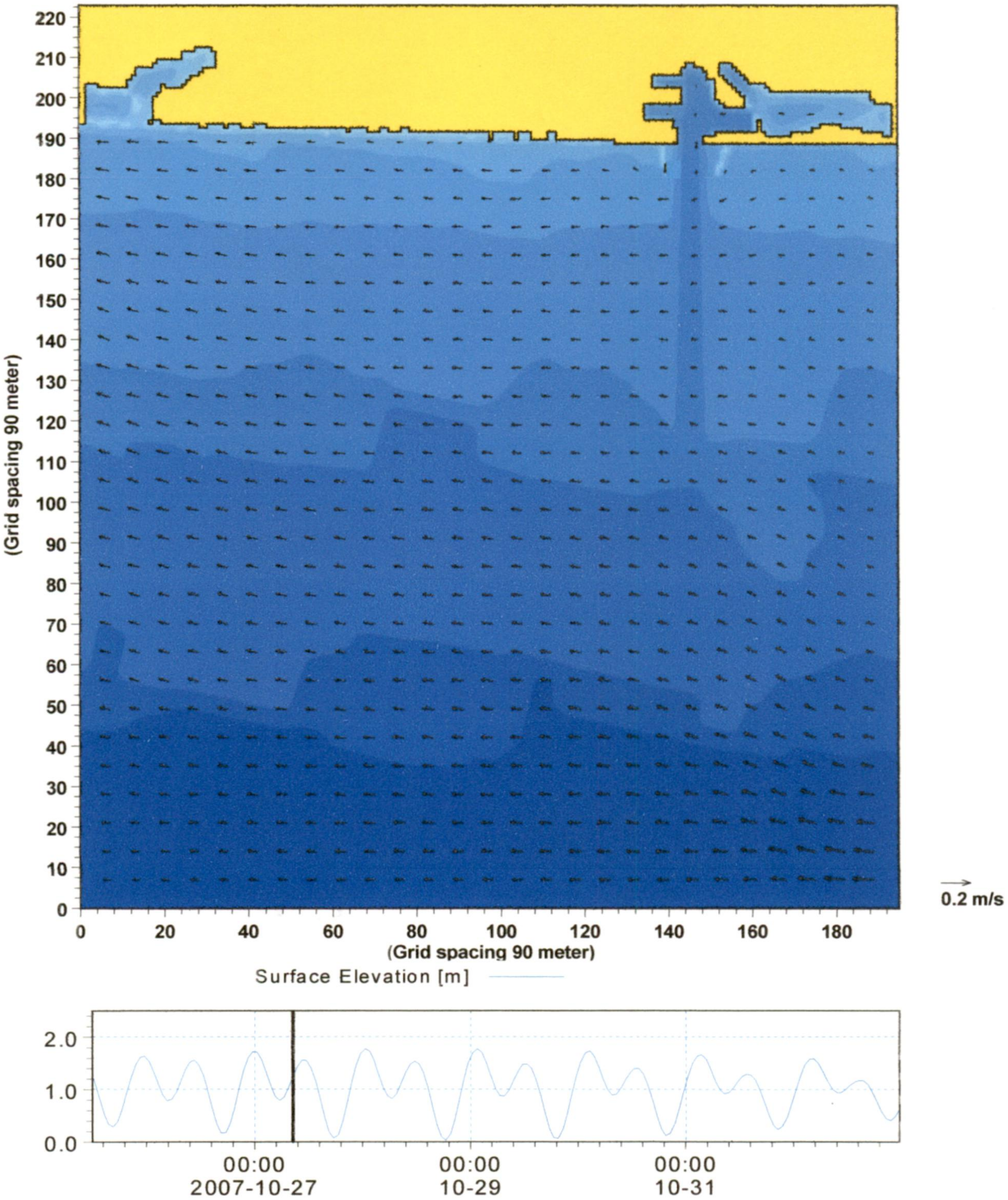


FIG. 31: FLOW FIELD DURING MID FLOOD FROM SECOND LOW WATER

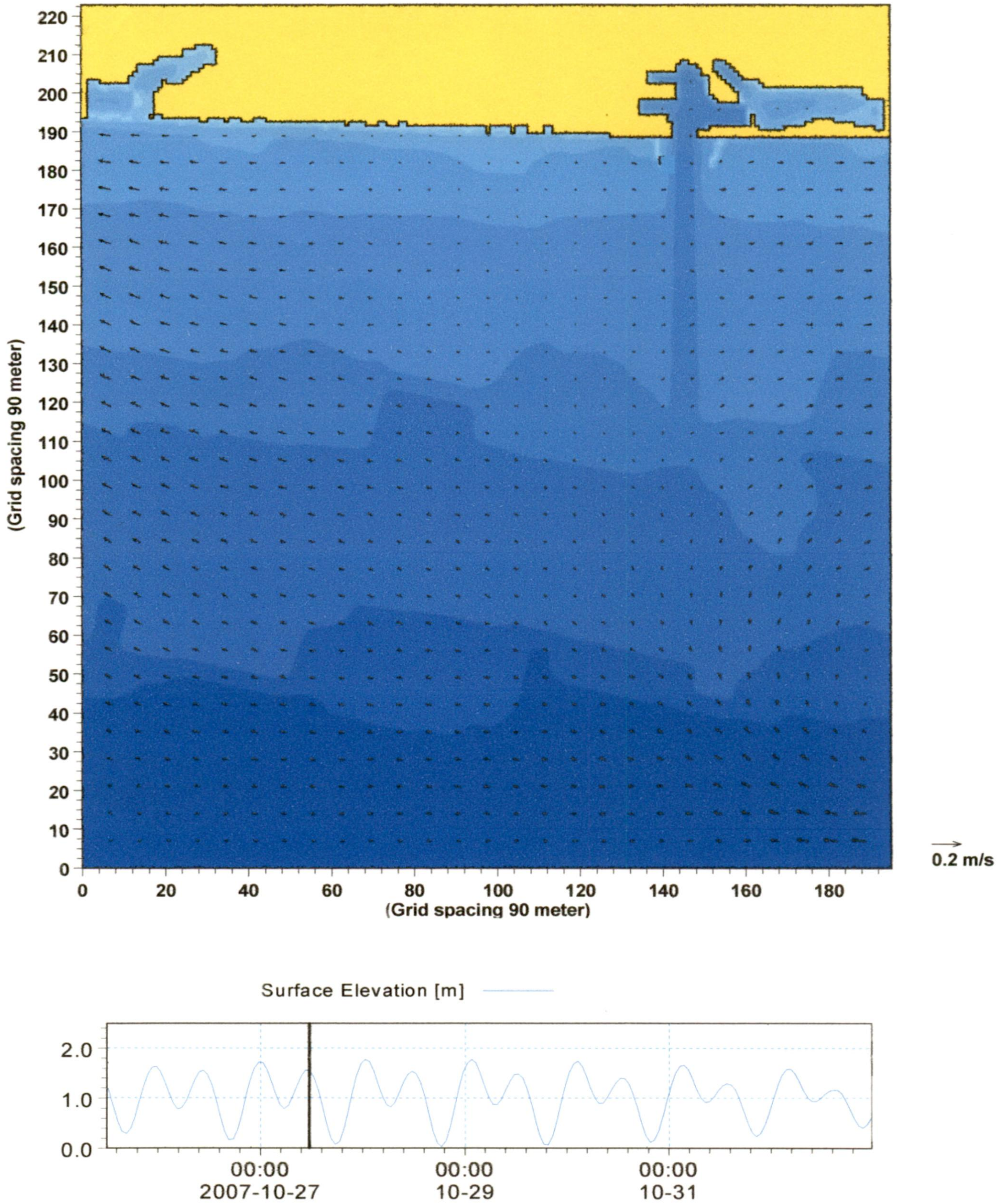


FIG. 32: FLOW FIELD DURING SECOND HIGH WATER OF TIDE

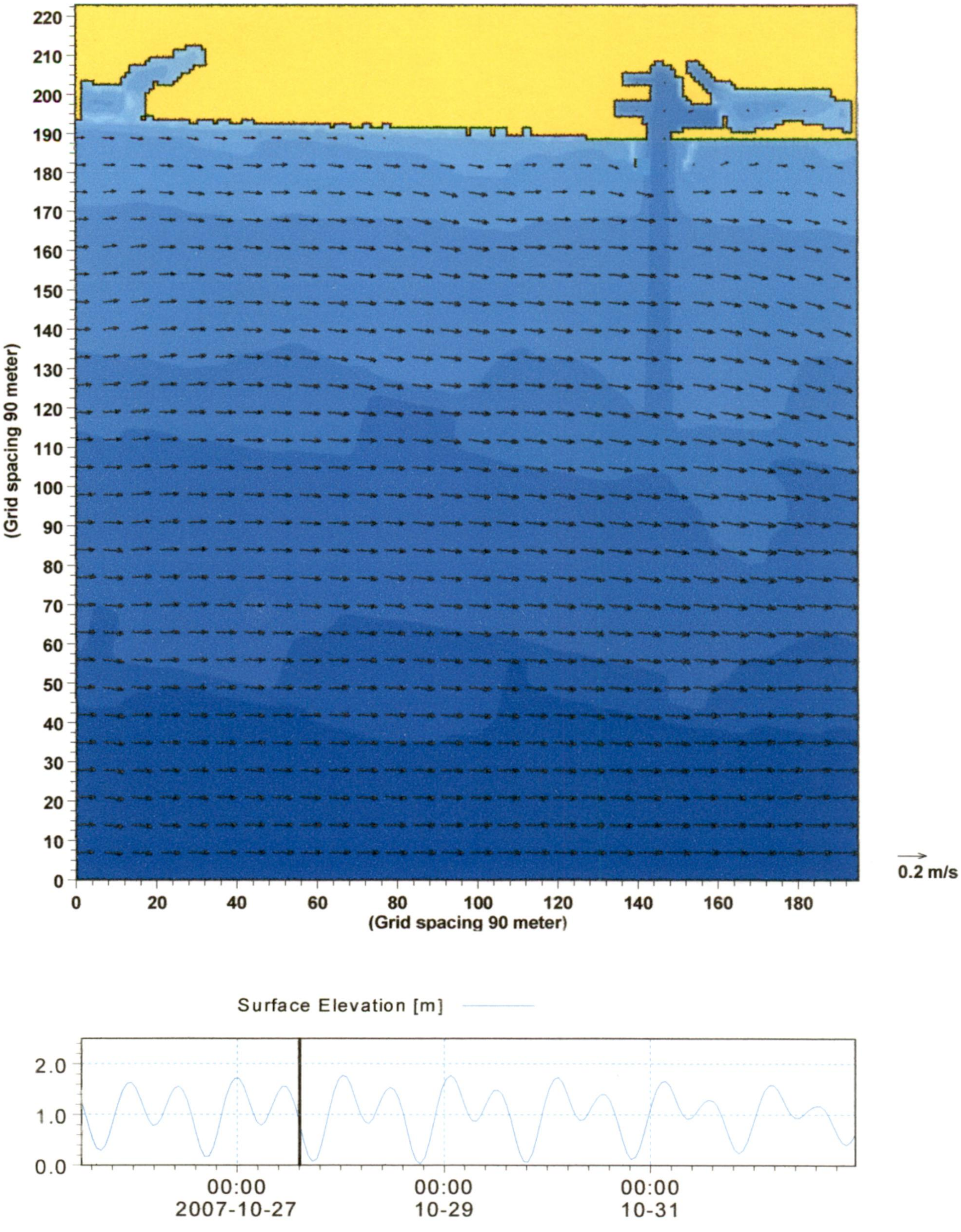


FIG. 33: FLOW FIELD DURING PEAK EBB AT THE END OF TIDE

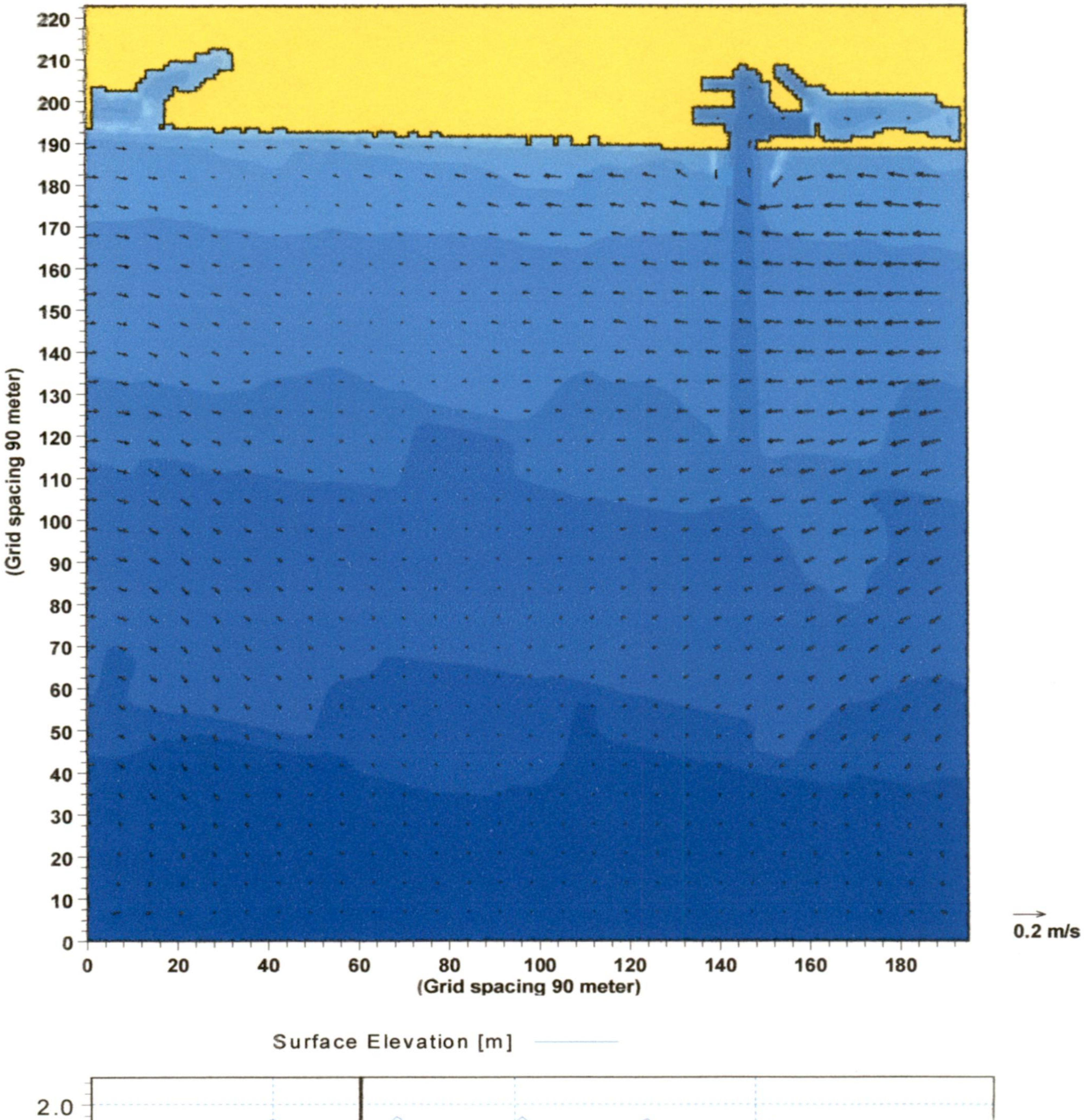


FIG. 34: FLOW FIELD DURING LOW WATER AT THE END OF TIDE

# RESULTS AND DISCUSSIONS

## 8.1 Description of Studies

Open water disposal of dredged sediment is a common method adopted by the major ports in India. Apart from careful assessment of the environmental impacts ports are interested in knowing the trajectory and spread of the material to avoid the return of the sediment in the Navigational channels and Berthing Basins. If the disposal location for dredged material is not chosen properly for the prevailing hydrodynamic conditions and sediment characteristics, substantial volumes of disposed material could find their way back into the port operational areas, resulting in loss of depth for navigation and berthing of vessels. Therefore, it is necessary to study the sediment fate and transport mechanism (dispersion) under the action of coastal currents and waves. The investigation for locating suitable disposal site can be done either by direct numerical simulation or through tracer techniques using radioactive tracer material.

Numerical simulations require elaborate field data and proper simulation of the physics through calibration and validation for realistic assessment of the fate of the sediments. Radio Active Tracer (RAT) technique is a direct in-situ method for assessing both qualitatively and quantitatively the fate of the sediment under the real time prototype conditions of the site.

For the Indian scenario Bhabha Atomic Research Centre (BARC) has conducted a number of Radio Active Tracer (RAT) studies (H. J. Pant et Al 1989)[27]. The radiotracer technique involves preparation of suitable tracer, injection at the point of interest and monitoring the tracer concentration. A range of radio isotopes can be used for the sediment transport studies. Bed load sediment transport studies are generally carried out using long lived tracer like Scandium ($^{46}$Sc) glass with about 1% scandium, which is powdered to appropriate size and activated in a nuclear reactor to produce Scandium-46. The RAT studies were carried out in India mainly for selecting suitable dumping site for disposal of dredged material.

Recently exclusive studies were conducted by BARC and CW&PRS at New Mangalore Port (NMPT)[28] for the period from October 2007 to January 2008 and from January 2009 to April 2009. From the results of analysis of seabed samples from New

Mangalore Port, fractions ranging between 60μm to 100μm size were used for the studies. Scandium-46 with half-life of 84 days, emitting gamma energies 0.887 MeV and 1.12 MeV in the form of scandium glass powder was selected as a tracer for the studies. The tracer used to label the seabed sample and injected at the proposed dumping location. After injection tracking of the radio activity was done as indicated in the table 4 below:

**TABLE 4: TIME TABLE OF ACTIVITIES**

| DATE | ACTIVITY CONDUCTED |
|---|---|
| 23/10/2007 | Background survey |
| 24/10/2007 | Tracer injection to sea bed |
| 25/10/2007 | First post injection tracking |
| 14/11/2007 | Second post injection tracking |
| 18/11/2007 | Third post injection tracking |
| 23/01/2008 | Fourth post injection tracking |

The background survey conducted on 23/10/2007 at the study area indicated a natural background radiation in the ranges of 1500-2000 cpm. On 24/10/2007, the bed material labelled with Scandium-46 was injected at the dumping site location of latitude $12^0$ 57.567" N and longitude $74^0$ 41.685" E. The isocount contours and transport diagram for the first post injection tracking is shown in ch.6. The velocity of movement was 182 meters/day & the general direction of movement of tracer was predominantly towards west. During the second post injection tracking, the general movement of tracer was towards north-west direction (Ch.6.). The velocity of movement was about 25 meters/day calculated over a period of 20 days with thickness of bed (based on radioactivity count) as 1.7 cm and and transport rate was 0.63 tonnes/day/m. In the third post injection tracking, the predominant movement of the tracer was towards north-northwest (Ch.6). Velocity of transport was 8.2 m/day, transport thickness was 1.7 cm and rate of sediment transport works out to above 0.21 tonnes/day/m. The fourth post injection tracking also showed that the movement of tracer was predominantly towards north-northwest direction(Ch.6). Velocity of transport was 6.8 m/day, transport thickness was 2.5 cm and quantity was 0.26 tonnes/day/m.

## 8.2 Results of Numerical Model

The Radio Active Tracer technique though is reasonably accurate and carried out directly under prototype conditions. This is, however, very time consuming, expensive and requires elaborate arrangements, right from preparation of radioactive tracer, injection and tracking. Numerical simulation of the same could work out to be very quick and less expensive, though relatively less accurate. The available numerical modelling software generally simulates the erosion, transport, settling and deposition of sediments (both cohesive and non-cohesive) and requires a number of input parameters. Some of the parameters are

- Settling velocity
- Critical shear stress for erosion
- Critical shear stress for deposition
- Erosion co-efficient
- Power of erosion
- Suspended sediment
- Concentration at open boundaries
- Dispersion co-efficients
- Thickness of bed layers or estimate of total amount of active sediments in the system
- Transition co-efficients between bed layers
- Dry density of bed layers

The main output possibilities are:

- Suspended sediment concentration in space and time
- Sediments in bed layers given as masses or height
- Net sedimentation rate
- Computed bed shear stress
- Computed settling velocities
- Updated bathymetry

Attempts was made in the present investigation for simulation of the bed load movement of the tracer material as measured in the BARC experiment for New Mangalore Port (NMPT). MIKE-21 software module namely HD (Hydrodynamic) and MT (Mud Transport) were used for investigation. In the present problem the movement of the tracer material was required to be uniquely identified by the numerical model simulation. In the MIKE-21 module, the simulation of sediment movement would also include the advective as well as dispersive transport of the existing bed material including the boundary input of ambient suspended sediments. In the initial simulations, it was observed that the model was showing movement of material in the whole domain or area due to which the movement of disposed material (Tracer) could not be distinguished from the ambient conditions of sediment transport. The guiding principle to segregate and uniquely identify the movement of the disposed material was given below :

*To define the various parameters in such a way that no erosion from the actual bottom will be allowed and the disposed dredged material fraction will act independently.*

For this the following methodology was adopted in the MT module of MIKE-21 software:

I. In the definition of bed layer thickness, only 0.05 m thickness was given at the injection point and rest of the model bed thickness set to zero.

II. In specifying the density of bed layers, sediment diameter of 0.015 mm was given at the injection point and 0.6 mm for rest of the model bed.

III. Initial and boundary concentrations for suspended sediment were set to zero for whole model area.

IV. Critical shear stress definition for erosion and deposition was uniquely defined as a shear stress field linearly varied between 0.01 $N/m^2$ near the injection site and 0.02 $N/m^2$ at the boundaries.

V. Dispersion coefficients are defined as 1 in both the x, y directions.

Before setting up the mud transport model for study of dispersion of dredged material, the hydrodynamic model was required to be set precisely as described in the chapter 7. Once the hydrodynamic model results come satisfactory, then the mud transport model was started for simulation, because it uses the result of HD model as an input. The change in bed thickness has been taken as a parameter for tracing the dispersion of dredged material disposed in present study. MT Model results had not come satisfactory easily, but it required number of simulations with lot of combinations of various input parameters. Results from MT model simulations for observing the dispersion behaviour of disposed dredged material at injection site of BARC are show in figs. 38 to 45. Since, numerical model is computing change in bed thickness and in BARC studies counts per minute have been given, direct comparison between these two parameters was not possible. Hence, both change in bed thickness from numerical model computations and counts per minute from BARC studies at various observed time had been normalised (by dividing the different values from their peak value of that duration) and then these parameters have been compared (Fig. 46 to 59). Standard deviations have also calculated for each of the normalised distributions. The tables 5 to 18 showed the normalised values and standard deviations for different comparisons.

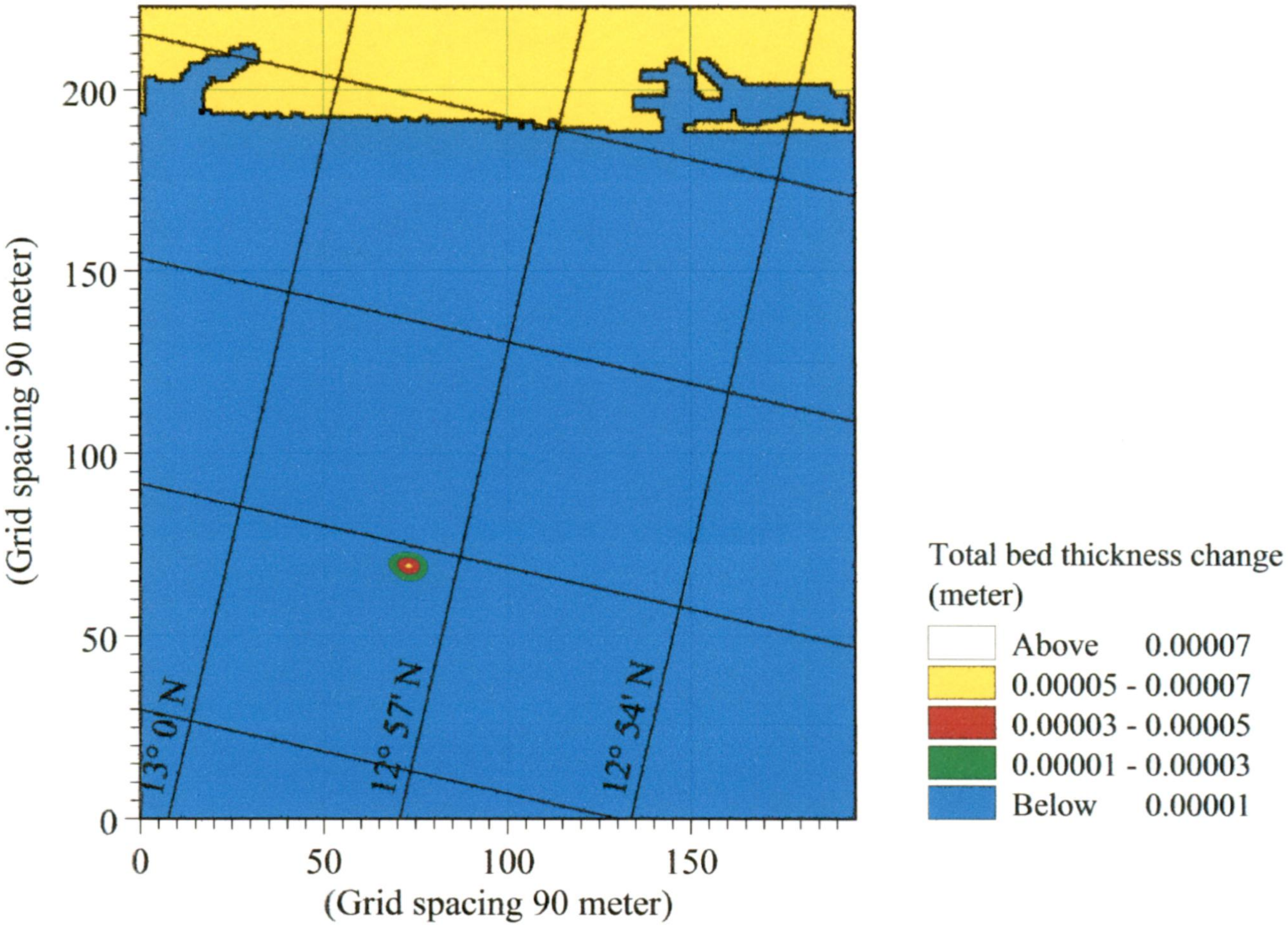


**FIG. 38: PLOT SHOWING NEW MANGALORE PORT AND STUDY AREA**

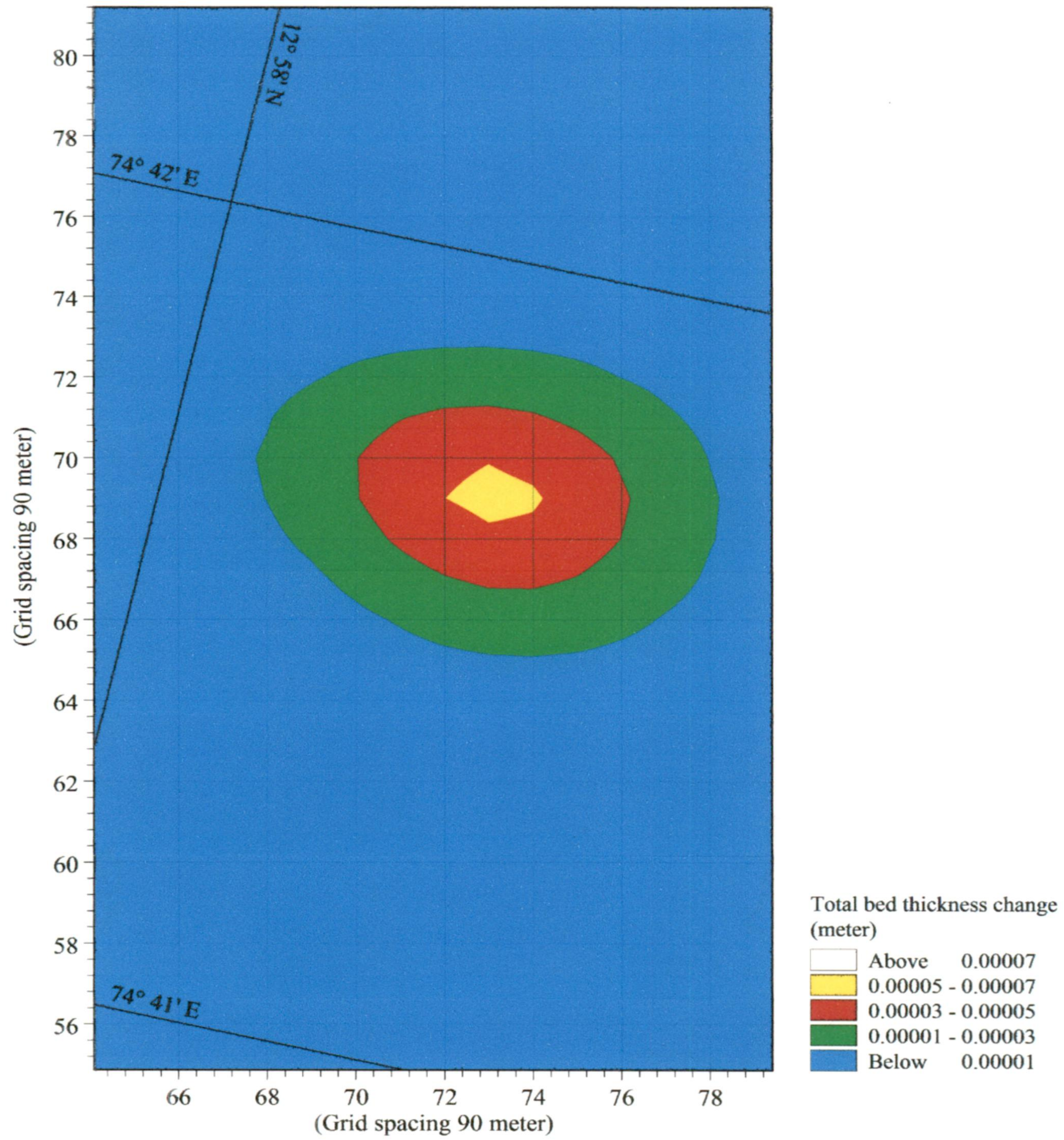


**FIG. 39: PLOT SHOWING DISPERSION OF DREDGED SPOIL AS A BED LOAD MOVEMENT COMPUTED BY NUMERICAL MODEL EQUIVALENT TO ISOCOUNT CONTOURS OF FIRST POST INJECTION TRACKING (FIRST INVESTIGATION)**

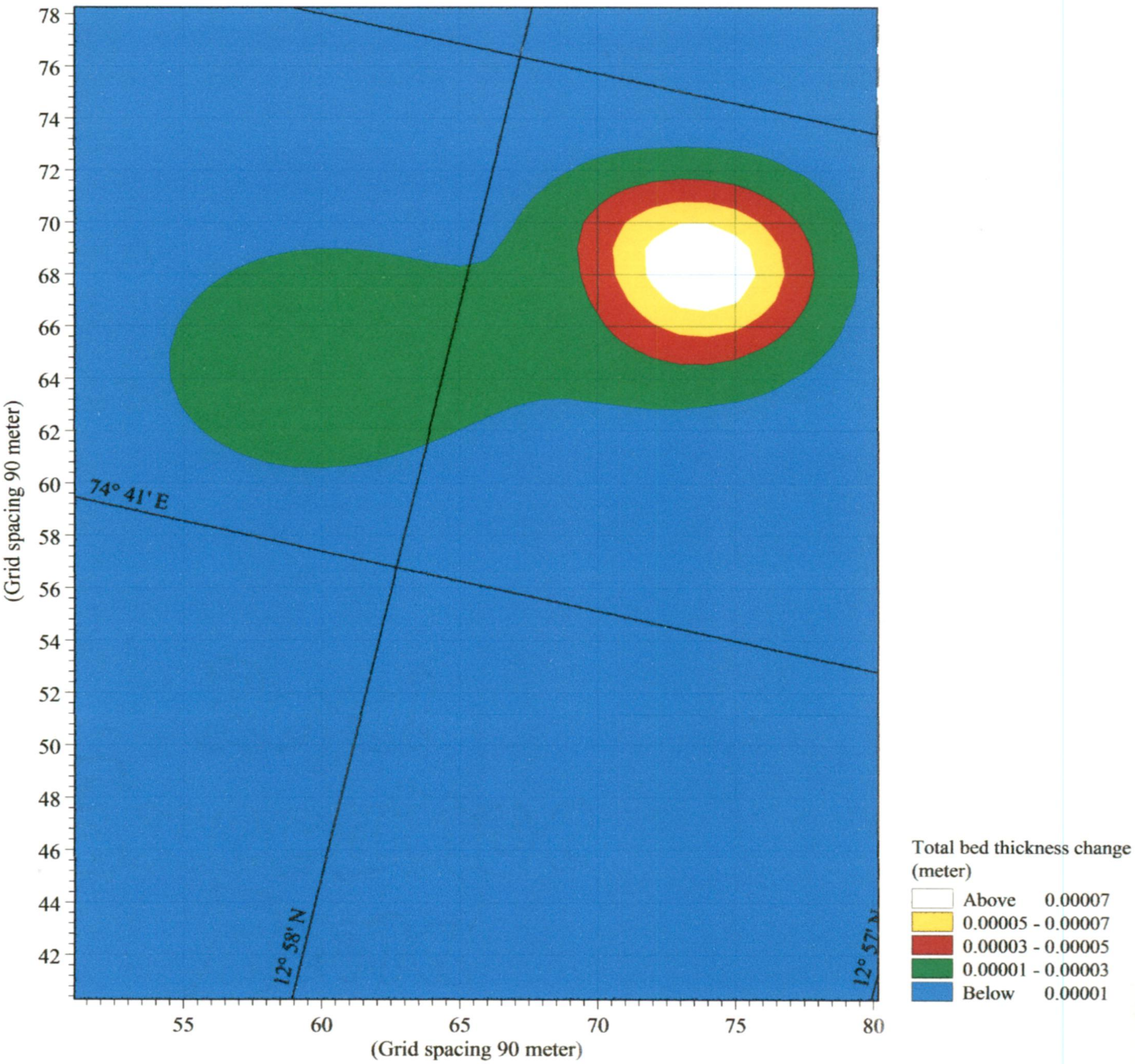


FIG. 40: PLOT SHOWING DISPERSION OF DREDGED SPOIL AS A BED LOAD MOVEMENT COMPUTED BY NUMERICAL MODEL EQUIVALENT TO ISOCOUNT CONTOURS OF SECOND POST INJECTION TRACKING (FIRST INVESTIGATION)

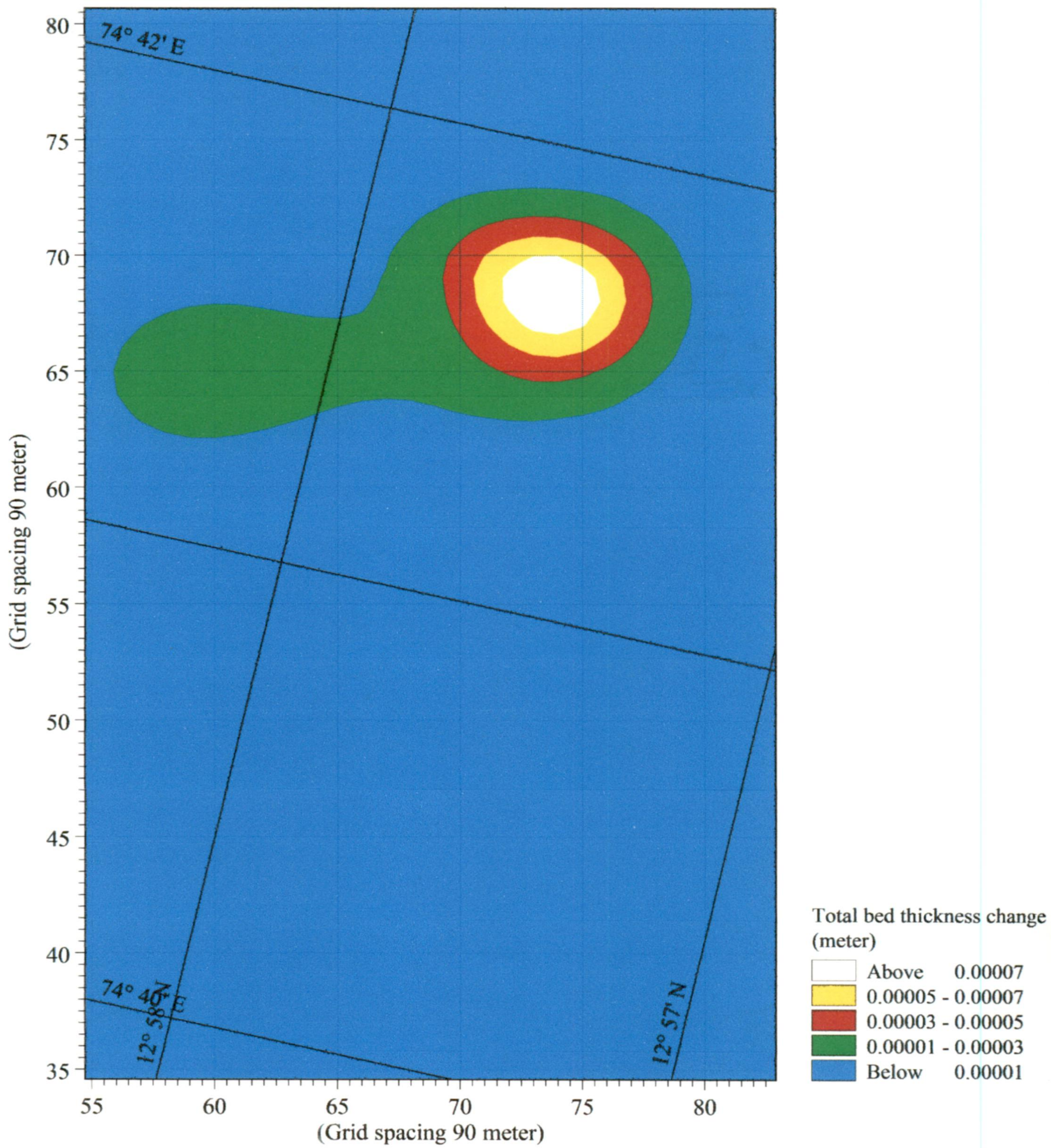


**FIG. 41: PLOT SHOWING DISPERSION OF DREDGED SPOIL AS A BED LOAD MOVEMENT COMPUTED BY NUMERICAL MODEL EQUIVALENT TO ISOCOUNT CONTOURS OF THIRD POST INJECTION TRACKING (FIRST INVESTIGATION)**

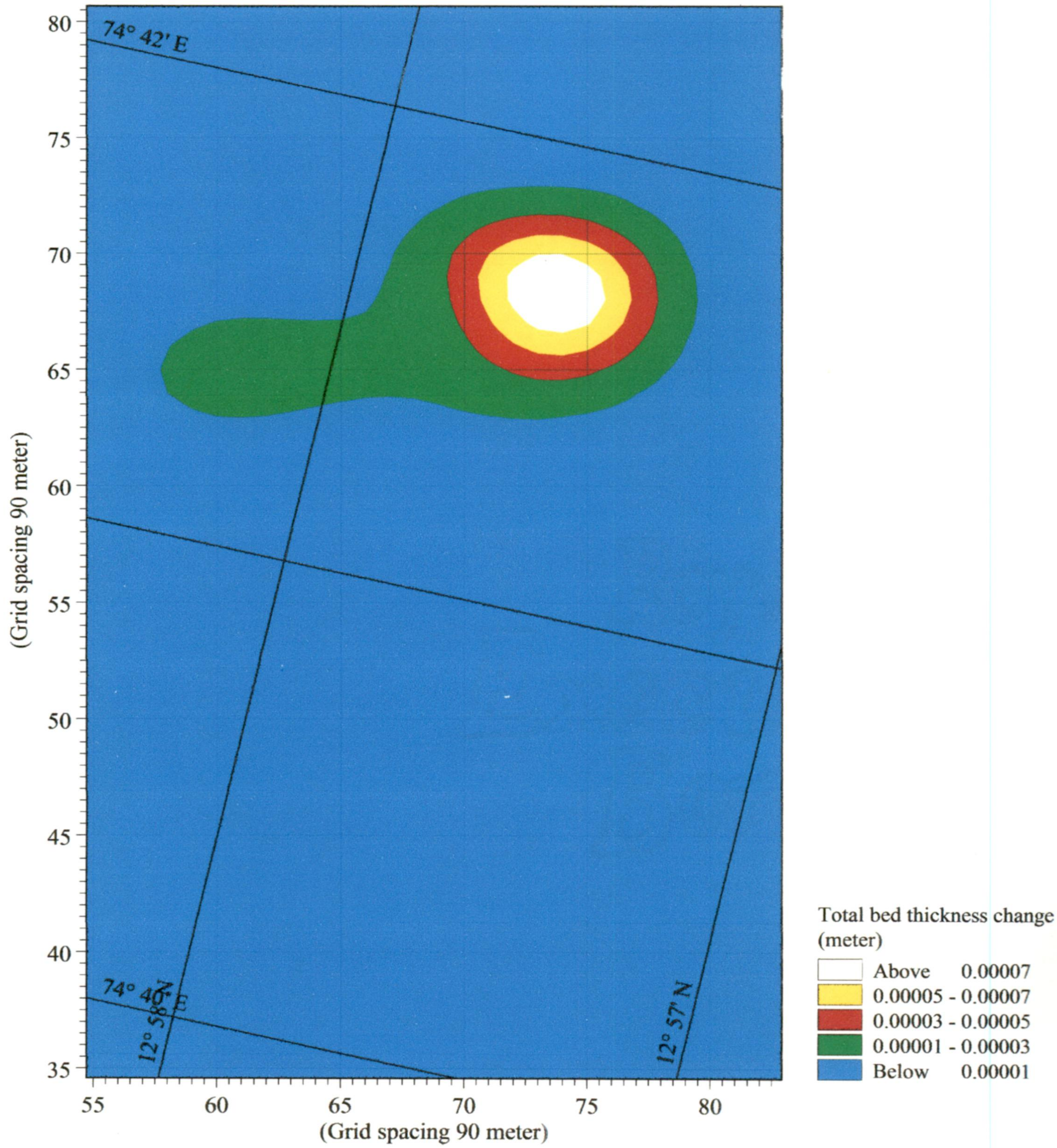


FIG. 42: PLOT SHOWING DISPERSION OF DREDGED SPOIL AS A BED LOAD MOVEMENT COMPUTED BY NUMERICAL MODEL EQUIVALENT TO ISOCOUNT CONTOURS OF FOURTH POST INJECTION TRACKING (FIRST INVESTIGATION)

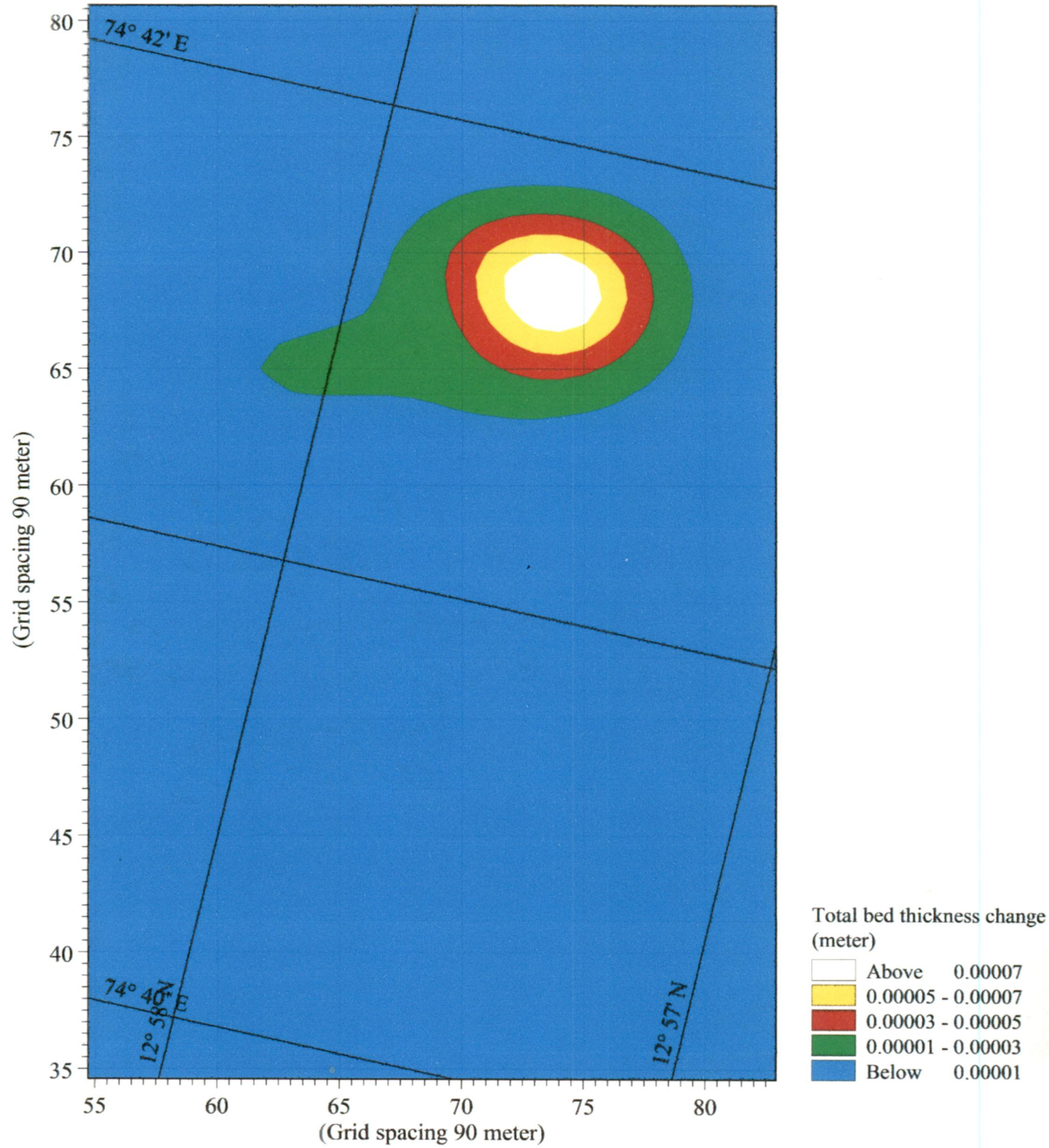


**FIG. 43: PLOT SHOWING DISPERSION OF DREDGED SPOIL AS A BED LOAD MOVEMENT COMPUTED BY NUMERICAL MODEL EQUIVALENT TO ISOCOUNT CONTOURS OF FIRST POST INJECTION TRACKING (SECOND INVESTIGATION)**

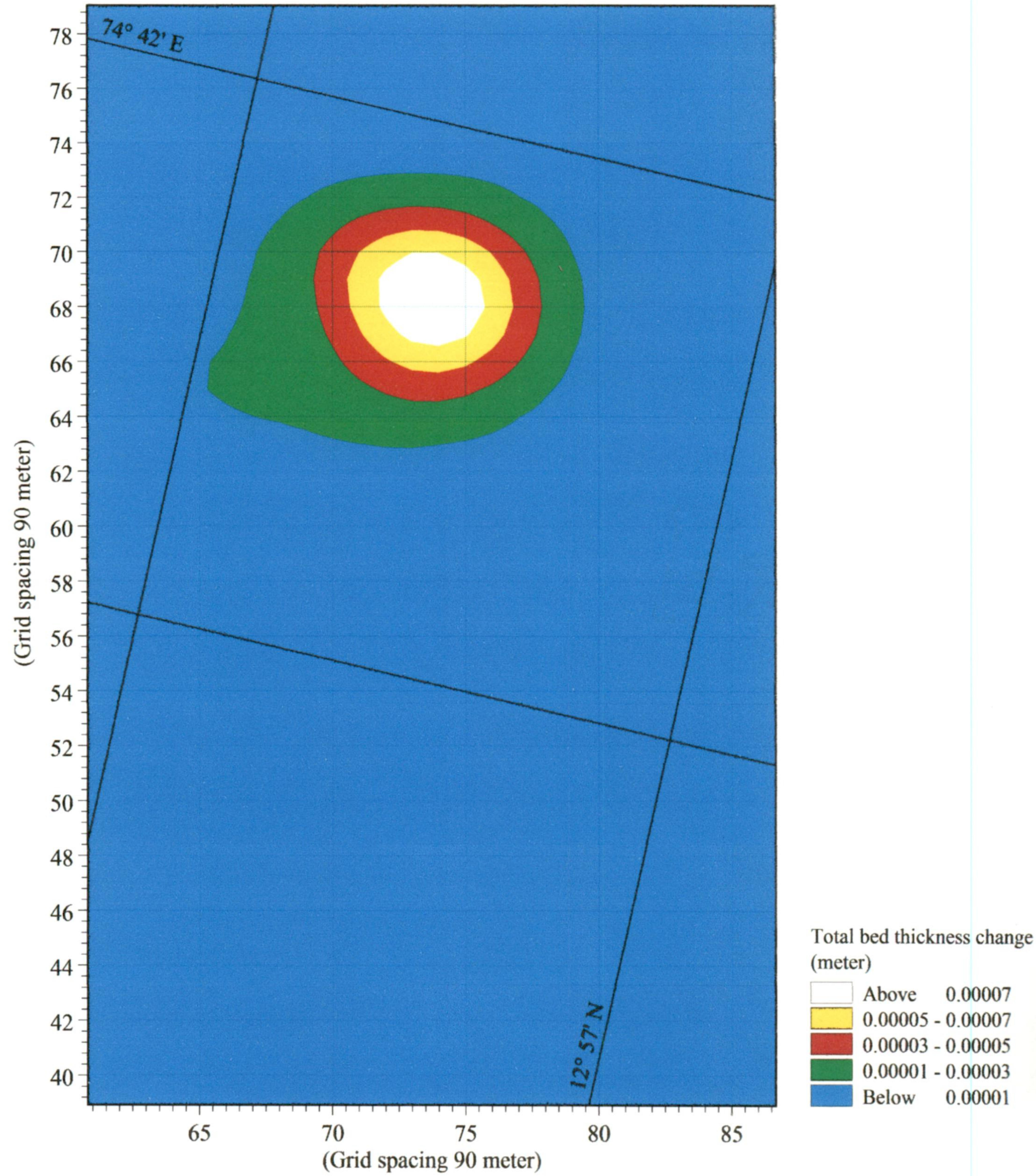


FIG. 44: PLOT SHOWING DISPERSION OF DREDGED SPOIL AS A BED LOAD MOVEMENT COMPUTED BY NUMERICAL MODEL EQUIVALENT TO ISOCOUNT CONTOURS OF SECOND POST INJECTION TRACKING (SECOND INVESTIGATION)

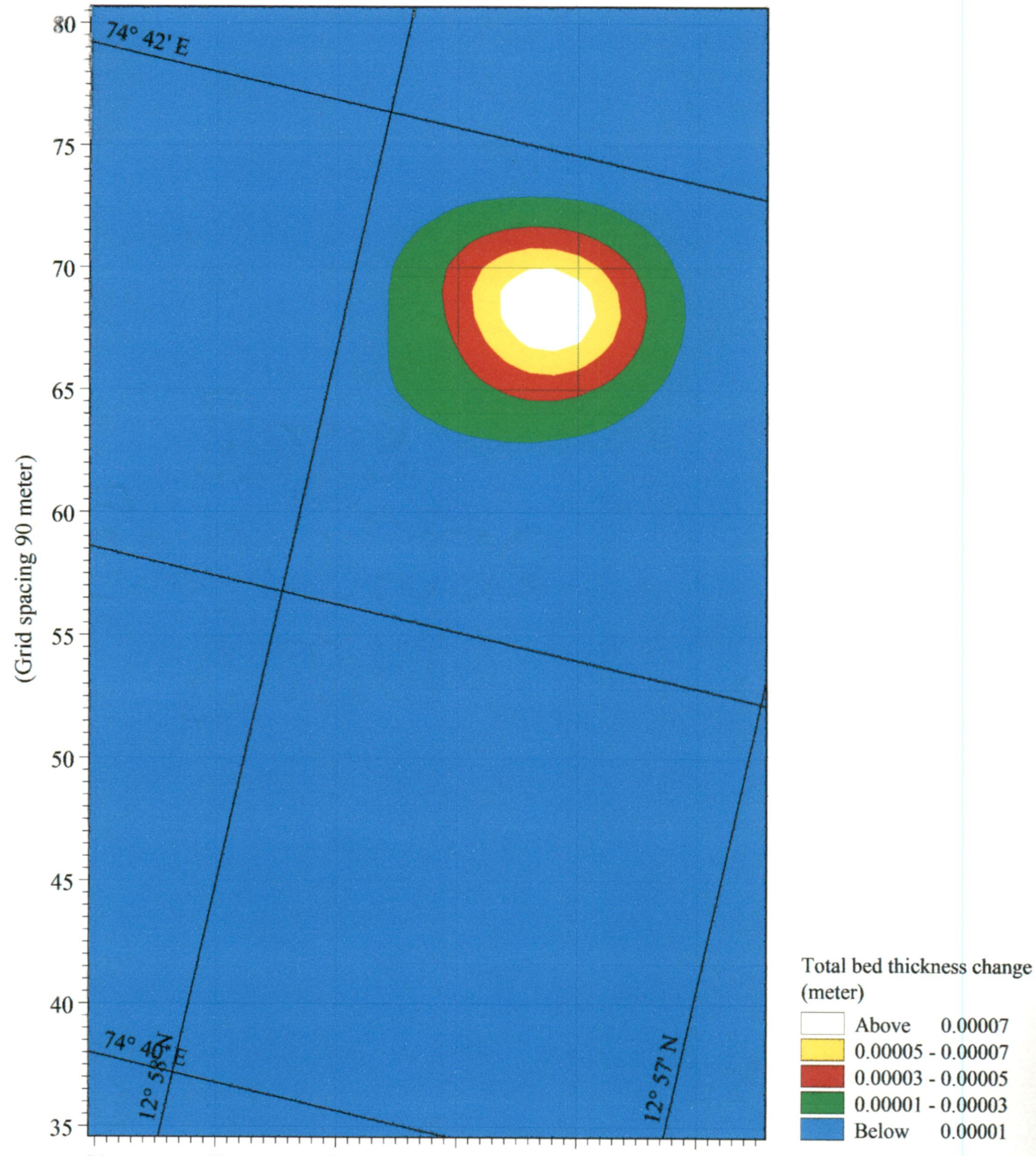


**FIG. 45: PLOT SHOWING DISPERSION OF DREDGED SPOIL AS A BED LOAD MOVEMENT COMPUTED BY NUMERICAL MODEL EQUIVALENT TO ISOCOUNT CONTOURS OF THIRD POST INJECTION TRACKING (SECOND INVESTIGATION)**

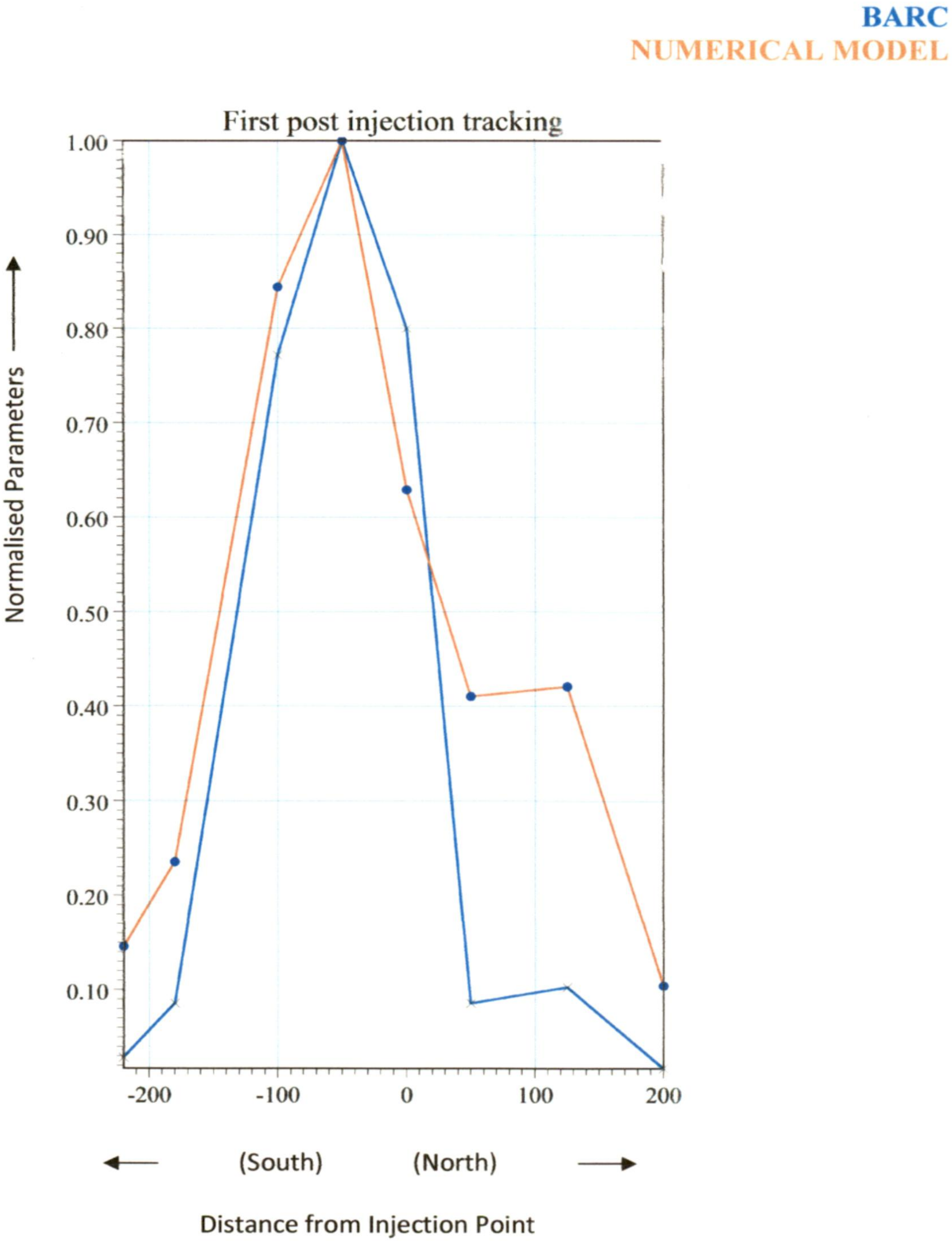


FIG. 46: COMPARISON BETWEEN NORTH-SOUTH DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR FIRST POST INJECTION TRACKING (FIRST INVESTIGATION)

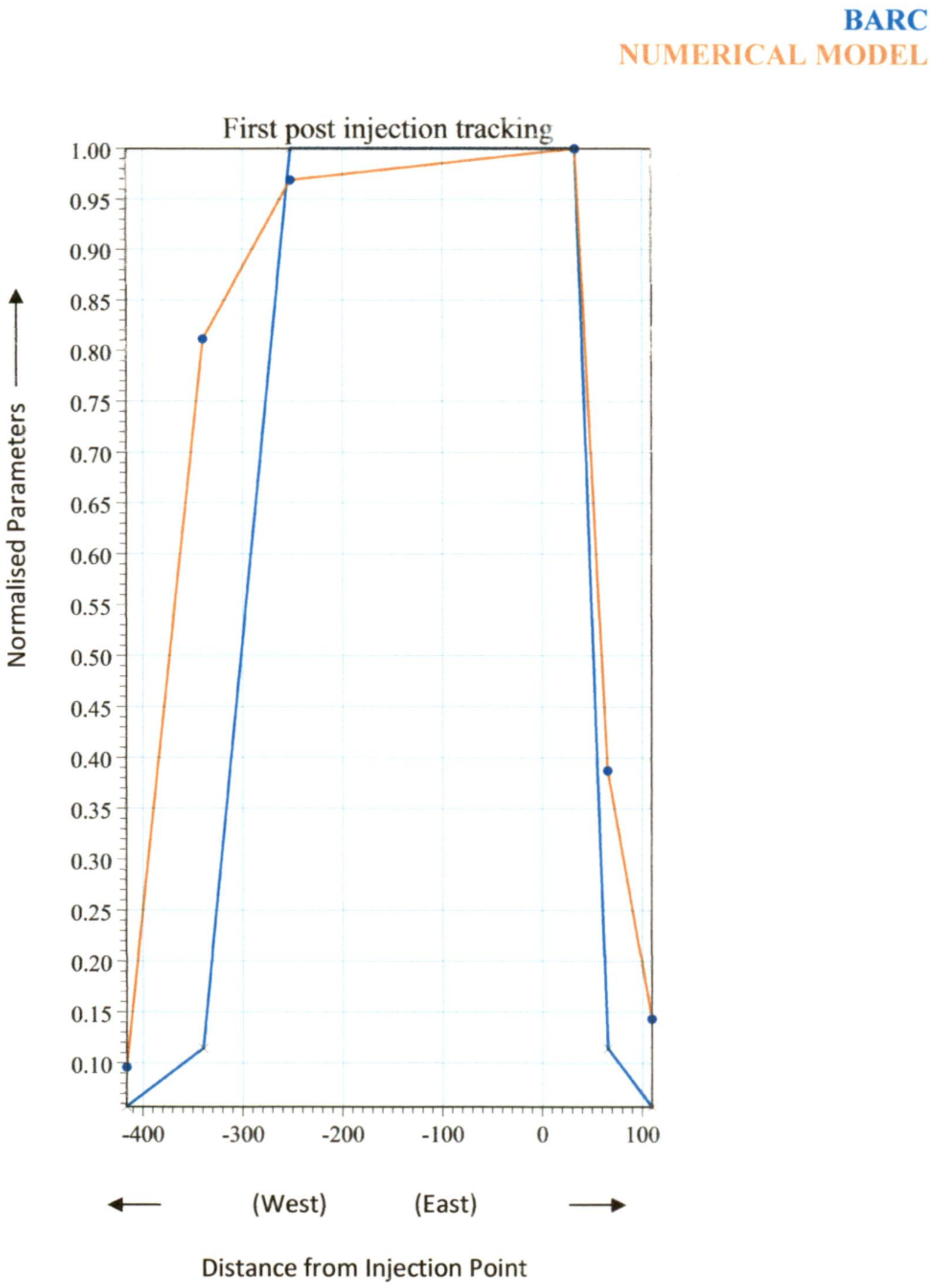


FIG. 47: COMPARISON BETWEEN EAST-WEST DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR FIRST POST INJECTION TRACKING (FIRST INVESTIGATION)

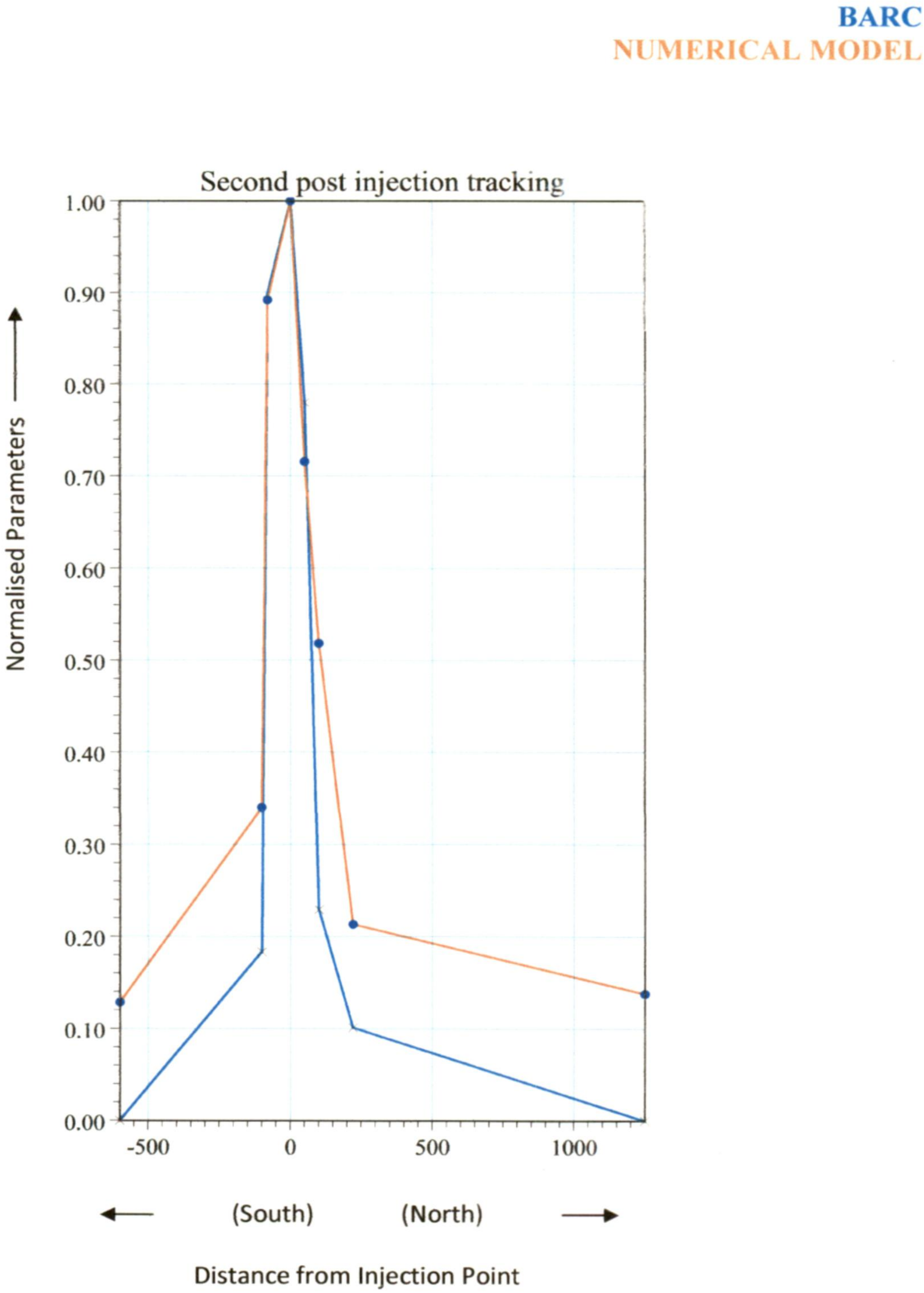


FIG. 48: COMPARISON BETWEEN NORTH-SOUTH DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR SECOND POST INJECTION TRACKING (FIRST INVESTIGATION)

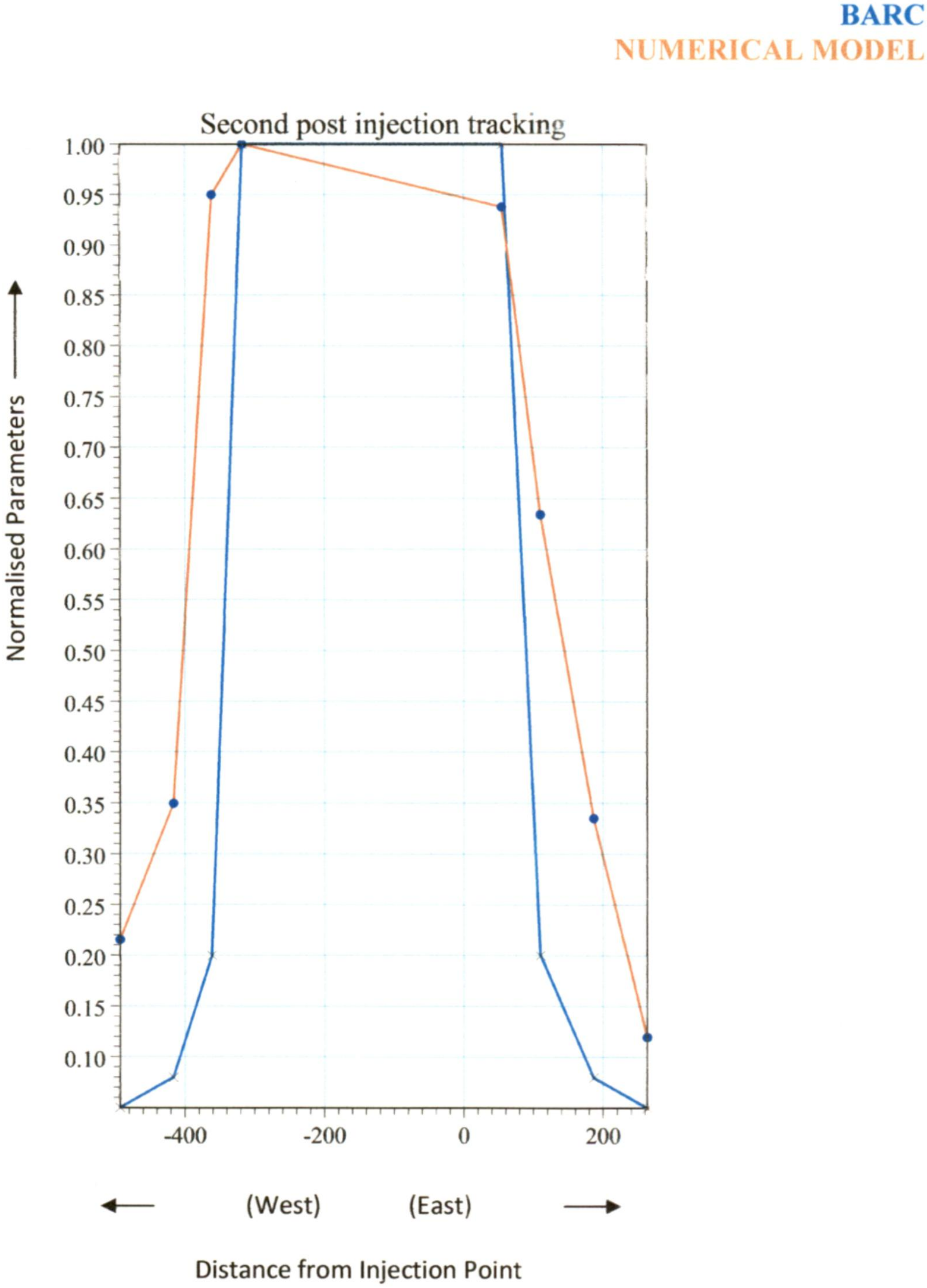


FIG. 49: COMPARISON BETWEEN EAST-WEST DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR SECOND POST INJECTION TRACKING (FIRST INVESTIGATION)

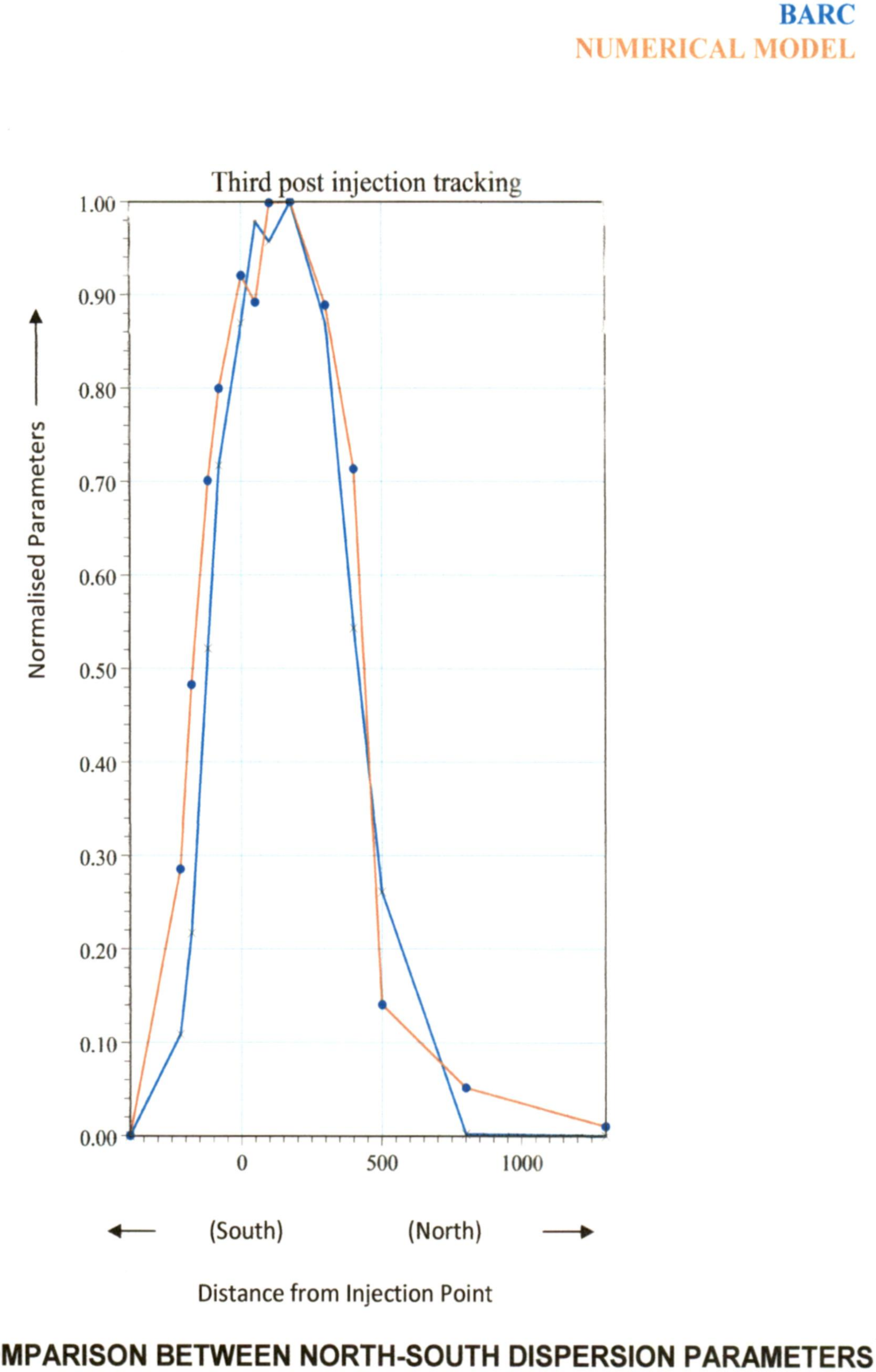


FIG. 50 : COMPARISON BETWEEN NORTH-SOUTH DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR THIRD POST INJECTION TRACKING (FIRST INVESTIGATION)

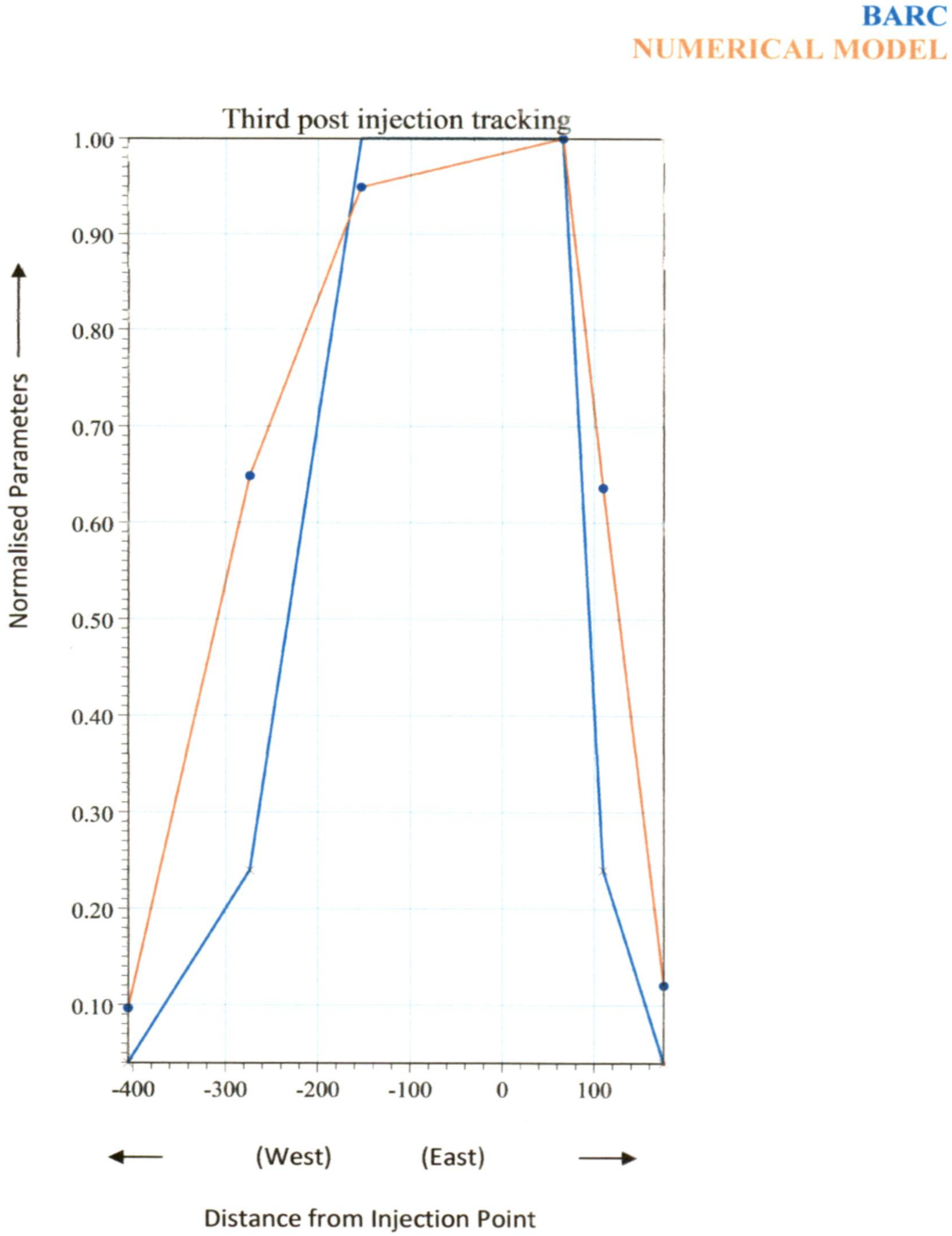


FIG. 51: COMPARISON BETWEEN EAST-WEST DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR THIRD POST INJECTION TRACKING (FIRST INVESTIGATION)

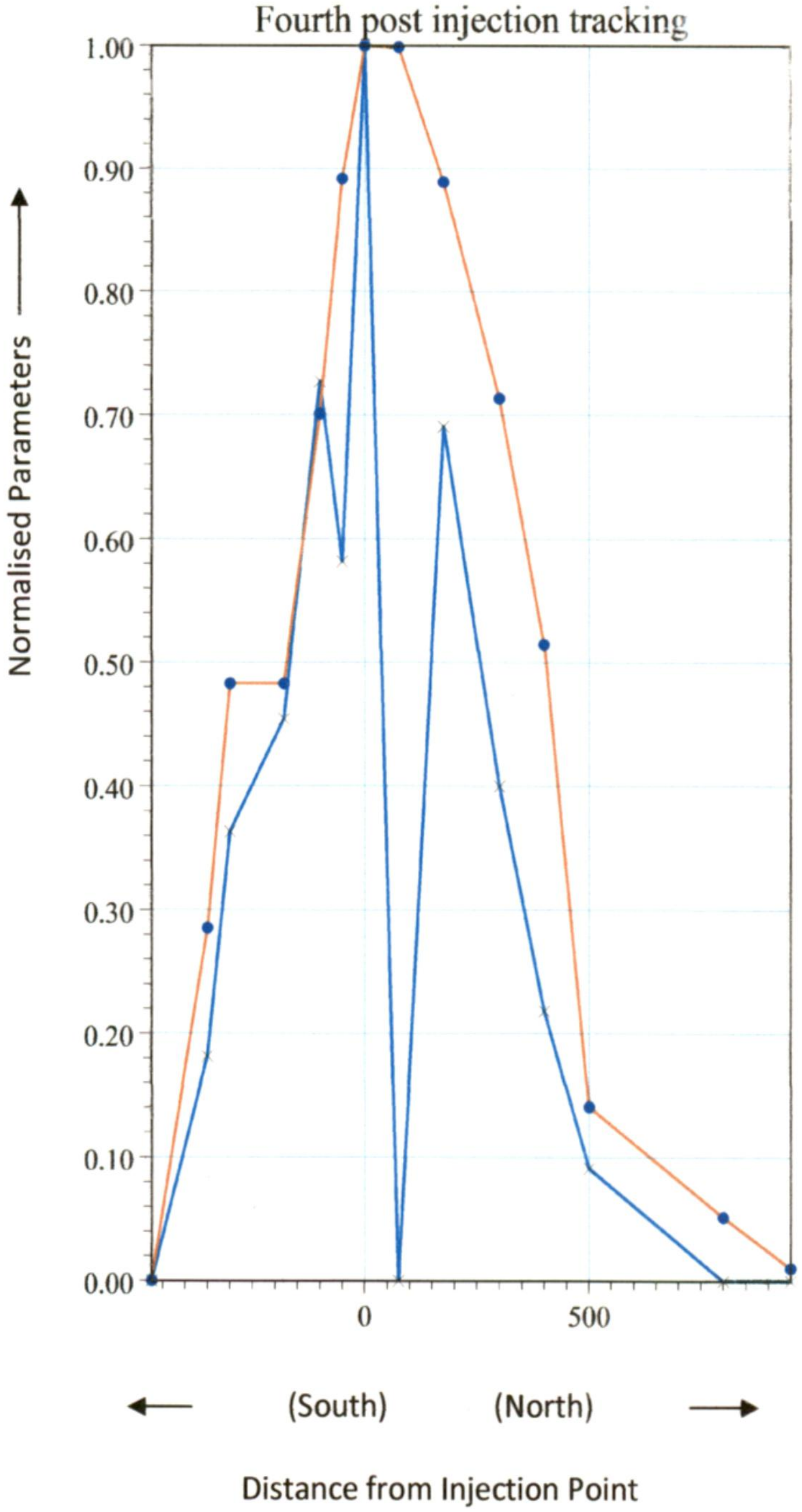


FIG. 52: COMPARISON BETWEEN NORTH-SOUTH DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR FOURTH POST INJECTION TRACKING (FIRST INVESTIGATION)

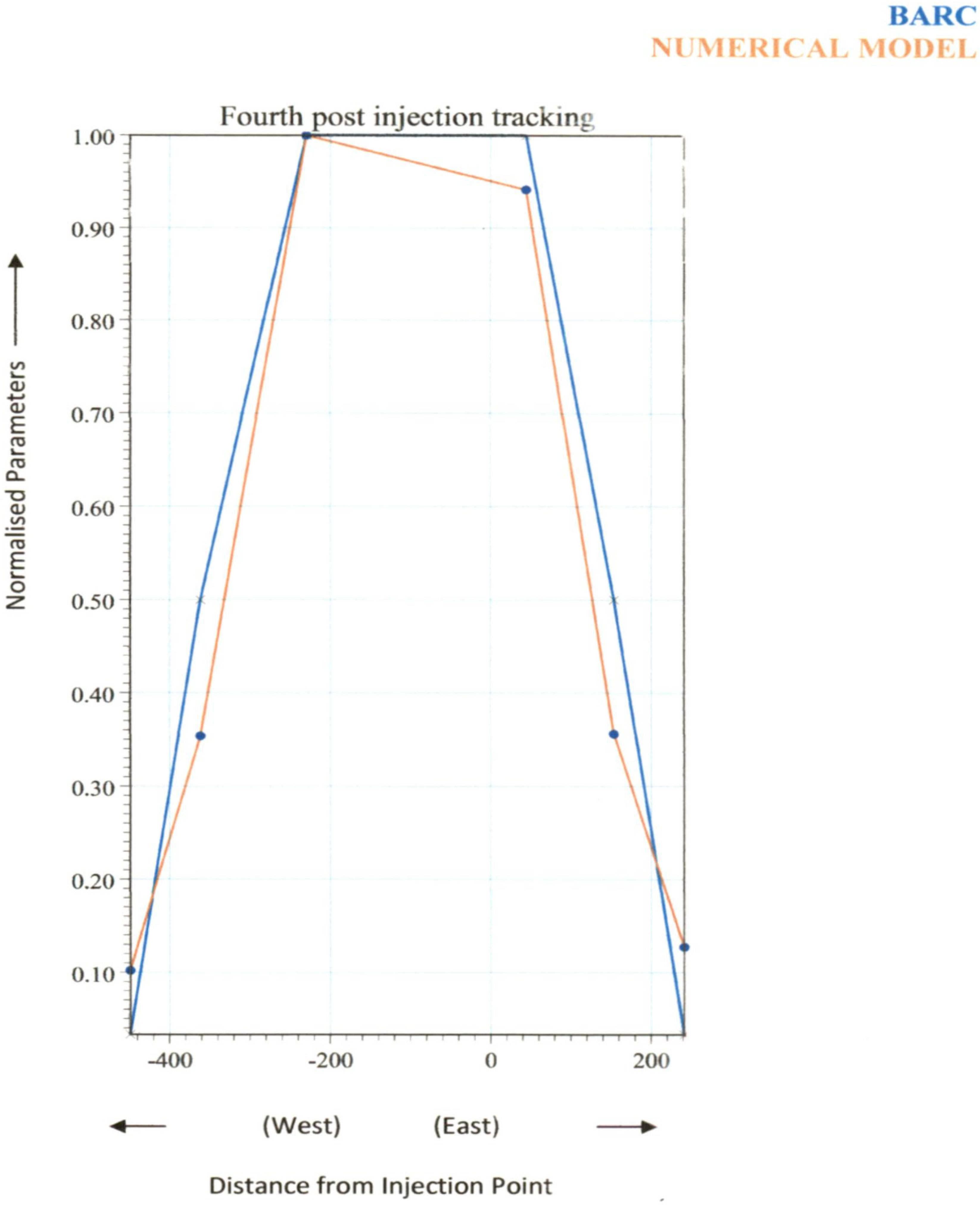


FIG. 53: COMPARISON BETWEEN EAST-WEST DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR FOURTH POST INJECTION TRACKING (FIRST INVESTIGATION)

**BARC**
**NUMERICAL MODEL**

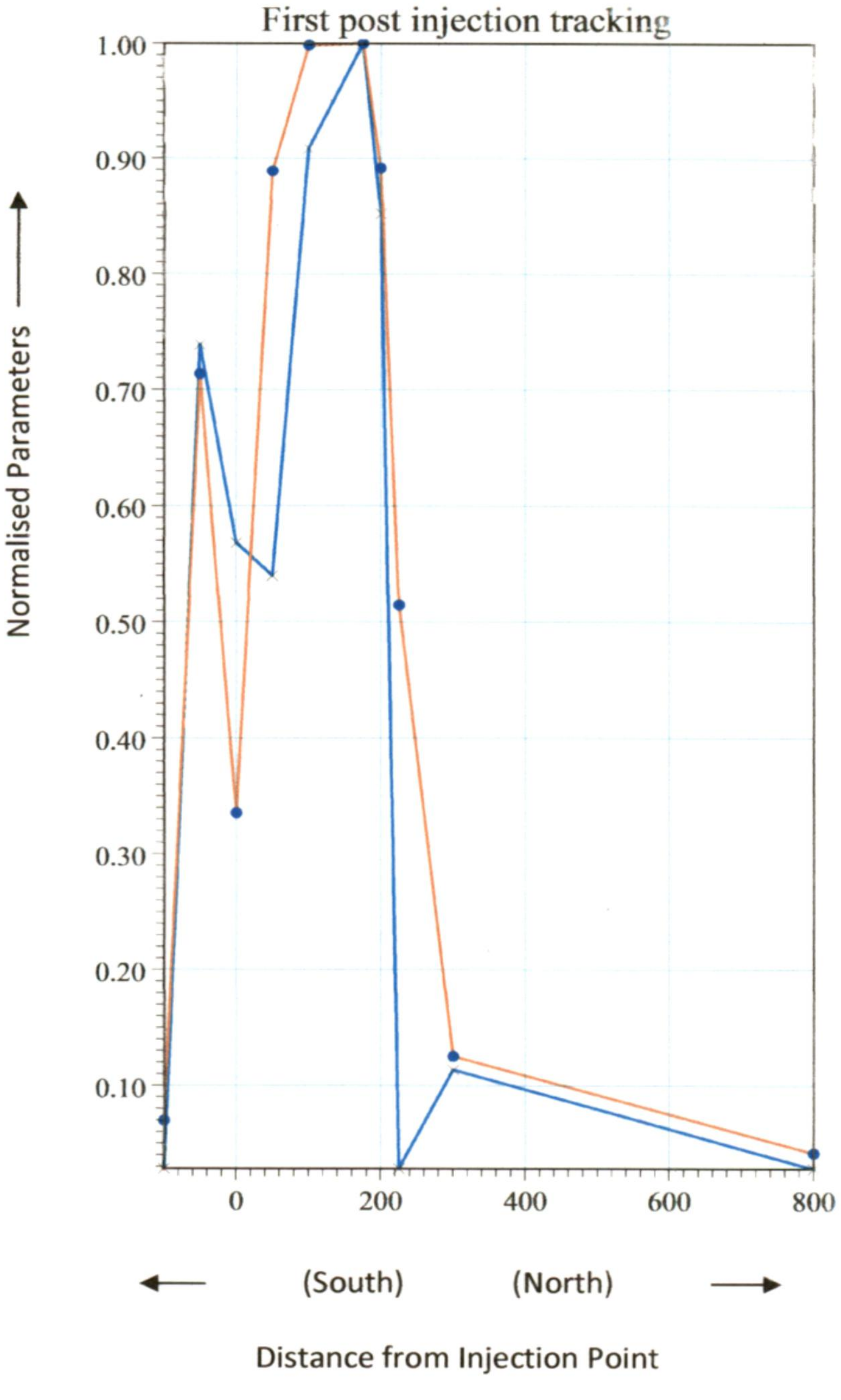


FIG. 54: COMPARISON BETWEEN NORTH-SOUTH DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR FIRST POST INJECTION TRACKING (SECOND INVESTIGATION)

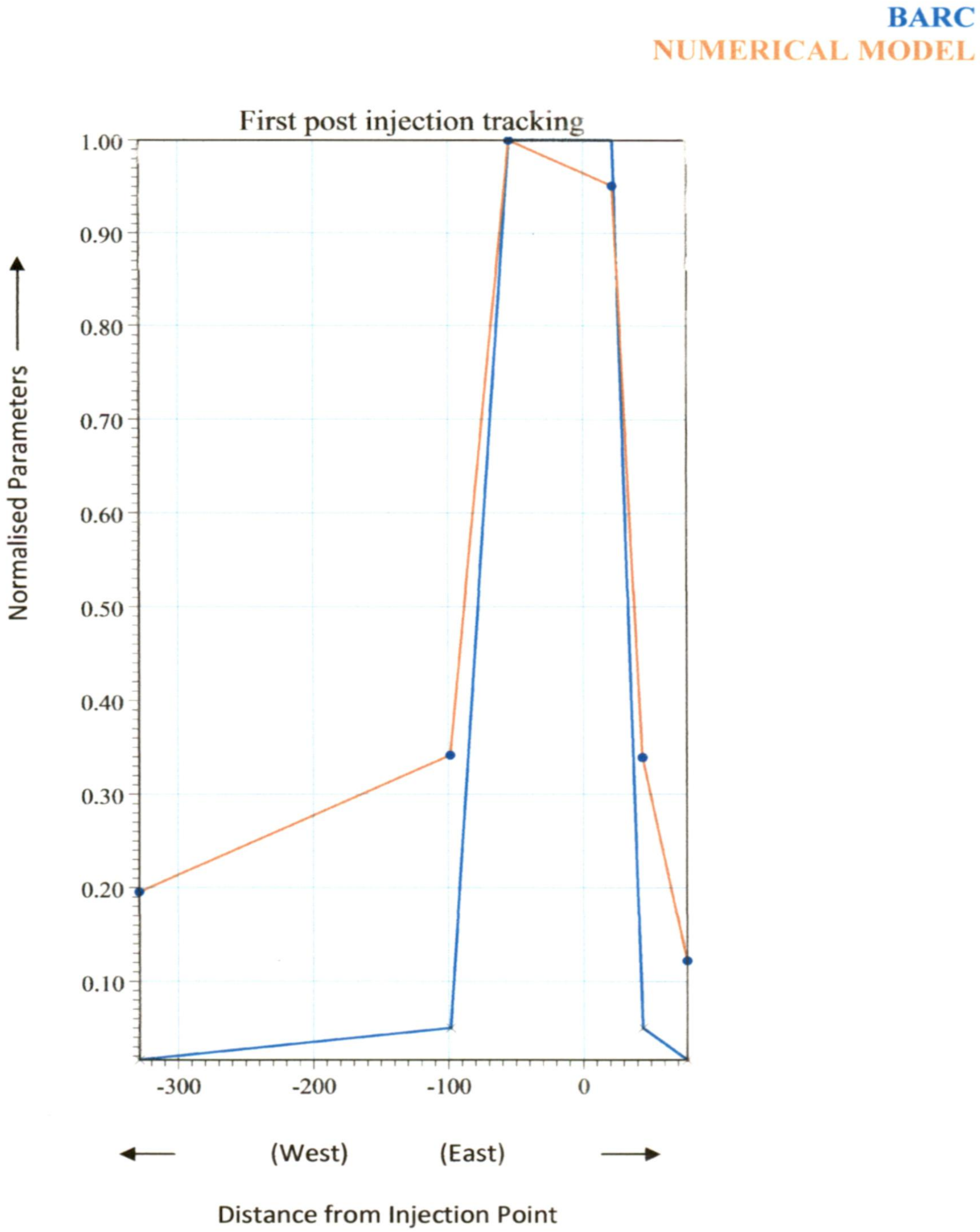


FIG. 55: COMPARISON BETWEEN EAST-WEST DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR FIRST POST INJECTION TRACKING (SECOND INVESTIGATION)

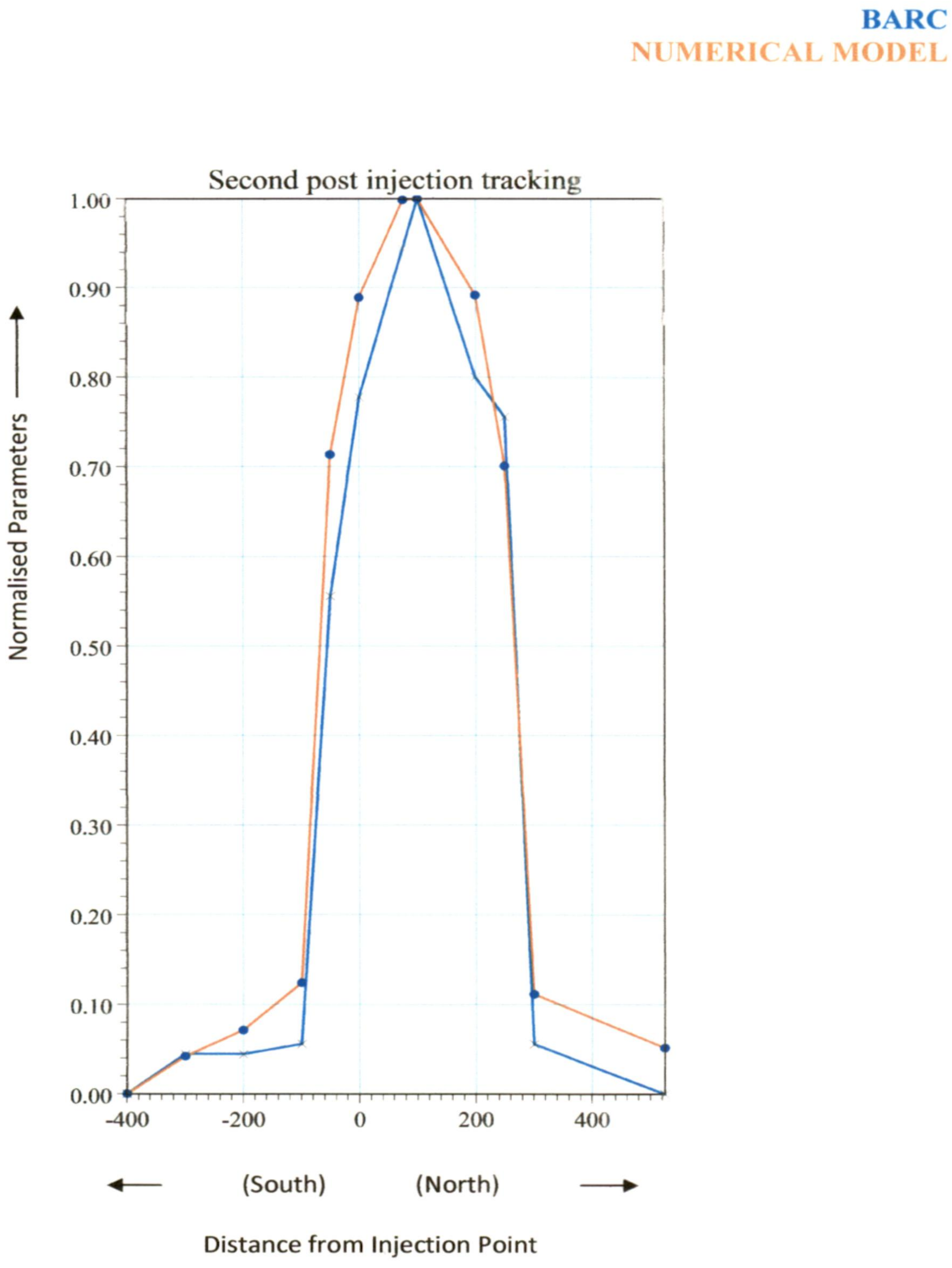


FIG. 56: COMPARISON BETWEEN NORTH-SOUTH DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR SECOND POST INJECTION TRACKING (SECOND INVESTIGATION)

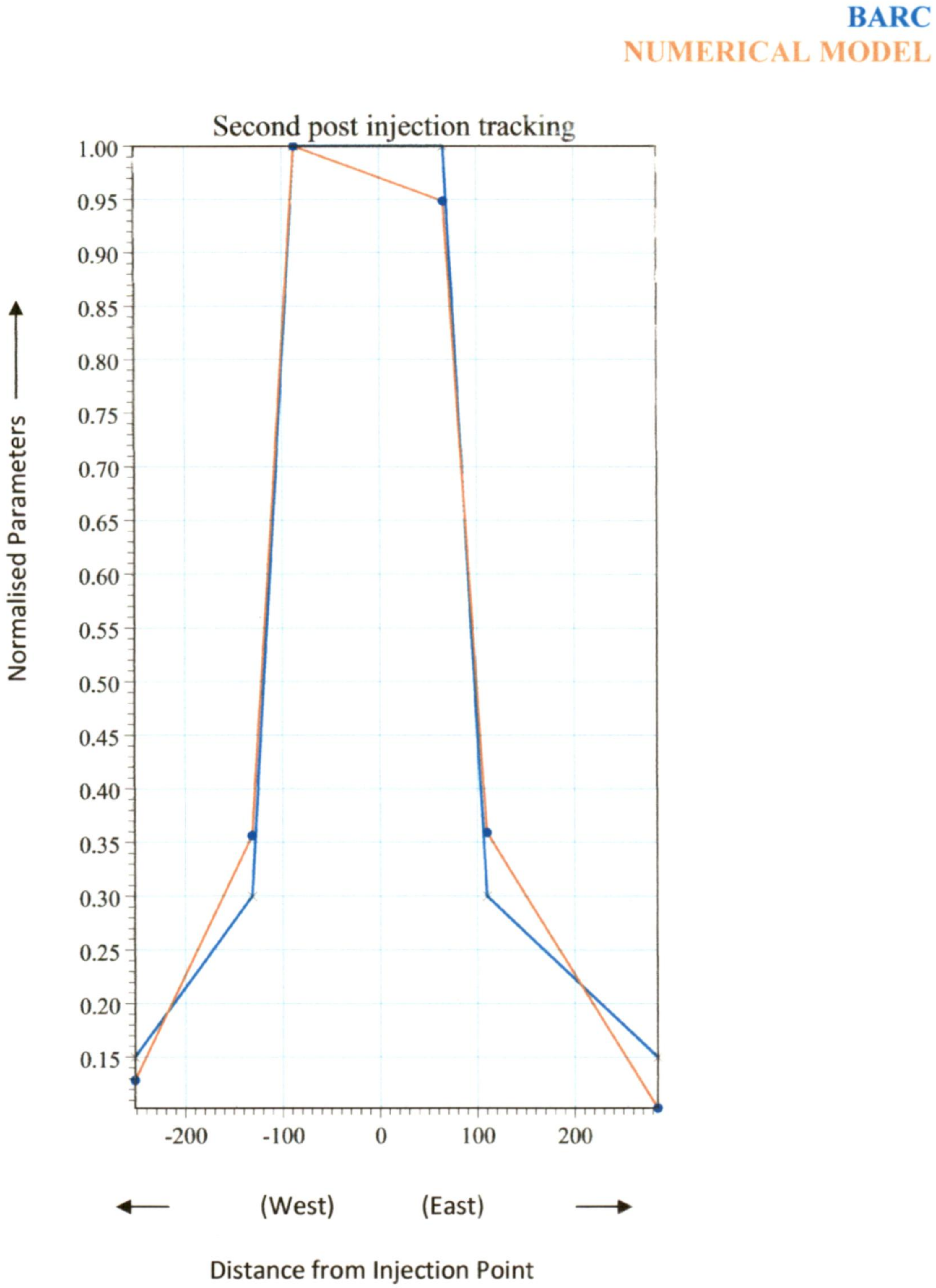


FIG. 57: COMPARISON BETWEEN EAST-WEST DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR SECOND POST INJECTION TRACKING (SECOND INVESTIGATION)

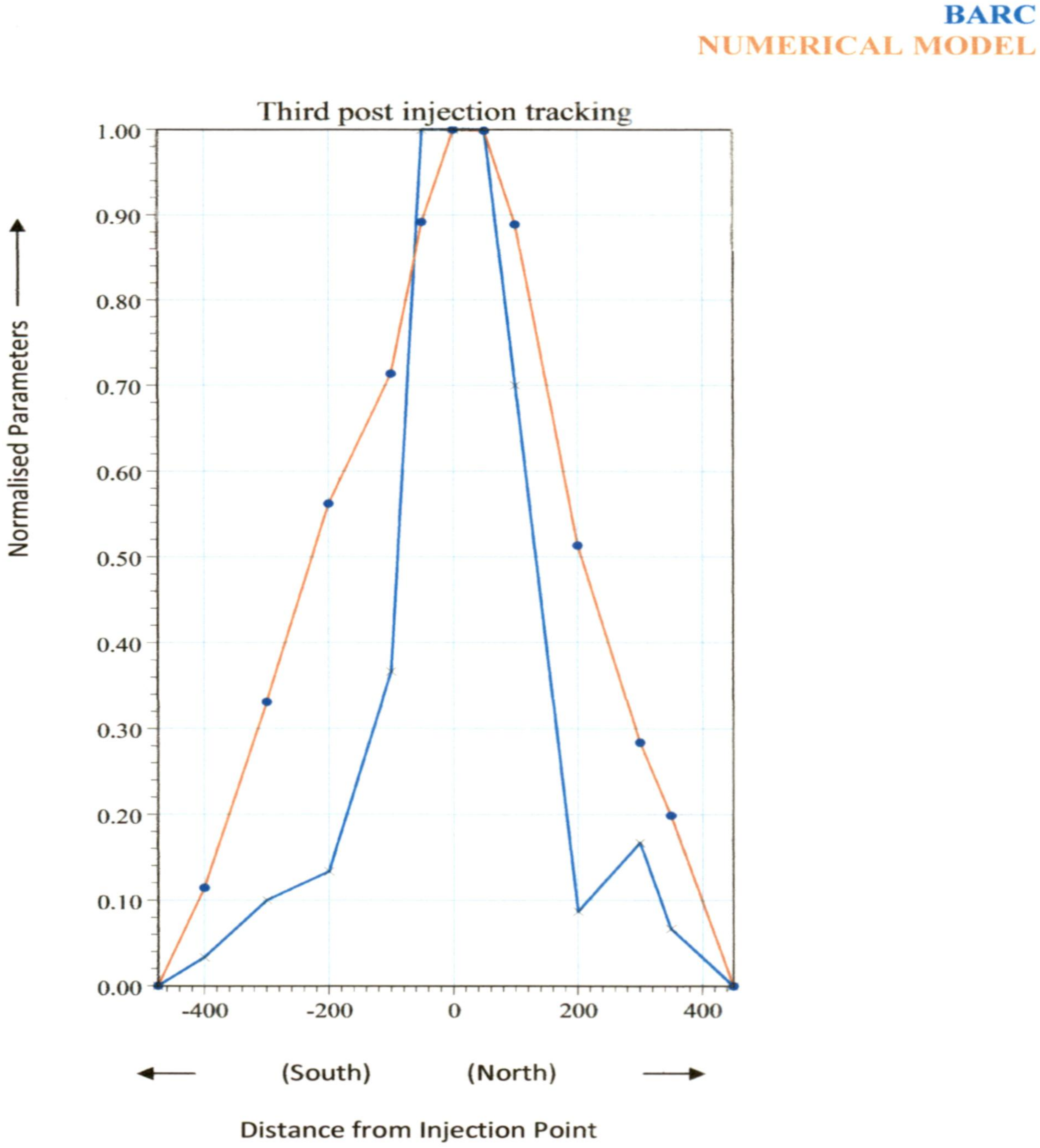


FIG. 58: COMPARISON BETWEEN NORTH-SOUTH DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR THIRD POST INJECTION TRACKING (SECOND INVESTIGATION)

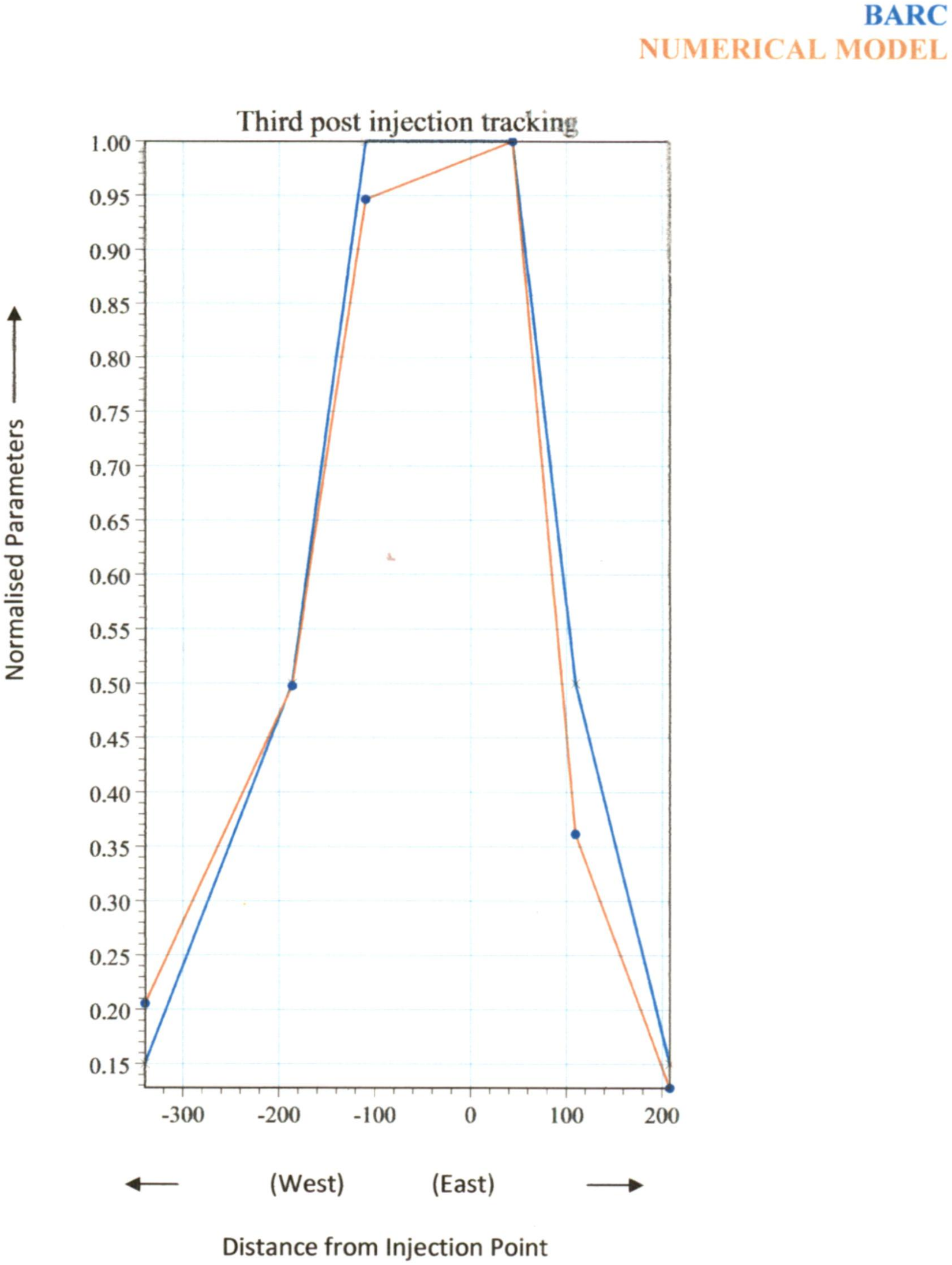


FIG. 59: COMPARISON BETWEEN EAST-WEST DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR THIRD POST INJECTION TRACKING (SECOND INVESTIGATION)

# COMPARISON BETWEEN NORTH-SOUTH DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR FIRST INVESTIGATION (Table 5- 8)

## TABLE 5: First post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| -220 | 0.05 | 0.0285714 | 0.7 | 0.145833333 |
| -180 | 0.15 | 0.0857143 | 1.13 | 0.235416667 |
| -100 | 1.35 | 0.7714286 | 4.05 | 0.84375 |
| -50 | 1.75 | 1 | 4.8 | 1 |
| 0 | 1.4 | 0.8 | 3.02 | 0.629166667 |
| 50 | 0.15 | 0.0857143 | 1.97 | 0.410416667 |
| 125 | 0.18 | 0.1028571 | 2.02 | 0.420833333 |
| 200 | 0.03 | 0.0171429 | 0.5 | 0.104166667 |
| **Std. deviation** |  | 0.416866 |  | 0.326393414 |

## TABLE 6: Second post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| -600 | 0 | 0 | 0.922 | 0.128412256 |
| -100 | 0.2 | 0.1834862 | 2.44 | 0.339832869 |
| -80 | 0.98 | 0.8990826 | 6.4 | 0.891364903 |
| 0 | 1.09 | 1 | 7.18 | 1 |
| 50 | 0.85 | 0.7798165 | 5.14 | 0.715877437 |
| 100 | 0.25 | 0.2293578 | 3.72 | 0.51810585 |
| 220 | 0.11 | 0.1009174 | 1.53 | 0.213091922 |
| 1250 | 0 | 0 | 0.99 | 0.137883008 |
| **Std. deviation** |  | 0.4206771 |  | 0.343696131 |

## TABLE 7: Third post injection tracking

| Distance from injection point | CPMx10E 7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| -400 | 0 | 0 | 0 | 0 |
| -220 | 0.05 | 0.1086957 | 2.05 | 0.28511822 |
| -180 | 0.1 | 0.2173913 | 3.47 | 0.482614743 |
| -120 | 0.24 | 0.5217391 | 5.04 | 0.700973574 |
| -80 | 0.33 | 0.7173913 | 5.75 | 0.799721836 |
| 0 | 0.4 | 0.8695652 | 6.62 | 0.920027816 |
| 50 | 0.45 | 0.9782609 | 6.41 | 0.891515994 |
| 100 | 0.44 | 0.9565217 | 7.18 | 0.998609179 |
| 175 | 0.46 | 1 | 7.19 | 1 |
| 300 | 0.4 | 0.8695652 | 6.39 | 0.888734353 |
| 400 | 0.25 | 0.5434783 | 5.13 | 0.71349096 |
| 500 | 0.12 | 0.2608696 | 1.01 | 0.140472879 |
| 800 | 0.001 | 0.0021739 | 0.37 | 0.051460362 |
| 1300 | 0 | 0 | 0.075 | 0.010431154 |
| **Std. deviation** | | 0.3968895 | | 0.376351132 |

## TABLE 8: Fourth post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| -475 | 0 | 0 | 0 | 0 |
| -350 | 0.1 | 0.1818182 | 2.05 | 0.28511822 |
| -300 | 0.2 | 0.3636364 | 3.47 | 0.482614743 |
| -180 | 0.25 | 0.4545455 | 3.47 | 0.482614743 |
| -100 | 0.4 | 0.7272727 | 5.04 | 0.700973574 |
| -50 | 0.32 | 0.5818182 | 6.41 | 0.891515994 |
| 0 | 0.55 | 1 | 7.19 | 1 |
| 75 | 0 | 0 | 7.18 | 0.998609179 |
| 175 | 0.38 | 0.6909091 | 6.39 | 0.888734353 |
| 300 | 0.22 | 0.4 | 5.13 | 0.71349096 |
| 400 | 0.12 | 0.2181818 | 3.7 | 0.514603616 |
| 500 | 0.05 | 0.0909091 | 1.01 | 0.140472879 |
| 800 | 0 | 0 | 0.37 | 0.051460362 |
| 950 | 0 | 0 | 0.075 | 0.010431154 |
| **Std. deviation** | | 0.322084 | | 0.367345256 |

# COMPARISON BETWEEN NORTH-SOUTH DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR SECOND INVESTIGATION (Table 9-11)

## TABLE 9: First post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| -100 | 0.25 | 0.028409 | 0.5 | 0.069541 |
| -50 | 6.5 | 0.738636 | 5.13 | 0.713491 |
| 0 | 5 | 0.568182 | 2.41 | 0.335188 |
| 50 | 4.75 | 0.539773 | 6.39 | 0.888734 |
| 100 | 8 | 0.909091 | 7.18 | 0.998609 |
| 175 | 8.8 | 1 | 7.19 | 1 |
| 200 | 7.5 | 0.852273 | 6.41 | 0.891516 |
| 225 | 0.25 | 0.028409 | 3.7 | 0.514604 |
| 300 | 1 | 0.113636 | 0.9 | 0.125174 |
| 800 | 0.25 | 0.028409 | 0.3 | 0.041725 |
| **Std. deviation** | | 0.396844 | | 0.391336 |

## TABLE 10: Second post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| -400 | 0 | 0 | 0 | 0 |
| -300 | 0.2 | 0.044444 | 0.3 | 0.041725 |
| -200 | 0.2 | 0.044444 | 0.51 | 0.070932 |
| -100 | 0.25 | 0.055556 | 0.89 | 0.123783 |
| -50 | 2.5 | 0.555556 | 5.13 | 0.713491 |
| 0 | 3.5 | 0.777778 | 6.39 | 0.888734 |
| 75 | 4.25 | 0.944444 | 7.18 | 0.998609 |
| 100 | 4.5 | 1 | 7.19 | 1 |
| 200 | 3.6 | 0.8 | 6.41 | 0.891516 |
| 250 | 3.4 | 0.755556 | 5.04 | 0.700974 |
| 300 | 0.25 | 0.055556 | 0.8 | 0.111266 |
| 525 | 0 | 0 | 0.37 | 0.05146 |
| **Std. deviation** | | 0.417279 | | 0.427795 |

## TABLE 11: Third post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| -475 | 0 | 0 | 0 | 0 |
| -400 | 0.1 | 0.033333 | 0.82 | 0.114047 |
| -300 | 0.3 | 0.1 | 2.38 | 0.331015 |
| -200 | 0.4 | 0.133333 | 4.04 | 0.561892 |
| -100 | 1.1 | 0.366667 | 5.13 | 0.713491 |
| -50 | 3 | 1 | 6.41 | 0.891516 |
| 0 | 3 | 1 | 7.19 | 1 |
| 50 | 3 | 1 | 7.18 | 0.998609 |
| 100 | 2.1 | 0.7 | 6.39 | 0.888734 |
| 200 | 0.26 | 0.086667 | 3.69 | 0.513213 |
| 300 | 0.5 | 0.166667 | 2.04 | 0.283727 |
| 350 | 0.2 | 0.066667 | 1.43 | 0.198887 |
| 450 | 0 | 0 | 0 | 0 |
| **Std. deviation** |  | 0.411036 |  | 0.372777 |

## COMPARISON BETWEEN EAST-WEST DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR FIRST INVESTIGATION (Table 12-15)

### TABLE 12: First post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| 109.6 | 2 | 0.057143 | 0.6 | 0.143541 |
| 65.76 | 4 | 0.114286 | 1.62 | 0.38756 |
| 32.88 | 35 | 1 | 4.18 | 1 |
| -252.08 | 35 | 1 | 4.05 | 0.9689 |
| -339.76 | 4 | 0.114286 | 3.39 | 0.811005 |
| -416.48 | 2 | 0.057143 | 0.4 | 0.095694 |
| **Std. deviation** | | 0.472826 | | 0.410413 |

### TABLE 13: Second post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| 263.04 | 1 | 0.05 | 0.5 | 0.119617 |
| 186.32 | 1.6 | 0.08 | 1.4 | 0.334928 |
| 109.6 | 4 | 0.2 | 2.65 | 0.633971 |
| 54.8 | 20 | 1 | 3.92 | 0.937799 |
| -317.84 | 20 | 1 | 4.18 | 1 |
| -361.68 | 4 | 0.2 | 3.97 | 0.949761 |
| -416.48 | 1.6 | 0.08 | 1.46 | 0.349282 |
| -493.2 | 1 | 0.05 | 0.9 | 0.215311 |
| **Std. deviation** | | 0.416336 | | 0.35878 |

## TABLE 14: Third post injection tracking

| Distance from injection point | CPMx10E 7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| 175.36 | 0.5 | 0.04 | 0.5 | 0.120482 |
| 109.6 | 3 | 0.24 | 2.64 | 0.636145 |
| 65.76 | 12.5 | 1 | 4.15 | 1 |
| -153.44 | 12.5 | 1 | 3.94 | 0.949398 |
| -274 | 3 | 0.24 | 2.69 | 0.648193 |
| -405.52 | 0.5 | 0.04 | 0.4 | 0.096386 |
| **Std. deviation** | | 0.453019 | | 0.391293 |

## TABLE 15: Fourth post injection tracking

| Distance from injection point | CPMx10E 7 | Normalising the CPM | Change in bed thickness(x10E -5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| 241.12 | 0.2 | 0.033333 | 0.5 | 0.127226 |
| 153.44 | 3 | 0.5 | 1.4 | 0.356234 |
| 43.84 | 6 | 1 | 3.7 | 0.941476 |
| -230.16 | 6 | 1 | 3.93 | 1 |
| -361.68 | 3 | 0.5 | 1.39 | 0.35369 |
| -449.36 | 0.2 | 0.033333 | 0.4 | 0.101781 |
| **Std. deviation** | | 0.432392 | | 0.395507 |

# COMPARISON BETWEEN EAST-WEST DISPERSION PARAMETERS OBTAINED FROM BARC STUDIES & NUMERICAL MODEL STUDIES FOR SECOND INVESTIGATION (Table 16-18)

## TABLE 16: First post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| 76.72 | 0.8 | 0.016 | 0.5 | 0.121951 |
| 43.84 | 2.5 | 0.05 | 1.39 | 0.339024 |
| 21.92 | 50 | 1 | 3.9 | 0.95122 |
| -54.8 | 50 | 1 | 4.1 | 1 |
| -98.64 | 2.5 | 0.05 | 1.4 | 0.341463 |
| -328.8 | 0.8 | 0.016 | 0.8 | 0.195122 |
| Std. deviation | | 0.499588 | | 0.384729 |

## TABLE 17: Second post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| 284.96 | 3 | 0.15 | 0.4 | 0.102564 |
| 109.6 | 6 | 0.3 | 1.4 | 0.358974 |
| 65.76 | 20 | 1 | 3.7 | 0.948718 |
| -87.68 | 20 | 1 | 3.9 | 1 |
| -131.52 | 6 | 0.3 | 1.39 | 0.35641 |
| -252.08 | 3 | 0.15 | 0.5 | 0.128205 |
| Std. deviation | | 0.405791 | | 0.396535 |

## TABLE 18: Third post injection tracking

| Distance from injection point | CPMx10E7 | Normalising the CPM | Change in bed thickness(x10E-5) | Normalising the change in bed thickness |
|---|---|---|---|---|
| 208.24 | 3 | 0.15 | 0.5 | 0.128205 |
| 109.6 | 10 | 0.5 | 1.41 | 0.361538 |
| 43.84 | 20 | 1 | 3.9 | 1 |
| -109.6 | 20 | 1 | 3.69 | 0.946154 |
| -186.32 | 10 | 0.5 | 1.94 | 0.497436 |
| -339.76 | 3 | 0.15 | 0.8 | 0.205128 |
| Std. deviation | | 0.382099 | | 0.371542 |

CHAPTER – 9

# CONCLUSIONS AND RECOMMENDATIONS

## 9.1 Conclusions

From an inspection of the numerical model results compared with BARC results from the tracer studies, it can be concluded that

- Numerical model simulation results are very much comparable and acceptable also with Radio Active Tracer studies results conducted by BARC at NMPT for dispersion of dredged material.
- Numerical model simulation technique is very fast, economical, less cumbersome, sufficiently reliable compared to RAT technique, which require a lot of machinery, manpower and time for completion.
- Need for studying dispersion of dredged material is very much essential not only with reference to port facilities but for environmental considerations also, discussed in chapter 4.
- The physical process associated with disposal of dredged material completes in three phases i.e. convective descent, dynamic collapse and passive-diffusion by ambient currents. In the present study, only the third phase has been simulated because the first and second phases completed in very less time of the order of about 2 minutes and only third phase of dispersion lasts for longer duration.
- Existing software of MIKE-21, which is used for the present study, is not having any direct facility of dispersion studies. Hence, the model for dispersion study has been set by using Mud transport module of MIKE-21 in such a fashion that only disposed dredged material movement could be traced as bed load movement.
- A comparison of the change in bed thickness could only be accomplished in a qualitative sense since the change was too small to measure. However, model results generally agreed well in a qualitative sense with observed areas of deposition.
- Results from these simulations have substantiated that MIKE-21 can be used to accurately simulate the fate of material during disposal operations.

## 9.2 Recommendations for future studies

By seeing and comparing the results of present numerical model studies with RAT studies, following recommendation have been made

- The physical process of dispersion of disposal is basically a 3-dimensional problem, which should be simulated from software of 3-D nature. MIKE-21 software simulates only 2-D type problems and having limitations for this type of studies.
- Since dispersion process of disposal is very important from environmental point of view, hence it should be simulated through precise software of 3-D nature by experts of the mathematical modelling.
- Descent and bottom surge speeds, stripping; rates of dilution, total depositional areas and suspended sediment concentrations in the bottom surge should also be simulated.
- Additional research is needed to make future software even more useful for addressing environmental issues lies in the area of uncertainty.

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