STUDIES ON DREDGING IMPACT ASSESSMENT (DIA) AT COCHIN, A TROPICAL ESTUARINE HARBOUR

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dedicated to my beloved parents..

CERTIFICATE

This is to certify that this thesis entitled, "STUDIES ON DREDGING IMPACT ASSESSMENT (DIA) AT COCHIN, A TROPICAL ESTUARINE HARBOUR" is an authentic record of the research work carried out by Sri. Rasheed. K, under my supervision and guidance at the Department of Physical Oceanography, School of Marine Sciences, Cochin University of Science and Technology, in partial fulfilment of the requirements for the Ph.D degree of Cochin University of Science and Technology under the Faculty of Marine Sciences and no part thereof has been presented for the award of any degree in any University.

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CHAPTER 1

INTRODUCTION

The coastal zone acts as the major interface between land and oceans. The demand of this zone has been increasing day by day due to anthropogenic activities like construction of coastal structures, housing, fishing, dredging, mining and drilling, development of harbours and ports and so forth. Estuaries located near such coastal sites act as a connecting passage between rivers and adjoining seas and have a very special significance in the context of coastal zone management. According to Dyer (1979) estuaries are very important centres for human activity and serve as ideal sites for development owing to their fertile waters, sheltered anchorage and navigational access, eventhough they may occupy only a very small geographical area. Studies conducted all over the world (Lauff, 1967) show that most estuaries are the most productive, diversified but sensitive zones in coastal areas which support organisms in a wide range of tolerance. The transport of vital nutrients to the nearshore from the terrestrial regions is through the estuarine waterways. This in turn, results in recognising estuaries as an indispensable regime for the support of marine life and its existence. Large input of suspensate and bed load material eventually reach the coastal zone through such "gateways". Part of the material eventually settle in the estuarine bottom or in the nearby coastal areas. Major ports or harbours located in and near the coastal zone (many within estuarine bounds) are centres of intense marine activities, depending on the number and frequency of operational vessels at the site. Towards smooth marine traffic operations an important prerequisite is guaranteed adequate depth requirements. Seldom natural conditions favour free harbour operations at a time of enhanced human intervention in modifying coastal regimes within expanding horizons of advance technological means. In this context, sedimentation is one of the major conundrum facing many a ports of the world.

Sedimentation is a process of accumulation of suspended material as a part of natural processes in rivers, estuaries or seas. According to Dyer (1979), often the fine grained sediments like clay and silt get collided with other materials to form aggregates in seawater. In estuaries, however, the tidal currents and salinity have an important role in the sedimentation and flocculation processes. During a tidal cycle, after the completion of high/low tide, the current strength in the estuary gradually decreases and the slack period lasts for a few minutes/hours without the prevalence of strong currents. The speed of transportation of sediment within the estuary thence gradually reduces, when sedimentation rate maximizes and results in the settlement of suspended sediments on the estuarine bottom. With time, as the reverse process develops, the tidal currents gradually gain momentum after the high/low slack period which may likely disturb the bottom and resuspend the freshly sedimented particles but, concomitantly allowing sedimentation to continue depending on the hydrodynamic conditions. Again after a few hours, the slack period prevails leading to increased sedimentation rates. In short, during the intervention of the slack period (short time duration) sedimentation results and the depth of the estuary (channel(s) in case of harbours which are dredged) reduces. The periodic continuous reduction of the depth would thus adversely affect the usage of waterways within the port and harbour and also inhibits trade, commercial and recreational activities. The sedimentation problems in harbour areas including environmental impacts is not a new topic having been reported from both developed and developing countries; examples of a few are from Toronto and Dalhousie harbours in Canada, Boston harbour, Port of Liverpool, Thames port, Port Hamble and port of Dover in England, Port of Amsterdam and Rotterdam in Netherlands, Chugjiang estuary mouth in China, Gray harbour in Washington, Sulaibhikat bay in Kuwait, Western port & Esperance harbour in Australia, New York harbour & Norfolk harbour in U.S.A. etc. (Weinmann and Malek, 1978; Mahon, 1979; Bakker, 1979; Zhaosen, 1981; Fuhrmann and Dayal, 1982; Diamond, 1983; Tosswell and Webber, 1984; Berger et al., 1985; Coy and Goddard, 1987). A large number of reviews are available, highlighting the various aspects of sedimentation/desilting and its related issues (Windom, 1976; PIANC, 1977; Jones, 1981; Hunt and Bartel, 1983; Russell, 1984; Wildish and Thomas, 1985; Senten, 1989; Tortell et al., 1992; Peter, 1993 and Gill, 1995).

In India too, the major ports, namely Calcutta, Bombay, Madras and Cochin are facing serious threat from sedimentation. At all these ports, activities are critically connected which essentially are depth dependent for entry/exit of marine vessels. The port authorities spend large amounts on dredging for channel maintenance to afford smooth harbour operations.

The utilisation of waterways for business and recreational activities continues to grow day by day. The import and export of commodities are also increasing as ever before, necessitating a minimum draft in such operational routes. In order to remove the settled sediments on estuarine/rivers/nearshore seabeds, the planners usually adopt dredging techniques. According to Canter (1985) dredging is the counterpart of sedimentation, and involves the removal of several variable materials from the bottom of the sea, estuary or lakes in adverse conditions and subsequent disposal of dredged material spoil in open distant waters or on land. Dredging is an art but at present, is a science where man's large scale intervention in the marine environment has many fold manifestations (Cooper, 1974). The preliminary objectives of dredging are to improve navigation, implement flood control programmes, conduct mining operations, construction and reclamation activities in coastal zone and towards beach nourishment purposes.

The dredging activities may be conveniently divided into two (Bray, 1979). One is capital dredging which involves the construction of a new bed configuration in the marine environment and the other is maintenance dredging involving the upkeep of channel depths by retaining a constant bed configuration. According to Scott (1991) the efficiency of dredging operations is dependent on many variables within the dredging environment. These are sediment and water properties, current pattern, environmental restrictions, transportation and disposal requirements of dredged material. Akin to any other artificial process, dredging also brings about positive and negative impacts on the environment. These and allied aspects are discussed hereunder, first on environmental impact assessment briefly, followed by dredgig impact assessment, in detail.

2. ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

Lash et.al (1974) had defined environmental impact assessment as the process of attempting predictive studies on a proposed development, analysing and evaluating the results of the said development. The scientifically based environmental assessments are composed of two distinct phases: (a) predictive phase, means to predict the effects of expected impacts before development occurs and (b) a monitoring and assessment phase, which is meant to measure and interpret environmental effects during the development and after it has been completed (Rosenberg et al., 1981). According to Munn (1975), EIA is defined as objective and subjective cataloging of the total physical and biological effects of a proposed development. The study may also be held at a site under "environmental stress" where no such attempts were conducted beforehand; in such cases, experience from other instances will serve much to the cause. It requires continuous collection of the relevant data before, during and after the event; analysis of the data, followed by interpretation of the data and re-evaluation etc. Based on the report of the EIA, developmental activities may be carried out at any site. Dredging is one such activity which attracts impact assessment studies. This ensures that the impacts on the environment remains a minimum and provide adequate scope and protection of the ecosystem at the proposed site.

According to Golden et al. (1979), there are three basic steps to determine whether a proposed project requires an environmental impact statement. These are

1. definition of the purpose and scope of the proposed action
2. preparation of an initial environmental assessment

and

3. evaluation of whether there could be significant impacts for the proposed action.

The environmental assessment is an environmental report prepared to determine whether the proposed action requires the preparation of an environmental impact statement. The environmental assessment may be based on checklists, matrices, networks and specific studies of various parameters interlinked in the project (Golden et al., 1979; Rosenberg et al., 1981). The environmental assessment include,

(A) Data collection: in order to obtain the general characteristics of the site and the proposed action.

(B) Analytical technique: measure the impact with proper scientific equipments.

(C) Preparation of environmental assessment: it consists of analysing the impacts associated with the proposed action.

The environmental assessment narrates the following: (Munn, 1975) (1) Describe the proposed action (2) Describe the environment to be affected (3) Identify all relevant environmental impact areas (4) Evaluate the potential environmental impact (5) Identify adverse impacts that cannot be avoided, in which case, should action be implemented (6) Identify the conflicts with state, regional and local plans and programmes (7) Evaluate alternative to the proposed action (8) Discuss any existing controversy regarding the action. It has now been a standard practice in developed and developing countries to embark upon an assessment before new projects are sanctioned. In many a worse scenario, for existing exigency impact studies are being held, routine monitoring conducted and remedial steps implemented to correct the situation.

3. DREDGING IMPACT ASSESSMENT (DIA)

It is affirmatively stated that associated with any developmental activity involving (close) interaction with nature, dredging too, creates direct/indirect impacts on the marine environment. A study in this direction will include the effects of dredging, measurement and remedial measures. The picture evolves around the history of dredging (Gower, 1968) to concept on dredgers for fighting pollution control (Keneko & Watari, 1983) and there has been notable development in design and utility of dredging crafts (Bates, 1978). Alternate approach to maintenance form of dredging in estuarine harbour region has been proposed by Skelly (1983), in the context of DIA. The concept of restricted draft geometry (Roseman and Barr, 1983) and implementation of innovative dredging techniques is of recent origin (Aurant and Mamantov, 1983; Grover, 1983). Recognising the need for better environmental protection new approaches include both innovative and conventional dredging (Hayes et al., 1988) special projects and eco-friendly dredging concepts (Mc Cartney et al., 1991; Kirby, 1993). Gaining momentum on efforts to reduce the environmental effects to dredging programme proposed by Calhoun et al. (1984), a new awareness on EIA related to dredging (Ridell, 1985) are good instances in understanding the issues related to environmental management. Dredging impacts are site specific and may be categorized as (after Bray, 1979)

(a) Dredging site

(b) Transportation site and

(c) Disposal site

The dredging site is affected directly and indirectly by dredgers in operation. According to above author, this include the movement of dredger around the dredging site and consequent risk of collision, snapping, rubbing or jumping of wires attached to points on the shore which could cause damage to personals and property, accidental damage to underwater pipelines and cable, turbidity caused by agitation, overflow of dredged material, the formation of density layers from overflow waters and the destruction of fauna at the dredging site. Indirectly, the dredging processes are likely to cause noise disturbances and possibly annoyance to the local population.

The direct effects after dredging are the possibility of subsidence of adjacent works due to undermining and subsoil failure, alterations of local soil characteristics, change of local flow pattern together with changes in siltation in the dredged channels, destruction of spawning grounds by alterations in the habitat and the destruction of flora and fauna causing a depletion in local fish communities. The indirect effects are the possibility of beach drawdown i.e., the movement of material towards the sea due to the removal of offshore deposits, the refraction of waves caused by the change in the seabed, and consequent erosion and deposition, change of tidal flushing characteristics of an estuary consequent to alteration of sediment load, habitat damage etc.

At the transportation site, the effects are by leakage and loss of spoil enroute which leads to increased turbidity and issues related to short term toxicity.

At the disposal site, direct/indirect effects are noticed during and after dumping the spoil. These include the turbidity generated at the dump site due to the passage of spoil through the water, the movement of dredged spoil into the adjacent areas, consequent alteration of water quality and bed material, the refraction of waves caused by the alteration of sea bed and consequent changes in the coastal regime.

Environmental impacts of dredging are short listed as follows:

1) resuspension of bottom sediments
2) release of toxic substances
3) oxygen depletion
4) reduced primary production
5) temperature alterations
6) altered nutrient levels
7) benthic community alterations
8) problem at the sediment disposal site
9) sediment textural variations
10) change of extinction coefficients
and
11) mixing zone changes.

All the above changes have direct or indirect effects on the environment (Canter, 1985) elaborated as hereunder.

1. Resuspension of bottom sediments

During dredging, the sediment at the bottom gets disturbed and on resuspension is brought to the surface layers causing the turbidity of the water column to increase. Studies reveal that continuous or persisting turbidities have detrimental effects on organisms. According to Bray (1979), the resuspended sediments cause the clogging of fish gills, functionally create problems for filter feeders, place hurdles to migration etc. Sherk (1971) has elaborated on turbidity related effects due to dredging in the aquatic environment.

2. Release of toxic substances

The dredged sediments have a wide range of physical and chemical characteristics. Ports/harbours or estuaries located near industrial areas often receive discharge of wastes and effluents that bring about the build up of heavy metals, pesticides and other chlorinated hydrocarbons in bottom sediments. The pollutants which rapidly accumulate in the deposited sediments are released during dredging, often turning the aquatic media toxic around the dredged site and immediate neighbourhood. Windom (1976), has pointed out that among the toxic substances, the heavy metals, i.e. copper and zinc are common to all harbours which have received special attention as prime water quality indicators immediately after dredging process.

3. Oxygen depletion

Surface waters of the coastal area in contact with atmosphere, helps to retain high amounts of oxygen in the surface mixed layers. But at the time of dredging the surface waters mix with bottom waters which would have lesser amounts of oxygen and this adversely affects the quality of the water and that of the prevailing ecosystem. Frankenberg and Westerfield (1968) and Odum (1970) have identified the problem related to dredging in estuarine waters and observed the depletion of oxygen availability in such dredged areas.

4. Reduced primary production

The adequate presence of plankton in the ecosystem is an essential link in the marine food. Considerable variations in phytoplankton content has often been noticed in dredging areas. During dredging, the turbidity of the surface waters increase and consequently light penetration is reduced inhibiting photosynthesis to a large extent, so that phytoplankton blooming is eventually curtailed. Abundance in plankton content are highly susceptible to dredging and its related impacts. Another change in the phytoplankton content may occur due to the increase in nutrient release during dredging which likely would lead to enhancement in phytoplankton blooming.

5. Temperature alteration

Temperature change due to dredging is not of much importance in large tropical estuaries. Mixing with bottom waters, which leads to the decrease of surface temperatures, is mostly a localized phenomenon.

6. Altered nutrient levels

The deposited sediments of terrigenous or marine origin contain large amount of nutrients in the form of soluble phosphorous and nitrogen. On agitation, sediments which contain available nutrients are placed in suspension in the vertical, leading to enhanced nutrient levels by the action of continuous or maintenance dredging. These enhanced levels are not maintained for long but are incorporated by marine organisms; of significance is the fact that diversity increases depending on the changes in nutrient levels (Flint, 1979).

7. Benthic community alterations

Bottom terrain disturbances always disrupt the benthic community set up. The settlement of such organisms within the port area is considerably disturbed due to dredging to a large extent. A study by the Swedish scientist Rosenberg (1977) indicates that the reduction in number and of diversity of organism are the aftermath of the deleterious effects. The larval development in the vicinity of the dredged area is often strongly affected. The study from the Chesapeake bay area indicates that the benthic community showing seasonal fluctuations, never attains equilibrium after dredging activities. The study of the benthic community at the Botany Bay shows that the benthic fauna at the dredged area is different from the nearby non-dredged areas with respect to species composition and richness,`both of which are closely related to the sediment type (Jones & Candy, 1981). They also conclude that the macrobenthic faunal variations in the Botany bay is an indirect impact of dredging. A very recent report narrates the outcome of dredging on benthic recovery in Galveston Bay, Texas (Ray and Clarke, 1995).

8. Problems at the sediment disposal site

Criteria to locate a suitable place for sediment dumping is very important for dredging operations to succeed. Before the conduct of dredging and selection of site it is desirable to know the proper flow regime at the disposal site, tidal currents, waves and sediment characteristics and longshore drift features.

Usually the dredged sediments are disposed at offshore areas or utilized for developing recreational sites or for harbour development in order to construct bridges, roads or railways. The presence of marine organisms, their diversity and abundance are also to be considered at a disposal site, offshore area, before hand. Generally, the following aspects are considered for site selection:

(a) location sediment characteristics
(b) flow regime including waves and currents
(c) tidal pattern
(d) the presence of marine organism.
and
(e) distance from the dredged location.

The spoil is also used for land reclamation purposes which will serve the following positive considerations (Bray, 1979):
(a) it is cheaper to place the dredged spoil in a reclamation area
(b) it is ecologically acceptable for reclamation
(c) it is useful for port development, agricultural practices and for recreational uses.

9. Sediment textural variations

The variation is prominent at the dredged site and also at the disposal site, but indirect variations are observed at the nondredged site too. Generally, for a given set of sedimentation rate(s), the fine grained material deposit last after the coarse grained sediments due to density variation. On dredging, the pattern of layers on bottom is altered and bedload movements may be expected at the site of excavation. At the disposal site, especially in offshore areas, the effects of textural variations are pronounced on the benthic community (Canter, 1985).

The dredged sediment may be used for beach nourishment. This is artificial addition of suitable quality/quantity of sediments to construct a beach to provide stern protection of the coastal area and which would also serve recreational purposes. At the reclamation site, if the dumped sediments are of same texture as that of the region, the strength of the reclamation area will be very high, otherwise will be covered by sediments unconsolidated in nature, bound loosely.

10. Change of extinction coefficients

During dredging, the turbidity of the surface waters increase which leads to reduction of light penetration, so that transparency reduces considerably. This aspect may be considered along with primary production changes for a designated site.

11. Mixing zone changes

Mixing zone is where seawater and freshwater come in contact (say for an estuary) and phenomena like dispersion and mixing takes place to attain medium homogeneity. This zone may extend a few kilometers from the lower estuary to upper estuary. Dredging processes could totally disturb the mixing zone range thereby affecting the hydrodynamic stability. The accompanying variations are listed as follows:

a. hydrographic change
b. horizontal, vertical and longitudinal variations in salinity structure
c. channel morphology and stability
d. saltwater intrusion pattern
e. sediment pattern distribution
f. location of turbidity maximum
g. transport rates of nutrients to the sea
h. aquifer recharge
i. groundwater table levels
j. bank erosion
k. velocity alterations

and

l. pollution flushing and tidal prism.

The above listed changes will consequently alter the prevailing ecosystem characteristics too.

In many of the above listed environmental impacts of dredging most are negative in the upkeep of quality/quantity of existing coastal zone where harbours and ports are located. On the other hand positive impacts are best judged by their utility and application for a given scenario. To list a few (PIANC, 1977), these are:

a. improved navigation

b. removal of polluted sediments

c. collection of construction material

d. beach nourishment, as the case may be

e. mining for minerals

f. reoxygenation of sediments

g. salinity wedge limits may be beneficently controlled

h. land reclamation

i. compensation of land subsidence and

j. improvement of vista

Additional information related to experience on DIA and its allied aspects are available from Australia (Crabb, 1986), the United States experience (Herbich, 1985), the picture in China (Zhaosen, 1981) followed by the European experience (Parker, 1981) demonstrative and forceful experience of new Singapore airport (Ong, 1982), a small but important illustration from Bangladesh (Burren et al., 1981) coupled with India's another neighbour (Anon, 1977) and finally the Indian scenario (Anon, 1979) are worthly reading materials. The Dutch policy is illustrated by Bos (1987) and that for the northern Europe Anon (1991) addresses additional issues of dredging and environment.

4. DREDGING IMPACT ASSESSMENT (DIA) AT COCHIN PORT

Cochin is the second largest port along the west coast of India. Historically, this area is known for trade, commerce and cultural activities with other countries especially Arabia, Portugal and Holland. This harbour and its neighbourhood environment is most natural (Bristow, 1967) which has a free permanent connection (Cochin gut - tidal inlet) with the sea allowing land drainage derived from terrestrial sources. It has three dredged channels, one being the approach channel oriented along east-west direction of around 10km length and 500m width and the two inner channels located on either side of the Willingdon Island, i.e., Ernakulam channel of around 5km length with a width of 250-500m and Mattancherry channel of 3km long with a width of around 170-250m. All the three dredged channels are maintained at a depth of 10-13m. The tropical estuarine environment shows multitudinal features (Josanto, 1971; Kurup, 1971; Wellershaus, 1971; Manikoth and Salih, 1974; Qasim et al., 1974; Joseph, 1974; Joseph and Nair, 1975; Sankaranarayanan and Panampunnayil, 1979; Lakshmanan et al., 1982; Venugopal et al., 1982; Remani et al., 1983; Anirudhan et al., 1987; Lakshmanan et al., 1987; Sarala Devi and Venugopal, 1989; Balchand et al., 1990; Shibu et al., 1990; Joseph and Kurup, 1990; Ouseph, 1992; Nair and Balchand, 1993; Nair et al., 1993; Ajith and Balchand, 1994; Balchand and Nair, 1994; Shibu et al., 1995; Rasheed et al., 1995a,b & Ajith and Balchand, 1996) which characterize freshwater and seawater mixing (Gopinathan and Qasim, 1971; Wyatt and Qasim, 1973; Udaya Varma et al., 1981; Sankaranarayanan et al., 1986; Joseph and Kurup, 1987; Joseph, 1989; Chandramohan, 1989 & Sundaresan, 1989) and affords breeding ground for the marine organisms in juvenile form (Remani et al., 1983; Nair et al., 1988 and Sarala Devi et al., 1991).

Cochin backwaters is now well known to face serious environmental threat by way of intertidal land reclamation, pollutional discharges, expansion for harbour development, dredging activities, urbanisation and for many other factors (Gopalan et al., 1983). The construction of Thaneermukkom bund near Vaikom also created severe environmental consequences within and out of adjacent Kuttanad agricultural fields (Balchand, 1983). Extensive studies have been carried out in Cochin estuary especially on the physical, chemical and biological aspects as cited above but the issues dealing with environmental impacts of dredging was never addressed well but for scanty reports (Gopinathan and Qasim, 1971; Anto et al., 1977; Sundaresan, 1990; Rasheed and Balchand, 1995).

The sedimentation features at the Cochin port varies according to season(s). There are three seasonal conditions prevailing in this estuary i.e., monsoon (June - September), postmonsoon (October-January) and premonsoon (February-May). During the monsoon period, heavy rainfall result in heavy discharge through the rivers eventually reaching the estuary and waterways of port. Stratification often develops and results in conditions with less dense river water at surface and high dense seawater at the bottom layers. Such typical hydrographic features and circulation pattern complicates the sedimentation features in the estuarine channels.

In the postmonsoon season, the river discharge gradually diminishes and tidal influence gain momentum as the estuarine conditions change to a partially mixed type leading to weakening of stratification. This is mainly a transitional period.

In the premonsoon season, the river discharge is minimum and the seawater influence is maximum upstream; the estuary shows well mixed characteristics and homogeneity exists within the vertical water column. The development of turbidity maxima which occurs during high tide within the estuary is well noticeable.

During the pre and postmonsoon period, the sedimentation rate in the inner channels (Mattancherry and Ernakulam) is higher than in monsoon due to the tidal influence. The circulation pattern helps to bring more silt and clay into the estuary and especially during the slack period, sedimentation is the highest. But during the monsoon period, the physical processes alter leading to sedimentation in the approach channel (Gopinathan & Qasim 1971). This sedimentation feature results from the heavy discharge of water plus sediments brought out to the Cochin gut and deposited in the outer harbour. Simultaneous processes (turbulence due to currents) in the inner harbour leads to re-suspension of sediments and thus accumulation of sediment is reduced. Compared to the Ernakulam channel, maximum silting occurs in Mattancherry channel (Gopinathan and Qasim, 1971). Nearly 1/3rd of the reported silting from the three dredged channels during the year occurs in the Mattancherry channel. This may be due to the pattern of circulation in that part of the estuary where weak currents prevail.

The sedimentation in the port area creating a reduction of depth upto 1-2 m per year is clearly a problem for smooth conduct of marine traffic operations. According to Ducane et al. (1938), the heavy silting observed in certain years at Cochin port was definitely influenced by the appearance and movements of mudbanks in the close vicinity of the gut. Anto et al., (1977) observed that the longshore currents could also bring sediments into the channels. The primary income of the port depends on loading and unloading operations, transfer of oil and fertilizer, export of spices, coir etc. The maintenance type of dredging in the three channels is thus a very important activity for the uninterrupted port function throughout the year. In Cochin estuary, different types of dredgers are in operation. This include grab dredger, cutter suction dredger and trailing suction hopper dredger. For continuous maintenance dredging trailing suction hopper dredgers are most useful. This helps to dredge the sediment within short span of time over a wide area. For purpose oriented dredging near a berth or jetty, grab dredging has been very useful and is practiced in Cochin port too.

The following aspects attract a careful study in Cochin estuary (dredging site) and especially for Cochin port in the context of dredging and its net impacts on the coastal zone:

(1) investigate the proper bathymetry of the Cochin port area
(2) current pattern with seasonal variations
(3) influence of waves and tides
(4) salinity variations and stratification features
(5) sediment availability and silting features
(6) water quality changes

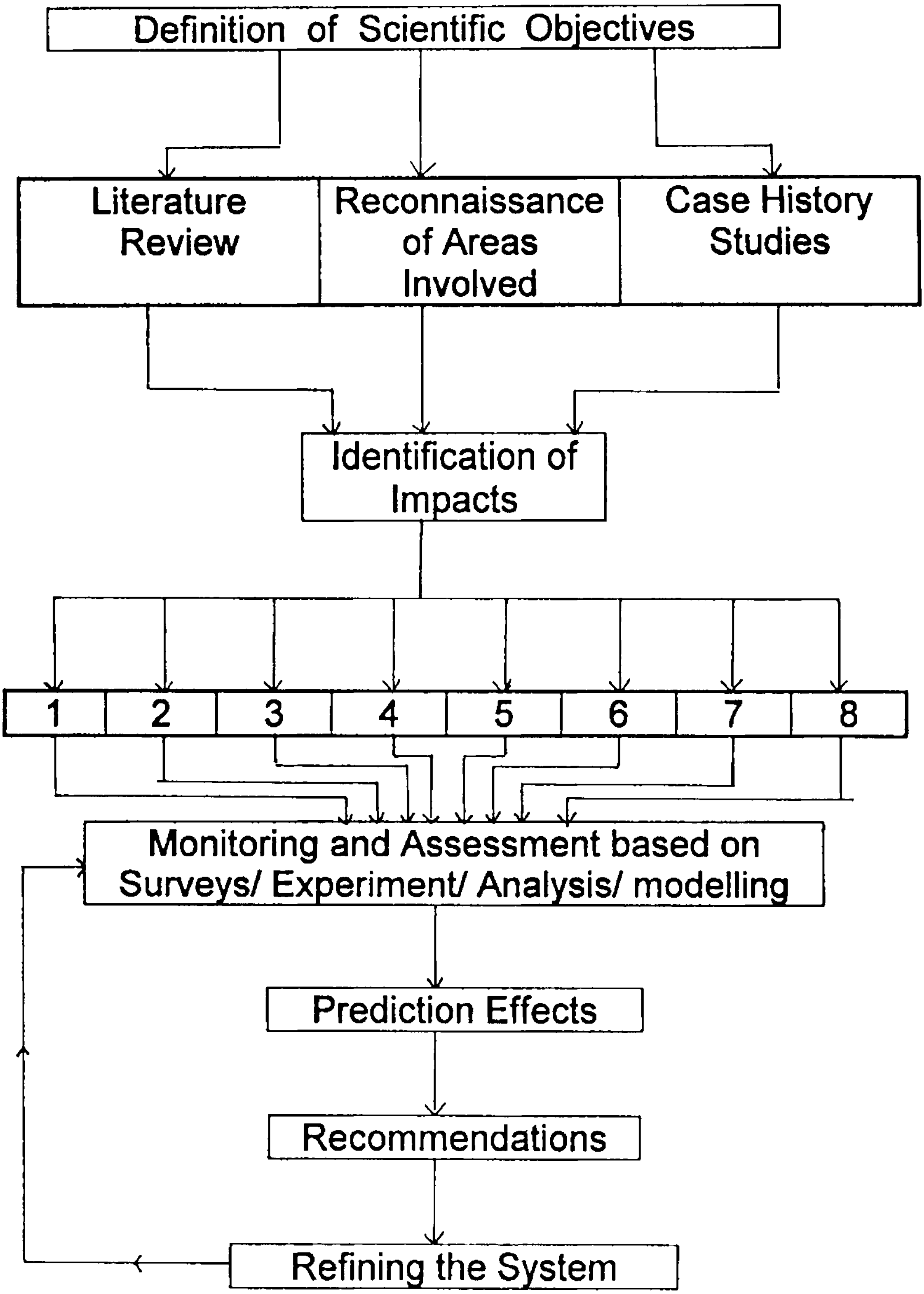
and

(7) benthic community and fisheries

Within the scope of this thesis, DIA has been carried out at the dredging site of Cochin port. The scheme of the work is detailed as below.

5. SCHEME OF THE WORK

The approach to the present study is depicted in Flow Chart 1. Before commencement of the actual field work, an attempt is made to define the developmental activity going to be implemented along with a clear and concise definition of the scientific objectives. Before



Flow Chart 1. Parametric based approach to DIA the implementation of the proposed project, background may be obtained from literature review, case history studies - similar to the proposed project - and reconnaissance of the region involved. Based on the preparatory work, the parameters relevant to the scientific objectives can fairly be identified; even those parameters which are likely to be affect while actually implementing the developmental process, that which may reflect the physical, chemical, biological and geological aspects of impacts could be designated for detailed analysis (Rosenberg et al., 1981). Selection of such parameters may be for short and long term impact studies. Within the scope of this thesis a total of eight parameters have been identified (currents, salinity, turbidity, transparency, sediment texture, nutrients, chlorophyll and benthic fauna) as of important interest. On identification, continuous monitoring / experiments / analysis of the parameters were conducted at the site, modelling, if required so. Based on the results, a judicious attempt helps to understand the system and to predict the various aspects of impact(s). An assessment of the environmental impact follows. Recommendations are also incorporated which is logically derived from analysis and (re-)predictions which include both positive and negative impacts are made. Based on this system approach the system may be refined for betterment. The above parametric based approach to DIA has been followed in this study.

The prime objective of this work is to get a detailed report on the positive and negative impact on the estuarine environment while conducting dredging operations on short term and long term basis and to work out the remedial measures to reduce the negative impacts at the dredging site.

The doctoral thesis consists of six chapters. Chapter 1 gives a general introduction to the topic and conducts a review on the dredging operations and impacts on the environment.

The material and methods required for the field investigation, analysis and interpretation of the data are given in chapter 2. Chapter 3 presents the results on dredging impacts at Cochin, a tropical estuarine port by conduct of field study on various parameters during the last two years. Highlighted are the positive and negative impacts on study on turbidity, sediment texture, nutrients and bottom fauna.

The short term impacts at a dredging site and the results thereof form part of the special field survey(s) related to dredging under chapter 4.

Chapter 5 deals with Dredging Impact Assessment (DIA) and provides a critical assessment of dredging based on the results from chapters 3 and 4; also included are viable means and alternate technology to mitigate issues concerned with sedimentation and dredging. An attempt is also made to evolve a DIA matrix on process vs impacts for future reference and guidance.

Chapter 6 gives summaries and the results of the present study.

It is hoped that the results of the present study will beneficially serve environmentalist/authorities who are concerned with the dredging operations or such similar projects affording them adequate opportunities to minimize/mitigate the negative impacts. They are also encouraged to run a criteria based evaluation of operations under DIA so as to evolve eco-friendly mode of environmental management.

CHAPTER 2

MATERIALS AND METHODS

1. INTRODUCTION

Cochin harbour is the second largest harbour along the west coast of India, located in the central parts of State of Kerala (9°55'44''- 9°58'04''N; 76°14'50''- 76°16'10''E). Source of water and sediments to this estuarine harbour is from two large rivers, one from the south, named as Muvattupuzha and other from the north, Periyar river and also from four smaller river catchment systems (Pamba, Meenachil, Manimala and Achankovil rivers) joining the estuarine system on the southern end. These rivers empty large amounts of freshwater to the adjoining nearshore region through the stable Cochin inlet. This harbour is maintained operational by three dredged channels, one being the approach channel having an orientation along the east west direction through the Cochin inlet. Within the harbour, two channels are maintained - the Ernakulam channel of 5km in length and 250-500m in width and the other Mattancherry channel of 3km length and 170-250m width. All three channels are marked in Figure 1. The channels are intermittently dredged throughout the year except during monsoon period in the approach channel due to rough weather conditions in the nearshore region. The amount of material dredged during different years is given below:

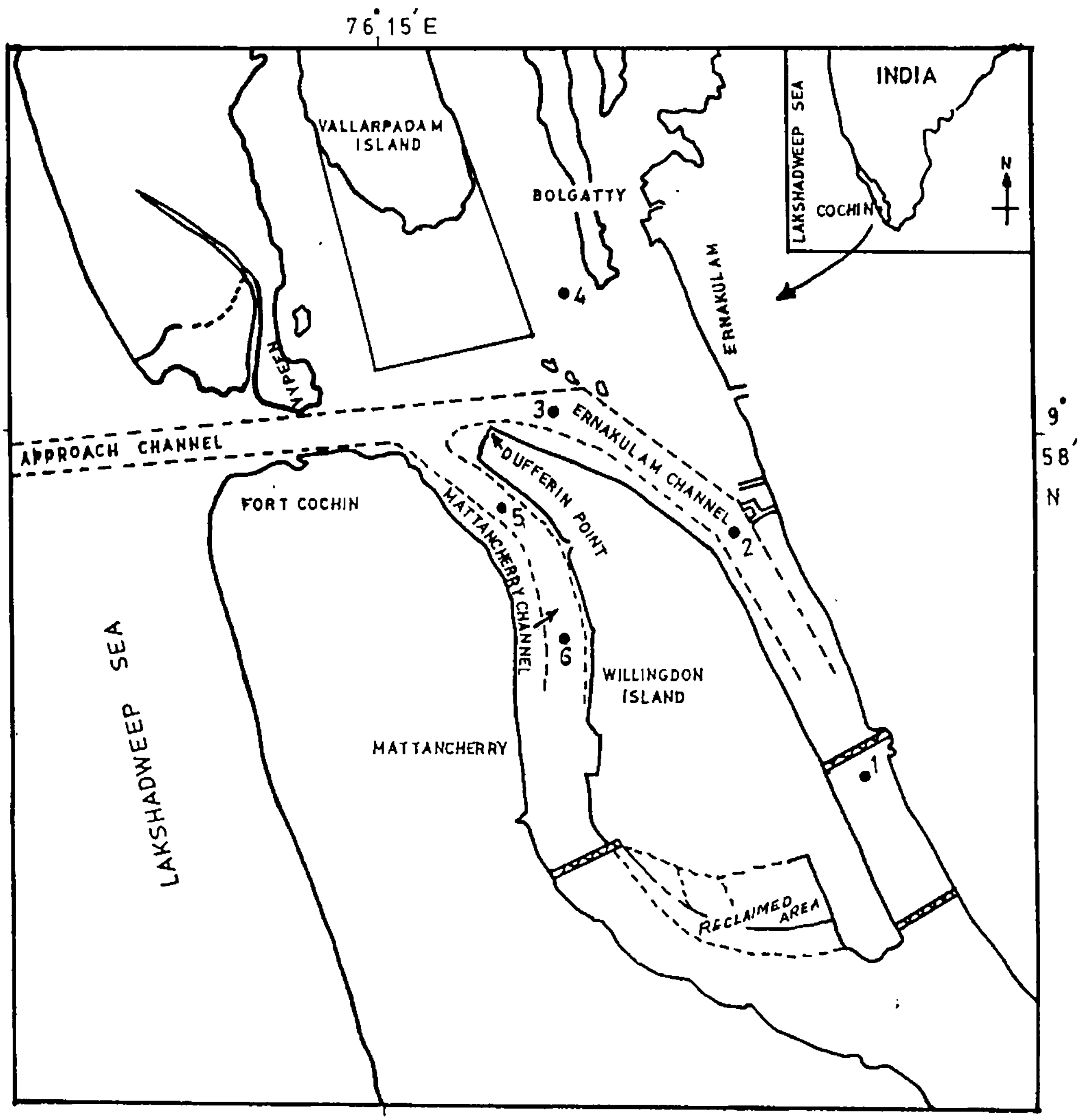


Fig. 1 Location map of stations 1 to 6 at Cochin harbcur.

Year	Dredging	Channels	Material Dredged($X10^6m^3$)
Sept. 1994 - March 1995	Maintenance	Mattancherry & Ernakulam	3.58
Sept. 1995- March 1996	Maintenance	Mattancherry & Ernakulam	3.89
Sept. 1996- January 1997	Maintenance	Mattancherry & Ernakulam	3.61

2. AREA OF INVESTIGATION

The area of investigation and location of stations are shown in Figure 1. Six stations were selected; four in the dredged channel sites of Ernakulam (stations 2 & 3), maintaining a depth of 10 to 13m and Mattancherry (stations 5 & 6) channels keeping 9.75 to 11m depths and the other two in the nondredged sites which are located away from the channel(s) which are at a depth of 3 to 5m (stations 1 & 4).

The field investigation was carried out on monthly basis for a period of two years (November 1994 to October 1996) at the dredged and non dredged sites. A special field survey was also conducted near the Dufferin point on 12/04/94 to study the features of salt-silt wedge; another study was held at a capital dredged area in the upstream of the Mattancherry channel (January 1994 to August 1994) to study the effects of intermittent dredging activity and associated sedimentation processes. Mattancherry channel was also investigated to identify short term impact on the environment before, during and after (from 09/01/96 to 11/01/96) dredging (see Figure 2 for above locations).

3. PARAMETERS

The instruments and procedure adopted during this study on various oceanographic parameters are given below.

a. Current speed and direction

These parameters were determined by direct reading current meter(s) (EMCON make) of accuracy (±2cm/s) which suits to read an integrated current value, utilizing savonious rotor plus magnetic compass of directional sensitivity ± 5°; the final current values were taken as the average of 3 consecutive readings.

b. Salinity

The salinity readings are obtained from a Hydrobios make Temperature-Salinity Bridge Model MC-5. Accuracy of the inductively coupled salinometer was ±0.05.

c. Suspended solids (Turbidity)

The suspended solids concentration (in JTU) was determined in the field by making use of an in-situ turbidity meter which makes use of the optical scattering principle (in range of 0 to 1000JTU, ±2%) make CIFT. Linear calibration was achieved by means

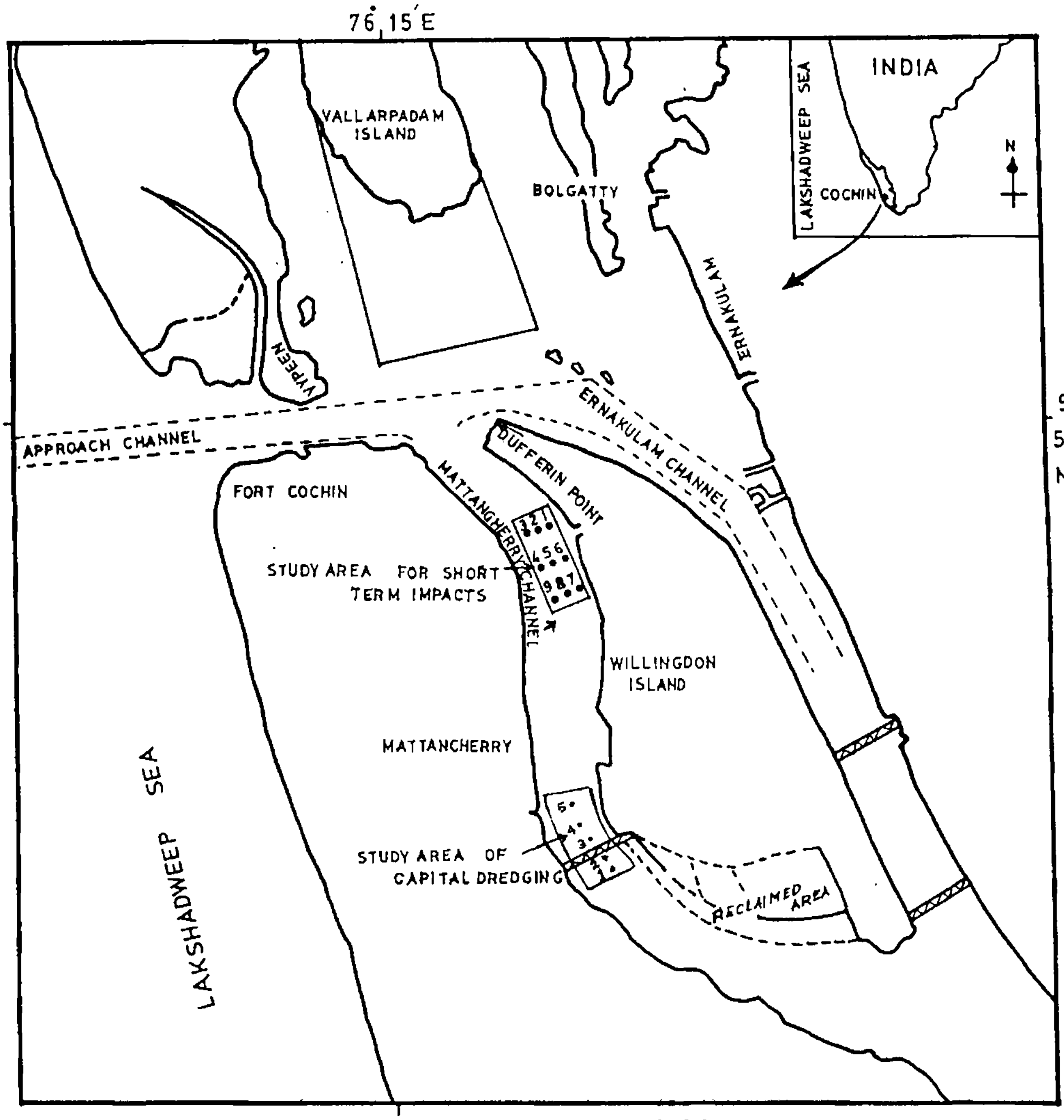


Fig. 2 Location of special field surveys
a) Dufferin point
b) Study area of capital dredging
c) Study area of short term impacts

of the following method. Water samples collected in a Hytech water sampler of 1.2 litre capacity from selected depths were filtered at 0.45μm (Whatman filter cum Millipore unit) and dry weight of filtrate was determined and instrumental readings calibrated (56 data sets) to report values in mg/l.

d. Transparency

Transparency of the water column was determined in terms of the mean of the depth (d_m) of disappearance and reappearance of Secchi disc. The extinction coefficient (K) was determined by the empirical relation $K = 1.7/d_m$, where d_m is expressed in meters.

e. Sediment textural characteristics

The sediment samples were collected using van Veen grab. The standard procedure as given by Carver (1971) was adopted towards pipette analysis. The grain size parameters such as mean size, S.D., skewness and kurtosis were calculated based on Folk and Ward (1957) and Lewis (1984).

f. Nutrients (Nitrite and Phosphate)

A. Nitrite: Bendschneider and Robinson (1952) method as suggested by Grasshoff (1976) was adopted for the estimation of nitrite. The nitrite in the sample was allowed to react with sulphanilamide in an acidic solution. The resulting diazo compound proportional to the initial concentration of the nitrite, was coupled with N-1 naphthyl ethylene diamine dihydrochloride forming a diazo dye. The extinction of the diazo dye was measured using spectrophotometer at 545nm. Cell to cell blanks and reagent blanks were also read and appropriate corrections applied.

B. Phosphate: Inorganic phosphate was estimated by the method of Murphy and Riley (1962). The samples were treated with a composite reagent containing molybdic acid and trivalent antimony. The resulting complex was reduced with ascorbic acid and molybdenum blue solution thus formed and was measured using spectrophotometer at 880nm. The cell to cell blanks and reagent blanks were determined and necessary corrections applied.

g. Chlorophyll *a,b,c*

The water samples from surface and bottom were collected using Hytech water sampler of capacity of 1.2 litres. Chlorophyll content in the samples were determined by the method proposed by Strickland and Parsons (1972).

h. Bottom fauna

Benthic fauna from the dredged and nondredged sites were collected using van Veen grab of size $0.05m^2$ every month between November 1995 to October 1996. The grab contents were hand sieved through a 0.5mm square mesh sieve in order to separate the organisms from the sediment. The residue from the sieve was preserved in 5% formalin. Organisms were identified upto genera. Field sampling and other procedural details followed are available elsewhere (Fauval, 1953; Damodaran, 1973; Ludwig and Reynolds, 1988).

i. Bathymetry

The data was collected onboard research vessel R.V.Nautilus (12m long with inhouse laboratory) and Flying Fish. The channel configuration and morphology was monitored by making use of STD meter (CIFT make) and corrections if any were incorporated by verifying the depth contours with bathymetric chart of Cochin Port Trust (CPT). The real time tidal observations were provided from the tide guage installed at the harbour region.

Dredging data relevant to the period of study was collected from the Cochin Port Trust.

The months pertaining to different seasons were selected as follows: Postmonsoon - October to January, Premonsoon - February to May and Monsoon - June to September.

CHAPTER 3

LONG TERM IMPACTS OF DREDGING

1. INTRODUCTION

To understand the long term effect of dredging, the field survey was conducted from November 1994 to October 1995 except the bottom fauna. The parameters discussed in this chapter are currents, salinity, turbidity, transparency (extinction coefficient), sediment textural characteristics, nutrients, chlorophyll and bottom fauna. The variation of parameters during different stages of the tidal cycle are discussed hereunder.

A. CURRENTS

The aspects on circulation within the estuary was attempted in a limited scale by the study of current vectors at stations 1 to 6 during the different stages of the tide. The direction of flow during flood was directed upstream in the bottom layers indicated by vectors 130° to 180°. At stations 1,2,5 & 6 this feature coincided with higher salinities often observed of the intruding seawater (Table 1). Feeble currents (< 20cm/s) have often been noted which mostly occur near the slack time of the tide stage associated with a wide range of directions typical for a harbour area under the influence of local currents, wake of ship transits and complex pattern of shear turbulence. On a seasonal basis, the postmonsoon was noted as a transitional period when stratified to and mixed conditions have been noted

Table 1   Current vectors at stations 1 to 6 from November 1994 to October 1995.

stns	depth(m)	November 1994 vel. (cm/s)	November 1994 dirn.*	December 1994 vel. (cm/s)	December 1994 dirn.*	January 1995 vel. (cm/s)	January 1995 dirn.*
	0	014	290	005	272	9	347
	1	008	287	007	109	13	029
1	2	026	187	018	138	62	029
	3	023	207	014	172	11	035
	4	027	206	002	141	11	045
	0	0	105	28	203	9	002
4	1	11	136	8	249	14	026
	2	12	146	7	312	14	149
	0	5	286	9	109	14	290
	2	28	244	15	121	7	348
2	4	43	186	17	154	9	313
	6	83	138	19	168	16	141
	8	63	148	20	176	13	028
	10	-	-	20	184	8	012
	0	1	196	2	036	25	114
	2	18	134	1	066	25	124
3	4	38	181	8	095	180	140
	6	37	133	7	104	47	103
	8	84	129	6	122	55	165
	10	-	-	6	054	89	210
	0	2	341	67	337	30	289
5	2	2	315	26	336	15	061
	4	17	183	19	003	15	030
	6	44	156	12	015	15	145
	8	-	-	9	001	121	142
	10	-	-	113	319	18	172
	0	7	273	63	337	15	086
	2	24	170	25	327	9	069
6	4	27	163	7	009	7	024
	6	15	157	17	187	4	106
	8	18	156	11	230	10	068
	10	-	-	9	169	5	221

(* direction in degrees)

(con't..2)

stns	depth(m)	February 1995 vel. (cm/s)	February 1995 dirn.*	March 1995 vel (cm/s)	March 1995 dirn.*	April 1995 vel. (cm/s)	April 1995 dirn.*
	0	20	004	95	016	16	108
	1	12	000	33	012	7	240
1	2	22	008	5	355	14	206
	3	83	059	12	144	25	197
	4	24	132	8	128	32	177
	0	32	204	37	163	7	224
4	1	28	219	31	175	17	072
	2	24	220	33	160	9	075
	0	6	353	83	304	14	063
	2	2	080	36	320	22	063
2	4	7	182	16	010	31	137
	6	4	179	49	028	17	147
	8	13	150	35	112	19	159
	10	30	160	35	117	23	160
	0	4	316	123	338	82	160
	2	25	000	32	289	18	176
3	4	24	035	20	270	24	168
	6	8	265	15	220	32	166
	8	12	256	20	139	50	195
	10	16	323	26	138	20	191
	0	21	009	250	304	13	141
5	2	4	338	160	308	9	235
	4	8	353	178	282	8	169
	6	10	145	186	235	10	319
	8	17	158	172	360	34	309
	10	22	136	160	142	-	-
	0	2	350	92	325	13	141
	2	13	299	32	309	9	155
6	4	14	285	26	252	8	169
	6	13	238	19	198	10	320
	8	16	251	23	192	34	328
	10	18	263	13	195	-	-

(* direction in degrees)

(con't..3)

		May 1995		June 1995		July 1995	
stns	depth(m)	vel. (cm/s)	dirn.	vel (cm/s)	dirn.	vel. (cm/s)	dirn.
	0	99	212	7	256	16	028
	1	82	169	8	259	15	160
1	2	40	186	10	213	8	064
	3	37	146	17	251	19	228
	4	25	167	16	358	15	300
	0	28	007	24	353	13	063
4	1	22	005	20	340	17	348
	2	20	004	18	320	26	347
	0	8	078	20	197	17	214
	2	35	131	16	120	19	179
2	4	73	139	26	150	19	109
	6	54	134	30	141	13	303
	8	32	150	36	155	13	302
	10	24	150	31	165	15	209
	0	77	122	16	295	16	130
	2	82	120	18	337	13	120
3	4	150	132	6	216	6	125
	6	247	120	6	178	13	100
	8	25	126	19	195	4	125
	10	188	126	12	179	4	095
	0	0	118	13	323	14	287
5	2	8	160	12	315	13	272
	4	15	134	15	327	12	219
	6	21	144	17	310	17	292
	8	20	137	19	300	16	306
	10	11	152	-	-	21	093
	0	0	189	16	333	14	012
	2	1	178	13	315	18	298
6	4	15	178	15	327	16	260
	6	15	174	16	310	18	158
	8	10	173	10	300	14	323
	10	12	132	-	-	10	353

(* direction in degrees)

(con't..4)

stns	depth(m)	August 1995 vel. (cm/s)	August 1995 dirn.*	September 1995 vel (cm/s)	September 1995 dirn.*	October 1996 vel. (cm/s)	October 1996 dirn.*
	0	14	026	26	215	12	336
	1	11	355	36	348	12	160
1	2	14	056	22	325	13	045
	3	13	268	26	317	23	149
	4	15	204	-	-	52	154
	0	15	306	15	173	15	010
4	1	23	312	17	346	28	034
	2	24	326	18	314	17	036
	0	10	329	22	312	30	062
	2	22	334	21	293	28	043
2	4	29	337	20	298	27	136
	6	26	331	14	334	29	135
	8	23	326	13	277	30	139
	10	14	331	15	093	30	137
	0	26	293	20	305	11	324
	2	19	311	23	277	11	156
3	4	14	311	23	265	11	168
	6	6	303	26	295	20	103
	8	14	360	14	286	31	117
	10	9	191	13	294	31	106
	0	14	284	26	289	42	319
5	2	33	327	18	293	26	242
	4	44	320	31	307	9	228
	6	28	302	41	300	12	180
	8	33	296	44	290	14	082
	10	23	312	-	-	-	-
	0	17	286	19	303	18	335
	2	25	321	19	003	16	327
6	4	63	316	44	345	14	195
	6	54	325	24	345	20	199
	8	26	320	11	012	27	211
	10	-	-	-	-	-	-

(* direction in degrees)

with aid of salinity values and well supported by the findings based on current vectors. During this period current strength vary from very low (1.0 to 20cm/s) to intermediate values (21 to 60cm/s) but at times, strong currents have been noted along the bottom. The postmonsoon is just characterized by low velocity currents, sluggish in nature in the absence of driving agencies like strong freshwater and nondominant tidal currents.

The premonsoon period is characterized by stronger currents than that of postmonsoon often exhibiting bi-directional flows at a station, when surface flows being directed towards the seaward side while that along the bottom, it is towards the river head (stations 2,3,5 & 6 of the dredged site during March 1995). In April and May 1995 as the flood tide progressed, all the locations in the dredged area do indicate low to intermediate velocities having a vector directed upstream. However, a clear circulation feature was not available at stations 1 & 4 of the non dredged site which are otherwise shallow locations. It follows that during the premonsoon, the deeper waters of the Cochin harbour, where dredging is held, typically respond to changes in tidal phases but shallow locations beyond the zone of dredging do not keep unison.

During monsoon, the flow conditions were largely influenced by the freshwater inflow which modified the estuarine conditions to a highly stratified one where lighter freshwater occupies subsurface waters above denser seawater at the bottom especially at those locations where dredging had excavated material.

Generally the velocities were low to intermediate (5 to 35cm/s) and the direction predominantly indicating outflow from the estuary. Since the observations coincided with the ebb to flood stage of the tide, high saline waters did occupy the deeper portions of the harbour region (dredged area) indicated by higher salinity values; and a few current vectors, feeble in magnitude but flowing upstream. Under these conditions, the net flow is directed seaward at velocities which are of lower order.

From the results of the investigation on currents, the lower estuarine regions can clearly be visualized undergoing three seasonal changes which is otherwise also well reflected in salinity values. The postmonsoon season being a transitional one, give rise to a range of vectors indicative of inflow as well as outflow and at certain stations multidirectional, depthwise. Such locations may bring about uneven distribution of trends of pattern in (mis-)understanding estuarine circulation.

The premonsoon is a period when tide plays a dominant role against feeble discharge from the riverine reaches and the current pattern evidenced upstream and downestuarine water movements. Finally the monsoon gives rise to mostly unidirectional current flowing seaward but often sluggish in magnitude during the ebb to flood phase. Velocities may often increase after the flood slack.

B. SALINITY

The estuarine processes and circulation is largely influenced by tides and this aspect plays an important role in deciding salinities at various points within the estuary. During the flood stage, the salinity decreases progressively up estuary and during ebb, the extent is shortened longitudinally, with slack periods bring about increase in deposition rates of sediments. The salinity values in the estuary also varies according to seasons and for this tropical estuary, monsoon season brings about stratification while in postmonsoon, salt wedge to partially mixed type was noticed and in premonsoon, no stratification was observed in the vertical (Udaya Varma et al., 1981). In the context of this study, all stages of the tide have been covered during different months to account for salinity changes in the harbour region and attempts to draw out the features of suspensate distribution with respect to estuarine characteristics.

During November 1994, station 1 shows an increase in salinity from surface to bottom (1.0 to 23.5) but at station 4 very low salinity values were observed (1.0 to 1.5) [Table 2]. But at the dredged sites in Ernakulam channel (stations 2 & 3) surface salinity was unity and bottom salinity values were very high (28.0 & 26.0 respectively). Station 5 in Mattancherry channel followed the pattern as that in Ernakulam channel but at station 6, bottom values were very low (5.7). The variation in salinities are attributed to the freshwater inflow at the surface waters, while a salt wedge occurs along the bottom layers. The observation period coincides with the flood phase of

Table 2 : Salinity values (Nov. 1994 to Oct. 1995) at station 1 to 6

stns	depth (m)	Nov.'94	Dec.'94	Jan.'95	Feb'95	Mar.'95	Apr.'95
	0	1.00	18.0	34.0	32.0	17.0	17.0
1	2	12.0	26.0	34.5	35.0	21.0	20.0
	4	23.5	33.0	35.0	35.0	21.0	24.0
	0	1.00	21.0	35.0	24.0	17.0	18.0
	1	1.00	23.0	35.0	25.0	22.0	25.0
4	2	01.5	30.0	35.0	28.0	25.0	27.0
	0	1.00	22.0	35.0	35.0	21.0	20.0
2	5	23.0	26.0	35.0	35.0	23.0	25.0
	10	28.0	34.0	35.0	36.0	23.0	25.0
	0	1.00	24.0	35.0	34.0	22.0	20.0
3	5	23.0	28.0	35.0	35.0	23.0	25.0
	10	26.0	35.0	35.0	35.0	23.0	28.0
	0	05.0	29.0	35.0	34.0	28.0	18.0
5	5	17.7	33.0	35.0	35.0	29.0	25.0
	10	30.5	35.0	35.0	35.0	30.0	27.0
	0	1.00	26.0	30.0	34.0	27.0	25.0
6	5	1.00	30.0	31.0	34.0	28.0	28.0
	10	05.7	33.0	32.0	35.0	28.0	30.0

stns	depth (m)	May'95	Jun'95	Jul'95	Aug'95	Sept'95	Oct'95
	0	06.0	03.5	08.0	07.0	05.0	10.0
1	2	28.0	07.0	32.0	26.0	15.0	14.0
	4	30.0	09.5	35.0	30.0	29.0	16.0
	0	05.0	10.0	07.0	06.0	08.0	05.0
	1	20.0	21.5	08.0	07.0	08.0	15.0
4	2	23.0	25.0	13.0	08.0	10.0	20.0
	0	06.0	05.0	07.0	10.0	06.0	10.0
2	5	30.0	06.5	33.0	18.0	18.0	20.0
	10	31.0	11.0	34.0	31.0	26.0	26.0
	0	06.0	05.0	09.0	10.0	08.0	15.0
3	5	27.0	11.0	32.0	30.0	22.0	21.0
	10	31.0	15.0	34.0	31.0	25.0	26.0
	0	13.0	07.5	10.0	10.0	09.0	15.0
5	5	30.5	11.5	32.0	26.0	12.0	23.0
	10	33.0	13.5	34.0	26.0	30.0	27.0
	0	17.0	09.5	11.0	10.0	10.5	17.0
6	5	19.0	10.0	32.0	23.0	13.0	21.0

the tide.

In December 1994 too investigation was carried out during high tide. The salinity gradually increases from surface to bottom at stations 1 & 4 while at the dredged sites (stations 2,3,5 & 6) the values were higher at surface with still higher values at bottom.

During the next two months, January and February 1995, identical tidal stages - commencing after the high tide slack to the ebb slack - a period where outflow from the estuary had commenced was incorporated in this study. All the stations during these two months indicated well mixed conditions in the vertical with complete absence of salt wedge. Most salinity values occurred about 34.0-35.0. From the above, it is inferred that the down estuarine harbour regions were highly influenced by the tidal stage and associated circulation due to deeper waters and this occurred in the absence of adequate freshwater inflow.

In March 1995, low surface salinities were observed at the non dredged stations and as depth increases salinities slightly increased. A similar feature is again noted for dredged locations. The tidal phase was ebb covering the slack period.

In April 1995, during the high tide period the non dredged sites (station 1) salinity values ranged between 17.0 to 24.0 and at station 4, it was recorded as 18.0 to 27.0. In the dredged area, salinity gradually increased from surface to bottom in the range of 20.0 to 30.0. The features are typical of premonsoon season.

In May 1995 too, high tide influenced the surface salinity; it was very low (6.0/5.0) in the non dredged area while bottom salinities were higher (30.0/23.0) at stations 1 & 4 respectively. The stations at the dredged locations indicated surface salinities to be higher compared to non dredged area and while bottom salinities were more or less the same as that of non dredged area. The low surface salinity values resulted due to premonsoon thundershowers.

In general, during the premonsoon period of 1995, the surface salinities at the non dredged area showed a low value compared to the bottom values. At the dredged area, surface salinities are comparable to the non dredged area but the bottom values are higher but the difference in range is small. The proximity of stations close to the barmouth and depth factors may bring about these features.

The field study during the monsoon (June to September 1995) was held at stations 1 to 6 during the tide stage commencing from ebb to flood. The tidal range during the four months are also comparable. The season is known for the voluminous inputs of freshwater resultant from runoff generated by the monsoonal rainfall. The input manipulates the estuarine conditions to that of a well stratified estuary at Cochin harbour which is evident from salinity values - more or less < 8.0 at surface and often > 30.0 at the bottom of the dredged site and highly varying (8.0 to 35.0) at non dredged site (stations 1 & 4). During June 1995, heavy freshwater runoff had considerably restricted the saline intrusion to the deeper part of the Cochin harbour (salinities < 15.0). In June 1995, low salinity values were observed at station 1 ranging from 3.5 to 9.5. At station 4, salinities 10.0 to 25.0 was noted. Similar features were also observed at the dredged area of Ernakulam and Mattancherry channel. At both the sites, salinity shows a gradual increase which indicated the seaward influence, but at the surface layers freshwater influence prevailed. The stratification feature and related estuarine circulation characteristics have been studied earlier (Udaya Varma et al., 1981, Joseph & Kurup, 1990). The results of this study do not deviate from the findings of earlier workers.

The month October 1995, falls in the postmonsoon season and follows a trend truely typical for a transitional period. The non dredged locations exhibited lower salinities compared to dredged sites, stations 2,3,5 & 6. The higher salinities at these stations coincided with the deeper waters of the estuary which is prone to intrusion of denser sea waters.

C. TURBIDITY

The important parameter which influence the water quality during dredging is the change of turbidiy which had also observed in earlier studies by Sherk, 1971., Windom, 1972., May, 1974 and Bohlen et al., 1979. The results on turbidity are represented on a monthly basis. As for any other harbour, turbidity at Cochin too exemplify a main feature of coastal waterbodies, especially that of an estuarine type where interactive forces dominate its distribution and settling rates. The extend of dredging and related impacts are reflected in the studies on water column suspended solids content and presence/ absence of nepheloid layers.

November 1994

During the month of November 1994, the turbidity at the dredged site showed an increase in values as depth increased (figure 3a). At stations 2 & 5, upto the depth of 10m, the turbidity was more or less same. But at stations 3 & 6 a sharp increase in turbidity was observed beyond 6m. This may be due to the increase in turbulence (at station 3, rapidly, current speeds changed from 37 to 84cm/s and at station 6, 15 to 18cm/s).

At the non dredged site, (station 1) the turbidity was more or less the same (82 to 90 mg/l) but at station 4 values varied in the range 89 to 169 mg/l.

December 1994

At station 2, in the Ernakulam channel, the turbidity did not vary with depth upto 7m, but thereafter a slight increase was observed. The maximum value observed at station 2 was 55mg/l. At station 3 in the same channel, the same tendency was evident but the turbidity value was greater than 82mg/l (figure 3a). Stations 5 & 6 in the Mattancherry channel showed

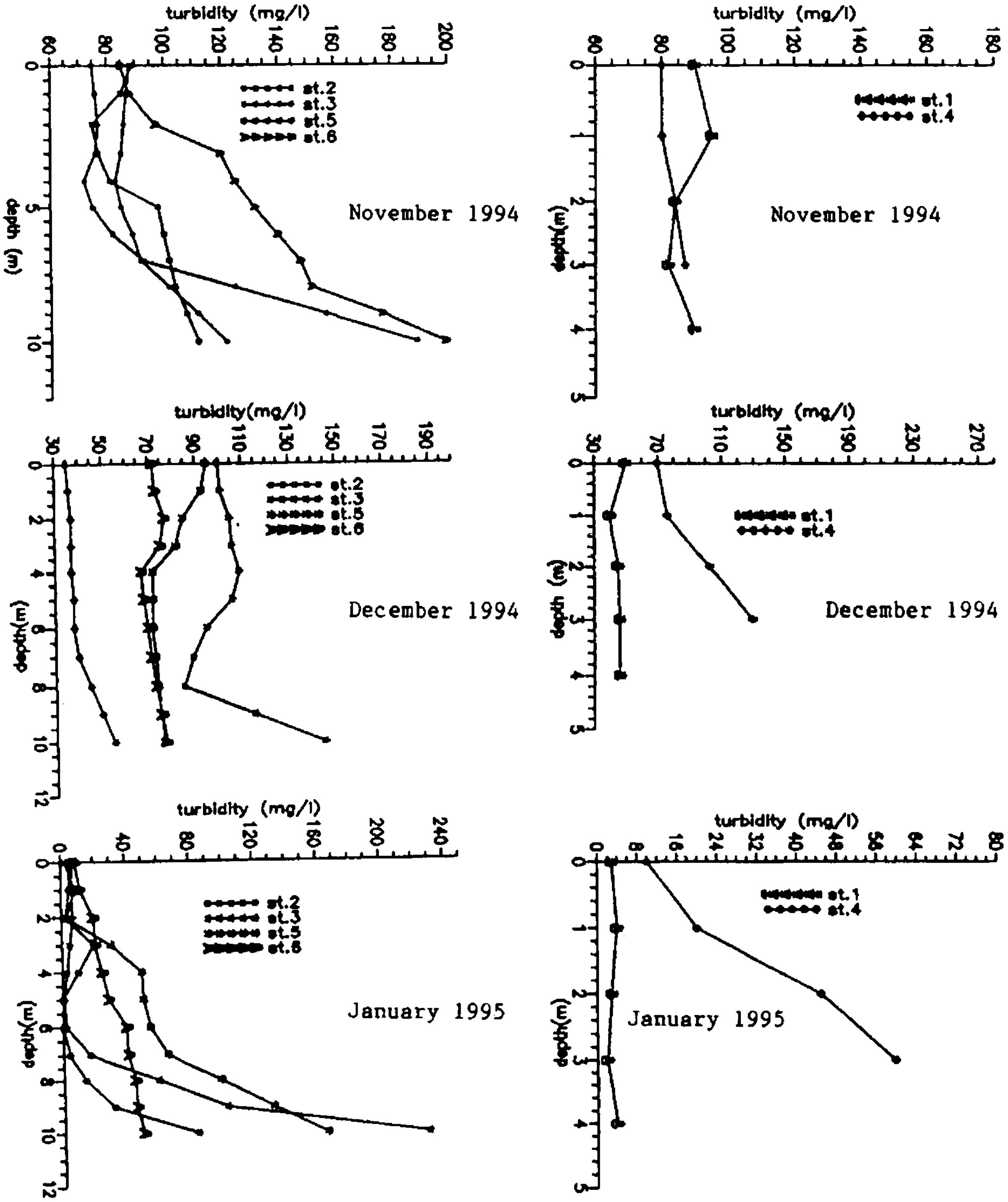


Fig. 3a Turbidity values at stations 1 to 6 during the month of November, December 1994 & January 1995.

consistent values - the range of values were between 75 to 90 mg/l.

At the nondredged sites (station 1), the turbidity variation was very limited from surface to bottom (50 to 46mg/l). At station 4, turbidity increased with depth, the observed value at surface was greater than 135mg/l and sharply increase to more than 250mg/l.

January 1995

At stations 2 & 3, the turbidity was very low (< 10mg/l) upto a depth of 6m, then shows a gradual increase; exceptionally high quantity was observed at a depth of 10m (230mg/l). At stations 5 & 6 very low turbidity values were observed upto 2m, followed by a gradual increase of turbidity (figure 3a). At station 5, the maximum turbidity was observed as 166mg/l at a depth of 10m.

At the nondredged sites, station 1, the turbidity values were very low (< 4mg/l) while at station 4, the values ranged from 10 to 70mg/l.

At the dredged site, the postmonsoon period of 1994 showed more or less, constant turbidity values to a depth of 6m and thereafter a sharp increase of turbidity was noticed in the depth range from 6 to 10m. Maximum turbidity occurred at depths of 8 to 10m. During this period, very low turbidity was observed at the dredged sites between the depths of 4 to 5m.

At the nondredged site, station 1, showed low turbidity values than the other nondredged site (station 4). Station 1 exhibited constant values as depth increased, but at station 4, there was a sharp increase of turbidity as depth increased.

February 1995

Dredged site again showed increasing turbidities as depth increased. At station 2, from surface to 5m, the turbidity was less than 10mg/l (figure 3b). Beyond 5m, it increased upto 66mg/l. At station 3, turbidity gradually increased from surface to bottom, 13 to 78mg/l. At stations 5 & 6 of Mattancherry channel the values gradually peaked at 8m, followed by sudden increase. At the nondredged site (station 1) turbidity varied from 3 to 17mg/l and at station 4 the content varied from 3 to 76mg/l.

March 1995

At the dredged sites turbidity values gradually increased from surface to bottom; station 2, a small change in content was observed upto 6m and after that a peak in turbidity content was noticed (figure 3b). At station 3, turbidity changed from 35mg/l at surface to 140 mg/l at 10m depth. At stations 5 & 6 of Mattancherry channel, turbidity changed from 5 to 100mg/l & 26 to 100mg/l respectively.

Interestingly at station 1, turbidity increased from surface to 1m and then gradually decreased as depth increased but at station 4, an increase of values with depth (30 to 100mg/l) occurred.

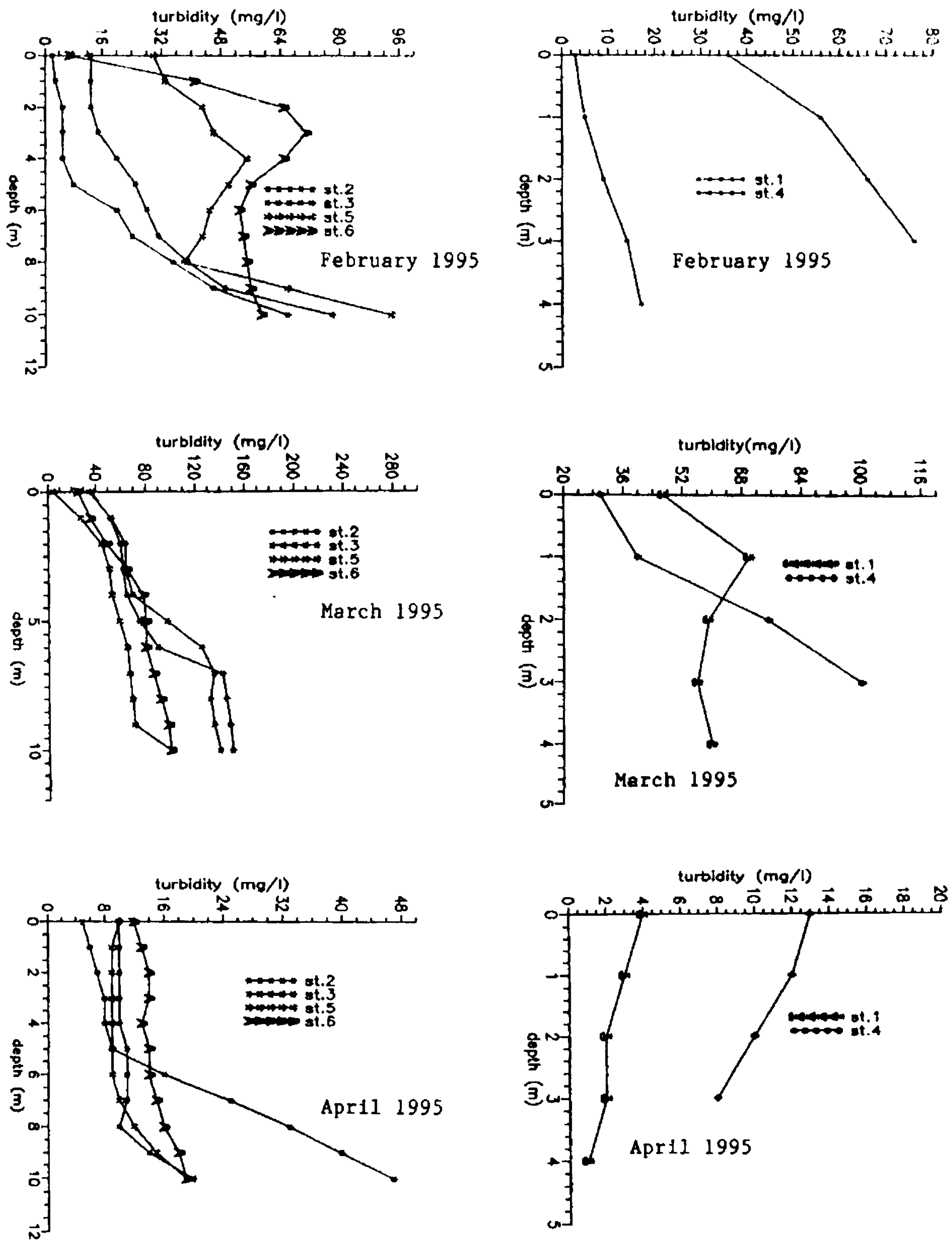


Fig. 3b Turbidity values at stations 1 to 6 during the month of February, March & April 1995.

April 1995

At the dredged site, except at station 2, more or less similar values in the range of 9 to 20mg/l were observed (figure 3b). At station 2, the range of values noted was from 5 to 47mg/l. At nondredged locations, turbidity values showed a decline; at station 1, the values ranged from 1 to 4 mg/l while at station 4, 8 to 13mg/l was observed.

May 1995

During this month, at stations 2 & 3, turbidity showed a gradual increase upto 8m and thereafter very high values were noticed (figure 3c). A similar trend was also observed at stations 5 & 6 in the Mattancherry channel. The maximum turbidity (260mg/l) was observed at a depth of 10m at station 5.

At the nondredged site, an increasing turbidity content was observed but limited in range; at station 1, the values varied from 12 to 45mg/l and at station 4, the change was from 12 to 25mg/l.

Generally, during the premonsoon period of 1995, turbidity values gradually increased upto a depth of 6 to 8m (ca 80mg/l). Further deep, the turbidity content increased sharply. But at the non dredged sites, turbidity showed a decreasing tendency with depth except in April 1995.

June 1995

Stations 2 & 3 of the Ernakulam channel showed steady turbidity values upto a depth of 8m; at station 3 a sharp peak of turbidity of 230mg/l was noticed beyond 8m (figure 3c). At

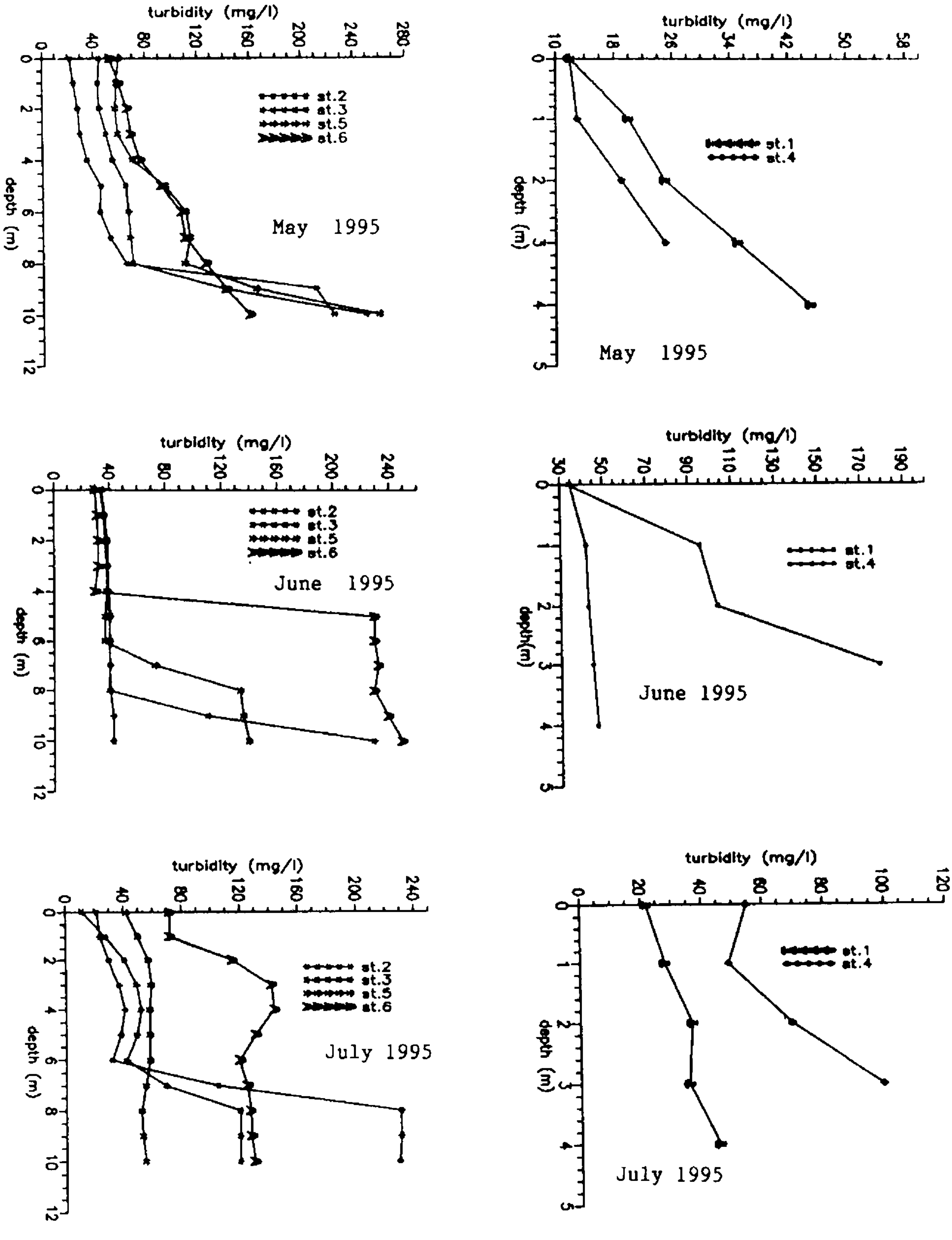


Fig. 3c Turbidity values at stations 1 to 6 during the month of May, June & July 1995.

stations 5 & 6 of Mattancherry channel, again a constant value upto 4m depth was observed and thereafter turbidity values increased considerably. Station 5 showed a maximum of 140mg/l and at station 6, 250mg/l content was observed.

Station 1 exhibited constancy but station 4 values increased from 34 to 178mg/l.

July 1995

At stations 2 & 3, the turbidity values increased beyond 6m depth to a maximum of 231mg/l & 120mg/l respectively (figure 3c).

The nondredged sites too showed an increase in turbidity with depth. At station 1, values ranged between 22 to 46mg/l and at station 4, between 55 to 100mg/l.

August 1995

Stations 2 & 3 showed an increase in turbidity initially in the upper 2m layer and then showed a decline (upto 4m at station 3 & 8m at station 2) and in the subsurface layers, the values further increased (figure 3d). At station 5, the turbidity decreased initially followed by continuously increasing turbidity with depth. At station 6, the values increased gradually upto 8m and then showed a fluctuating tendency.

The nondredged locations, station 1, exhibited values decreasing with depth but station 4 showed only a gradual increase.

September 1995

All the dredged locations (stations 2, 3, 5 & 6) showed more

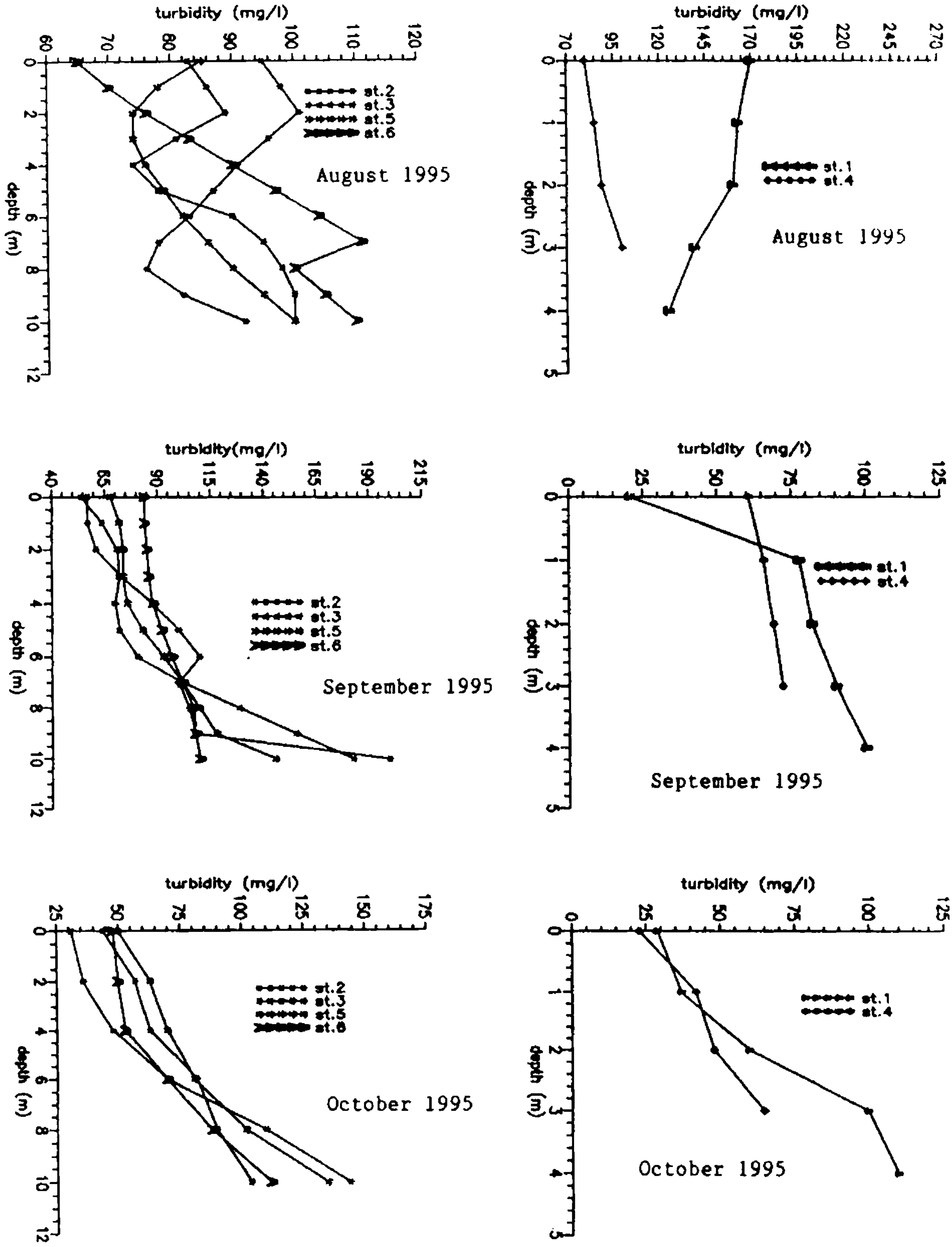


Fig. 3d Turbidity values at stations 1 to 6 during the month of August, September & October 1995.

or less constant values upto depths of 6m, beyond that the turbidity showed an increasing tendency. From a depth of 7m onwards, turbidity of the water column was greater than 100mg/l (figure 3d).

At the nondredged sites, station 1, an increase of values with depth occurred but at station 4, the content was restricted within a range from 61 to 72mg/l.

October 1995

General increase of turbidity was observed at all the dredged stations. The value ranges from 31 to 144, 44 to 104, 50 to 135 & 48 to 112 at stations 2,3,5 & 6 respectively (figure 3d).

Similar variations were also observed at the stations 1 and 4 at the nondredged sites.

During the monsoon period, higher turbidity values occurred from surface to bottom while comparing the postmonsoon and premonsoon period. At almost all the locations throughout the season surface values were greater than 40mg/l. Another distinguishable feature pertains to the sharp increase of turbidity observed throughout the season for depths more than 6m. Nondredged locations showed a general increase of turbidity except during August 1995, at station 1, a decreasing turbidity content was observed.

D. TRANSPARENCY

The extinction coefficient values representing results on studies on transparency are tabulated in table 3; the monthly

Table: 3

Extinction coefficient during November 1994 to October 1995

stns -->	1	2	3	4	5	6
Nov'94	2.61	3.09	2.62	2.83	2.13	2.43
Dec'94	2.00	1.89	1.79	2.62	1.00	2.43
Jan'95	2.27	1.70	1.79	2.43	1.70	1.89
Feb'95	1.55	1.55	1.70	2.43	2.83	3.40
Mar'95	3.40	3.40	2.27	3.40	2.27	2.27
Apr'95	1.70	1.70	1.89	2.00	1.89	2.00
May'95	1.89	2.43	2.62	3.09	2.13	2.00
Jun'95	3.78	2.00	2.43	3.09	2.43	2.62
Jul'95	3.86	1.89	1.89	2.12	2.00	3.80
Aug'95	2.00	2.00	2.13	3.80	2.13	2.43
Sep'95	2.43	2.27	3.25	3.85	2.13	1.89
Oct'95	2.43	1.89	1.79	1.89	2.62	2.00

variation is provided in figure 4. Low extinction coefficients indicate high transparency and less turbidity in surface waters and conversely high extinction coefficients indicate a low value in transparency and coincide with high values of turbidity.

The results are separately presented for dredged and nondredged sites. The results at the nondredged site (stations 1 & 4) showed a gradual decrease of extinction values throughout the postmonsoon season which indicate that light penetration in the surface water column increases as season advances; similar situation prevails at the nondredged area too. The observation during the premonsoon period showed that extinction coefficient values to follow a zig-zag path as season advances at nondredged sites. But during monsoon, both locations of nondredged area (stations 1 & 4) showed coefficients to be greater than 2 indicating the presence of higher turbidity in surface waters as a result of turbid freshwater inflow which is typical for tropical estuaries.

The observations on transparency at dredged sites (stations 2,3,5 & 6) as shown in the figure 4 indicate that during the premonsoon period values peak more than 2.5 at a few stations in February and March 1995 likely suggesting an increase of turbidity by way of dredging. The low values during the month of April 1995 may be due to temporary stoppage of dredging. During the monsoon season, the values are constant, indicative of homogeneity in water transparency at all stations except in July and September 1995 of stations 3 & 6 which showed high

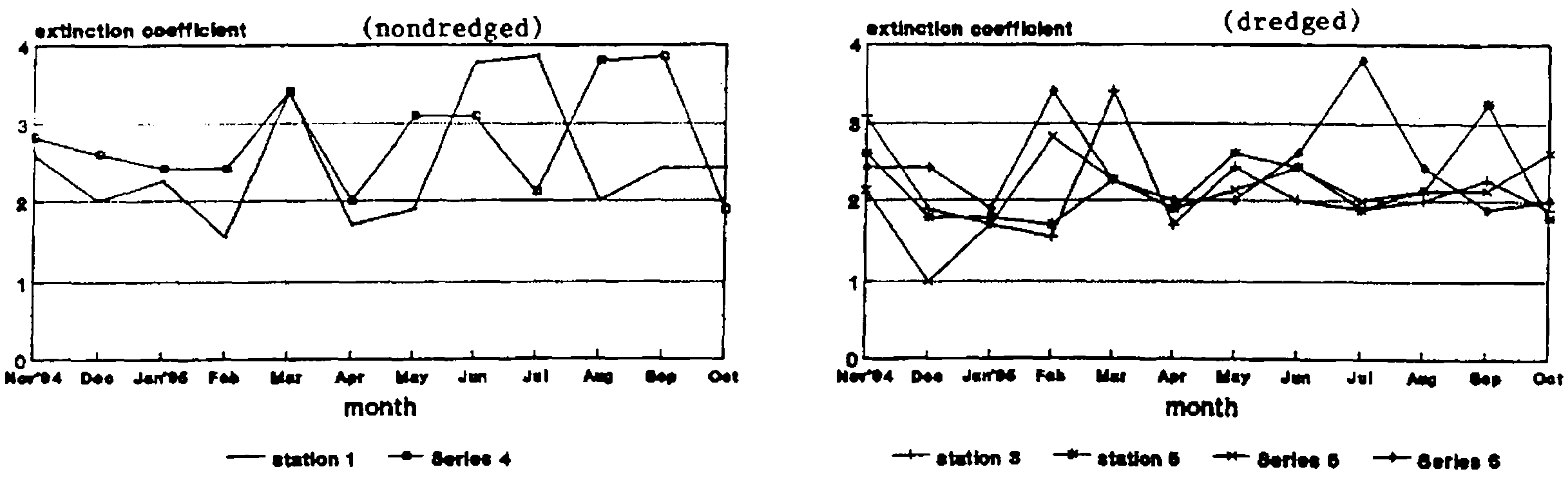


Fig. 4 Monthly distribution of extinction coefficient at stations 1 & 4 (nondredged) and 2,3,5 & 6 (dredged).

extinction coefficient values as an exception.

Comparing the results on a generalized basis for the two type of sites, the dredged area extinction coefficient values ranged between 1.00 to 3.80 with most values centered around 2.00 while that at the nondredged area, it lies between 1.55 to 3.86 while most values were was above 2.00. It follows that the deeper channel portions which are dredged to navigable depth often exhibit uniform characteristics but features at nondredged locations are influenced by inhomogeneity in seasonal geohydrographical conditions.

E. SEDIMENT TEXTURAL CHARACTERISTICS

1. Spatial features on sand fraction

a. Dredged locations (stations 2,3,5 & 6)

The sand content at station 2 during the premonsoon period of 1995 showed a general increasing tendency with respect to the postmonsoon of 1994 (figure 5). But the monsoon season of 1995 showed an increase of sand content. At station 3 during all seasons, the sand content was less than 7% except in January 1995. At station 5, sand content was very less in quantity (<10%) except during January and September 1995. The sand content showed a general decreasing tendency from March to October 1995 at station 6. During January & February 1995, sand content was comparatively more (10%) than during other months. At all the dredged sites of Cochin port area, generally less sand content

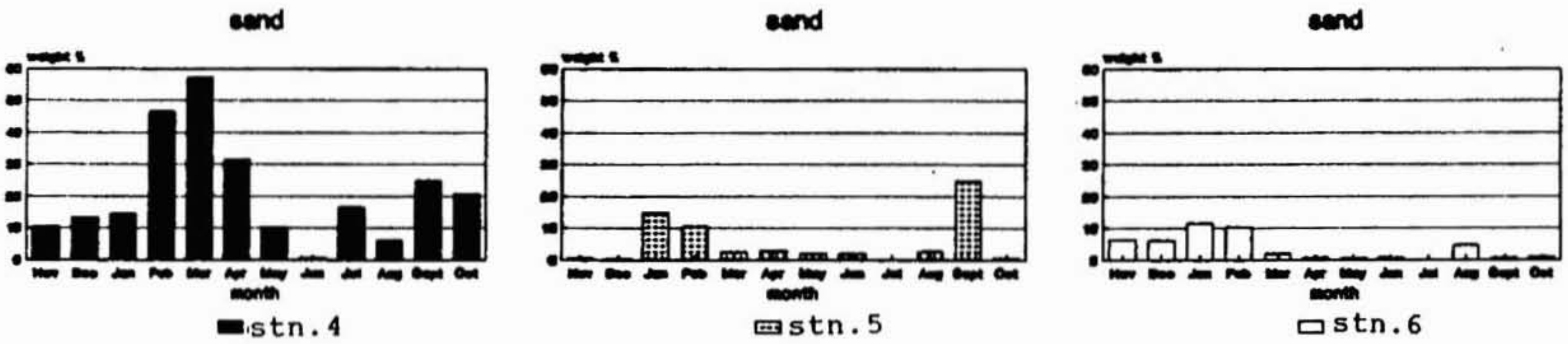
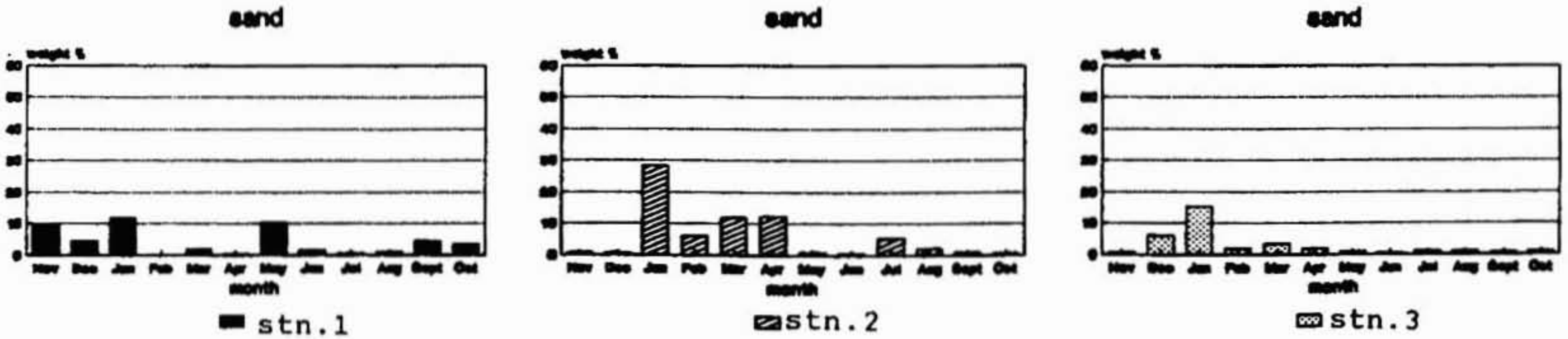


Fig. 5 Weight percentage of sand at stations 1 to 6 from November 1994 to October 1995.



was observed during the study period considering all the three seasons together.

b. Nondredged locations (stations 1 & 4)

The sand content at station 1 showed generally a decreasing tendency as season advanced and at station 4, the premonsoon of 1995 showed sharp increase of sand content ranging from 31 to 57%. As season advances, sand content decreased. At the nondredged sites, during monsoon of 1995, sand content was comparatively less. Generally, both sites showed less sand content except during the premonsoon period at station 1.

2. Spatial features on silt fraction

a. Dredged locations (stations 2,3,5 & 6)

At station 2, the silt content, in general, was around 60% to 80% (figure 6). The next station (3) depicts the silt content to increase from post monsoon of 1994 to premonsoon of 1995. During monsoon, the silt content (>80%) showed constancy (except June of 1995 when it was about 60%). According to Veerayya and Murthy (1974), the sediments of Mattancherry and Ernakulam channel contained mostly silt which varied between 50 to 70%. This study during 1994-95 corroborate with earlier studies on the higher content of silt in dredging channels. At station 5 no particular tendencies were noticeable in silt content as the season advances. During the months of September and October 1995, the silt content reduced to about 45% which was very less

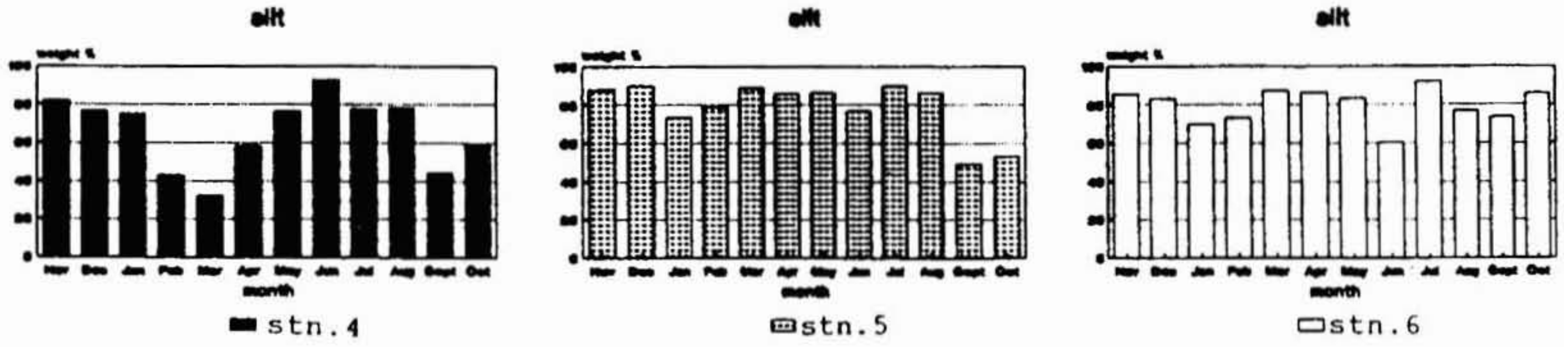
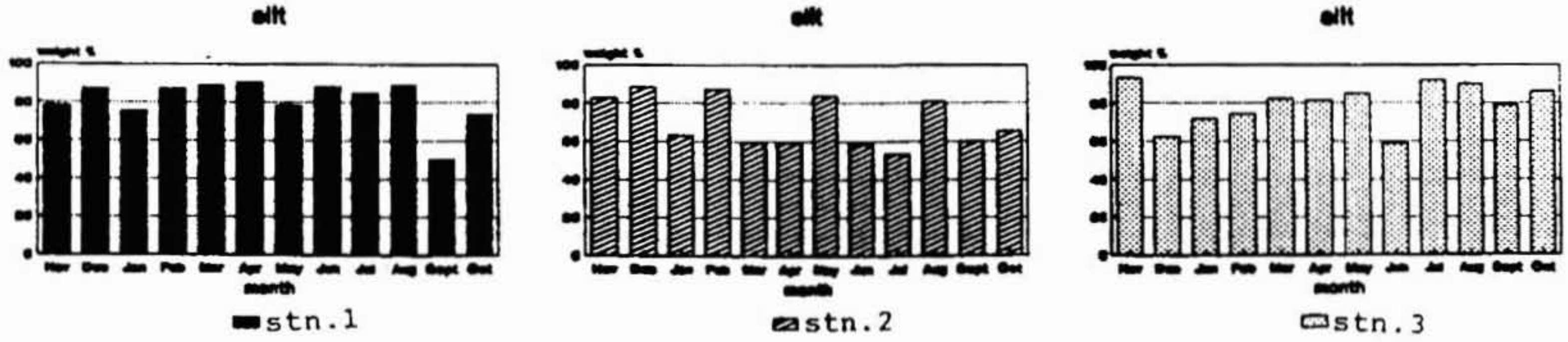


Fig. 6 Weight percentage of silt at stations 1 to 6 from November 1994 to October 1995.



compared to other months. The range of values observed was between 60 to 85% at station 6. This station did not show any consistent variation. During the month of June, silt content was less (about 60%). Josanto (1971) observed that during the premonsoon season, in the Ernakulam channel, very fine silt generally dominated. Results of this study also correlate with the earlier observations.

b. Nondredged locations (stations 1 & 4)

Figure 6 showed that, silt content was about 80% except during the month of September 1995 at station 1. Premonsoon of 1994 showed a decrease in silt content at station 4, but monsoon season showed an increasing trend in silt compared to the premonsoon season; and again it decreased during the postmonsoon of 1995. During the monsoon period, silt content varied in a wide range from 50 to 90%. At both sites (stations 1 & 4) silt content was very high during the study period. Sundaresan (1991) reported that silty sediments were more dominant (>90%) in Ernakulam channel during the premonsoon seasons than other fractions. The investigation during the premonsoon of 1994 in Ernakulam channel revealed the presence of silty sediments in the range 60 to 85% and in the Mattancherry channel, during 1994-95, in the range of 70 to 85 % except in the case of a couple of months.

3. Spatial features on clay fraction

a. Dredged location (station 2,3,5 & 6)

Generally the clay fraction at station 2 showed an increasing tendency from January 1995 to September 1995, but during May & August 1995 only it showed a decline (figure 7). The clay fraction varied between 10 to 20% except in December 1994 and June 1995 at station 3. In December 1994 and June 1995 a sharp increase to about 30-40% was noted. During this study the clay fraction at station 5 showed a consistent value (10%) except in June 1995 (21%), September and October 1995 (values ranged between 45 to 50%). At station 6, the values ranged between 10 and 20% except during June 1995 (40%), August 1995 (18%) and September 1995 (25%).

An anomalous increase of clay fraction was observed at all stations during the month of June 1995. Generally at the dredged sites an increase of clay fraction commenced by the end of monsoon season and a decline started when the season changed.

According to Josanto (1971), the sediments of the Mattancherry channel region during the premonsoon season showed an average median diameter of 9.6ϕ, which is that of clay texture. During the study period of 1994-95, the sediments of the Mattancherry channel (stations 5 & 6) was predominant in fine silt and very fine silt along with clay. According to Seralathan et al.,(1993) and Seralathan and Padmalal (1994), in Ernakulam and Mattancherry channels, muddy sediments dominated in the average mean grain size of 7.6ϕ. During the period

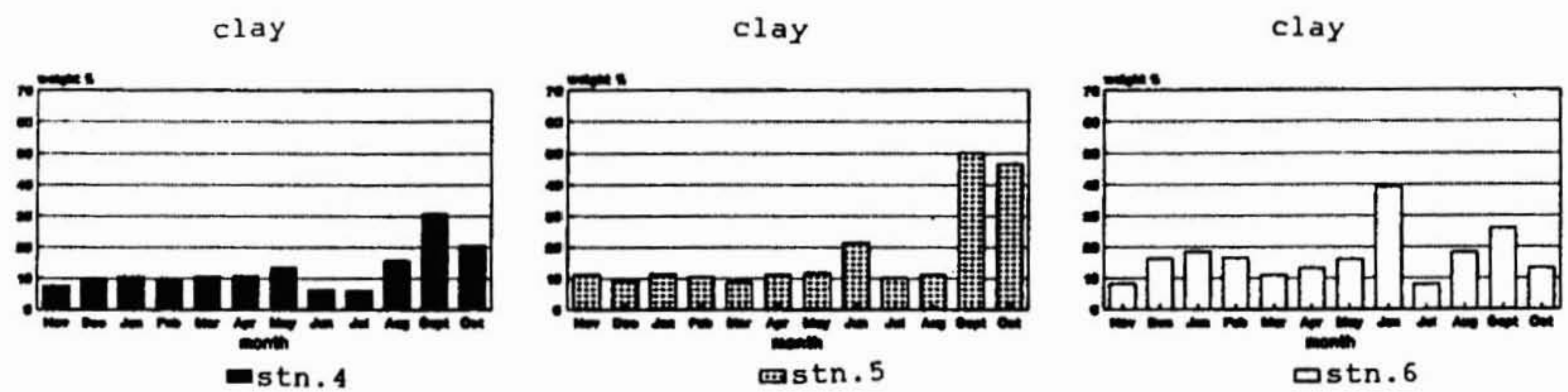
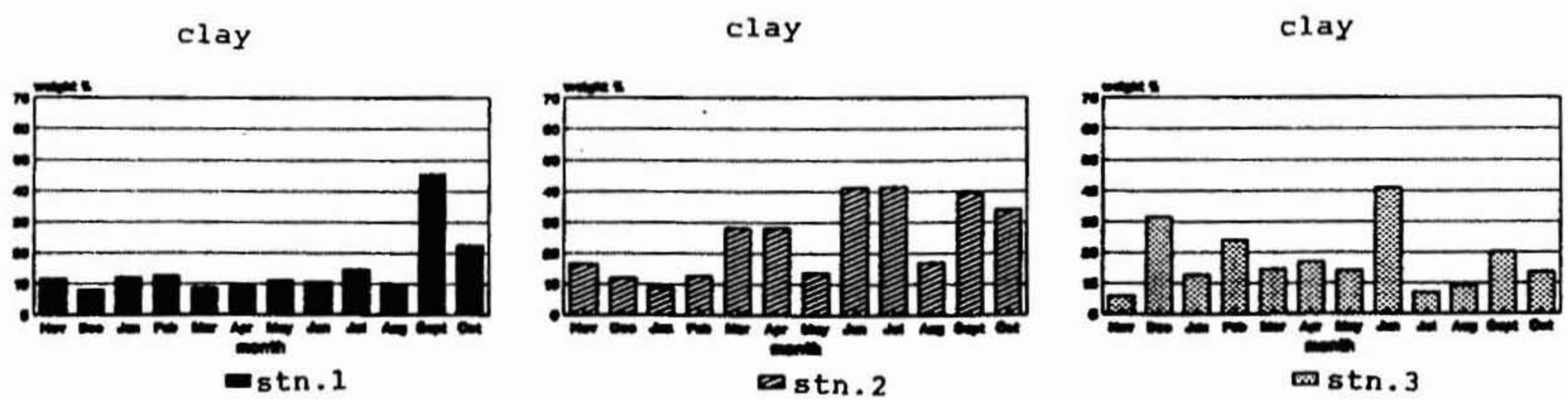


Fig. 7 Weight percentage of clay at stations 1 to 6 from November 1994 to October 1995.



1994-95. in Mattancherry and Ernakulam channels dredged sites the observations showed an average mean sediment size of 7.32ϕ. This finding well correlates with the early findings.

b. Nondredged locations (stations 1 & 4)

At the nondredged sites, stations 1 & 4, a consistent value of clay fraction, about 10%, except during September and October 1995 was noticed; there was an increasing presence of clay fraction towards the end of monsoon season (similar results are also reported for the dredged site but the range of values were higher than that of nondredged sites). Both dredged and nondredged sites showed an increase of clay fraction by the end of monsoon season. During the month of June 1995, all stations in dredged sites showed an anomalous increase of clay, but there was no such changes observed at the nondredged sites.

F. GRAIN SIZE VARIATION OF ALL FRACTIONS

During the postmonsoon season of 1994, at the dredged site fine silt, very fine silt and clay were dominant fractions (figure 8a & b). But the nondredged site characterized by medium silt plays a dominant role along with fine silt and clay fractions. At stations, where dredging operations take place during the premonsoon of 1995, fine silt, very fine silt and clay were dominating. At the nondredged sites, (station 1) medium silt, fine silt and clay were dominating while at station 4 fine silt was dominating (figure 9a & b).

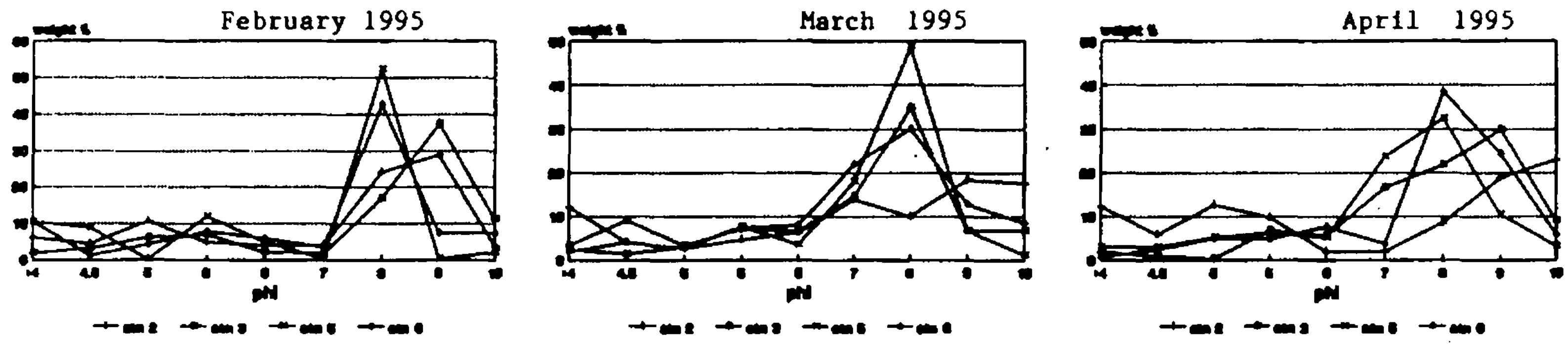
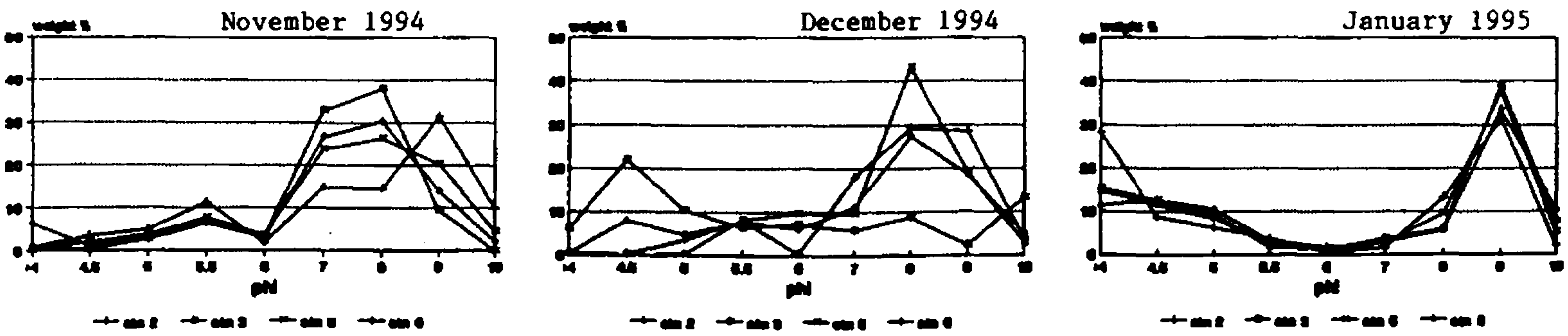


Fig. 8a Weight percentage vs phi values at stations 2,3,5 & 6 (dredged sites) from November 1994 to April 1995.



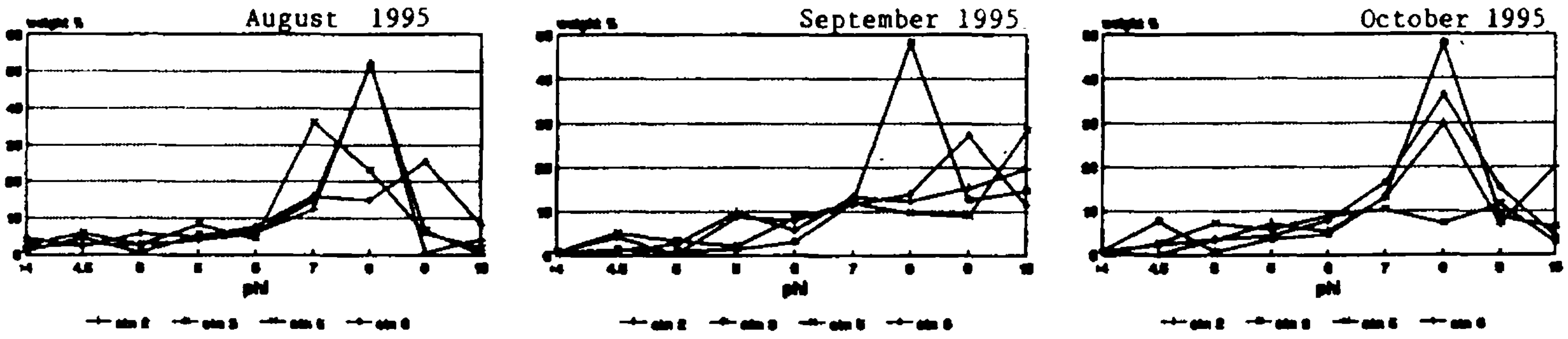
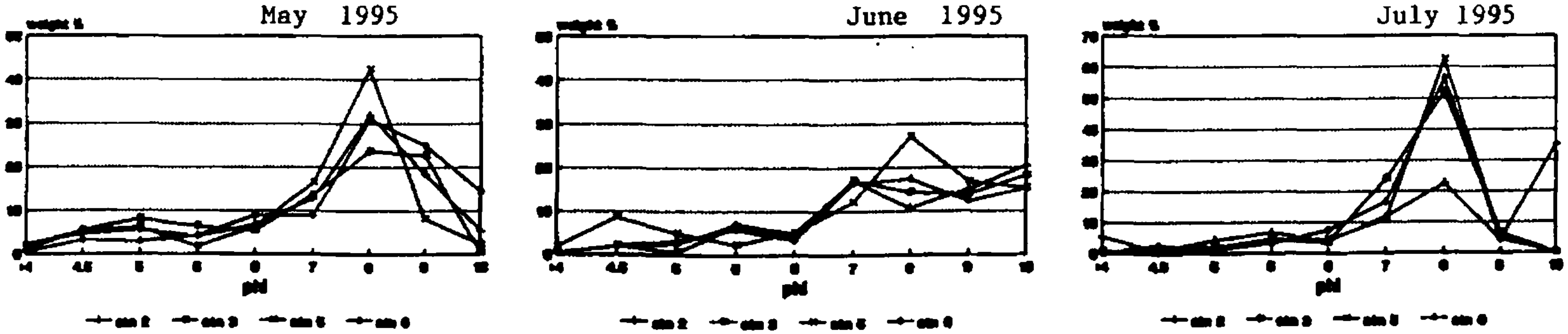


Fig. 8b Weight percentage vs phi values at stations 2,3,5 & 6 (dredged sites) from May 1995 to October 1995.



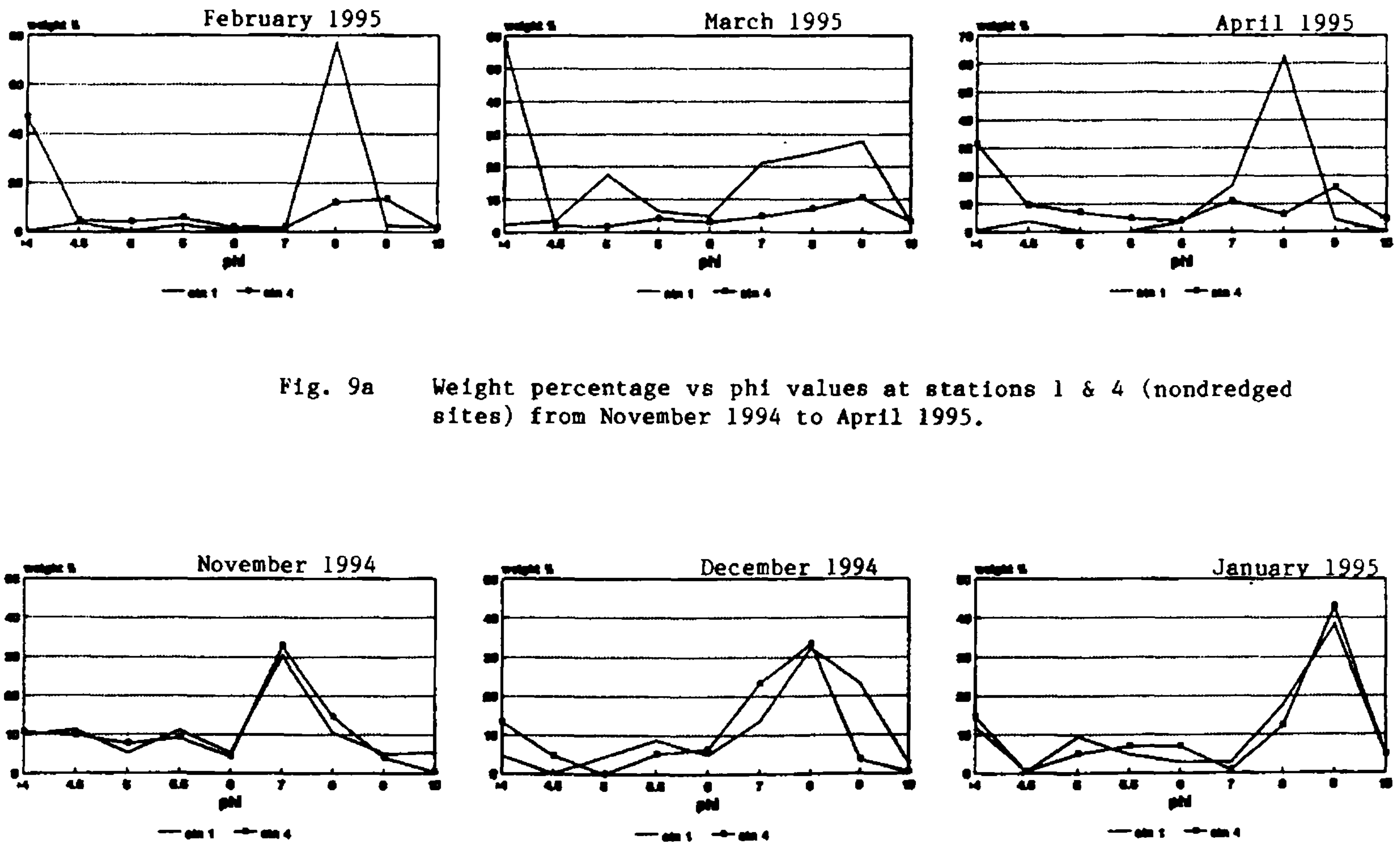


Fig. 9a Weight percentage vs phi values at stations 1 & 4 (nondredged sites) from November 1994 to April 1995.

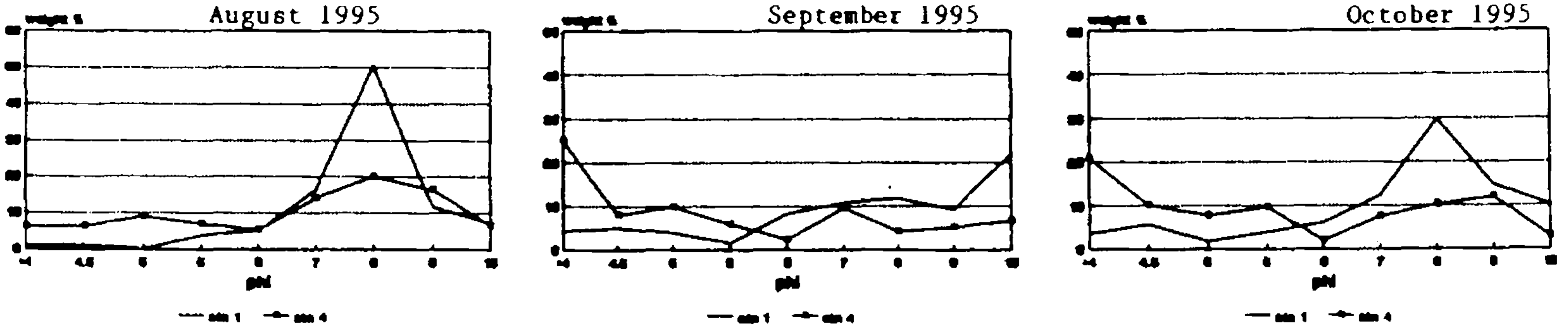
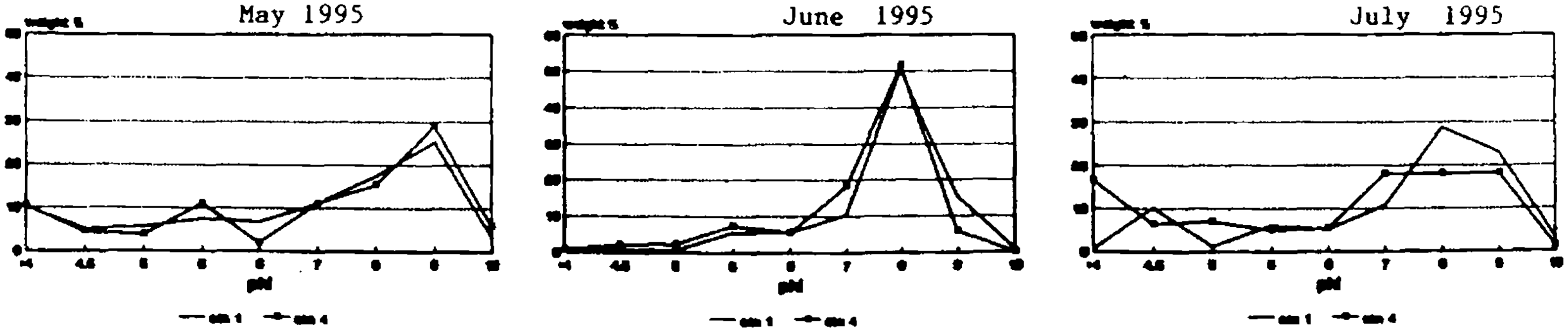


Fig. 9b Weight percentage vs phi values at stations 1 & 4 (nondredged sites) from May 1995 to October 1995.



During the monsoon season, fine silt, very fine silt and clay were dominating the dredged locations but the range of values were very high when compared to other two seasons. At the nondredged site, fine silt was dominating but by the end of the season, gradual increase in grain size was observed.

1. Results on standard deviation (S.D.), skewness and kurtosis

The S.D. of the nondredged sites (stations 1 & 4) indicate that the sediment of that area is poorly sorted during the postmonsoon season (Table 4); this may be due to the mixing conditions prevailing in the harbour region. But at the dredged site the value range suggests poorly sorted to very poorly sorted samples. Skewness at the nondredged site ranges from fine skewed to very coarse skewed. In the dredged sites it was fine skewed to coarse skewed. Kurtosis at the nondredged site ranges from very platykurtic to leptokurtic but at the dredged sites it ranges from very platykurtic to very leptokurtic.

The standard deviation of the nondredged site ranges from moderately sorted to very poorly sorted while at the dredged site poorly sorted to very poorly sorted occurence was prevalence during premonsoon. The skewness at the nondredged sites ranges from very fine skewed to coarse skewed but at the dredged stations near symmetrical to very coarse skewed was noted during the premonsoon period. Kurtosis at the nondredged area ranges from very platykurtic to extremely leptokurtic but at the dredged stations very platykurtic to very leptokurtic was noted.

Seasons	Standard Deviation		Skewness .		Kurtosis	
	N.D	D	N.D	D	N.D	D
Post Monsoon	Poorly sorted	poorly sorted to very poorly sorted	fine skewed to very coarse skewed	fine skewed to coarse skewed	very platy-kurtic to lepto-kurtic	very platy-kurtic to very lepto-kurtic
Pre Monsoon	Moderat-ely to very poorly sorted	poorly sorted to very poorly sorted	very fine skewed to coarse skewed	near symmetr-ical to very coarse skewed	very platy to extremely lepto-kurtic	very platy to very lepto-kurtic
Monsoon	poorly to very poorly sorted	poorly sorted to very poorly sorted	fine skewed to coarse skewed	very fine skewed to very coarse skewed	very platy to very · lepto-kurtic	very platy to very lepto-kurtic

Table 4 Standard Deviation (S.D), Skewness & Kurtosis during three seasons at nondredged (N.D) and dredged (D) sites.

In monsoon, standard deviation at the nondredged sites during the monsoon period ranges from poorly sorted to very poorly sorted. In the dredged site also same features as that of nondredged site is noted. Skewness at the nondredged site ranges from fine skewed to coarse skewed and in the dredged site, very fine skewed to very coarse skewed. Kurtosis at the nondredged sites ranges from very platykurtic to very leptokurtic in monsoon. In the dredged area, similar characteristics as that of nondredged site are noticeable.

All the seasons at the dredged site behaved constantly as poorly sorted to very poorly sorted; this may be due to the dredging activities except during the monsoon season when no dredging activities take place but the input of material from the land area through river discharge and from the sea by tidal flushing influence the hydrogeology of the area. In the nondredged sites, the degree of sorting as poorly sorted, moderately sorted to very poorly sorted and poorly sorted are well noted as the season passes from postmonsoon to premonsoon and then to monsoon.

Generally at the dredged site, skewness showed very fine skewed to very coarse skewed. Nondredged site also showed similar range of skewness as that of dredged site.

Kurtosis at both the sites indicate almost same peakedness (very platy to very leptokurtic).

G. NUTRIENTS

The presence of nutrients essentially support the growth of algae and further addition of large amount of nutrients into a waterbody generally produce enrichment of algae and other organisms (Chester, 1990) and thereafter leading to conditions of eutrophication. In this context, the estuarine features present totally a complex picture for "biostimulation", a general term used to describe the scenario of factors involved in the growth of algae in such waterbodies due to addition of nutrients. The nutrient inputs to estuaries are routed via industrial waste, municipal sewage or through the agricultural areas (non-point sources) and often result in sinks/sources in the aquatic environment (Forstner, 1976).

During the dredging process the bottom sediments plus water immediately above it get disturbed due to turbulence and the resultant churning action brings sediments and subsurface water to the surface layers. There is the likelihood of bottom sediments releasing quantitative amounts of nutrients under such conditions which may influence the estuarine biological system.

The nutrients, nitrite and phosphate were monitored from November 1994 to October 1995 at the dredged and nondredged sites.

1. Nitrite

The nitrite concentration at dredged sites of surface waters were as follows. During the postmonsoon period of 1994, the nitrite concentration ranged from 0.03 to 2.45µgat/l and at the nondredged sites, it was less than 1.0µgat/l (figure 10). When the season changed to premonsoon of 1995, the content was more or less within a constant range (1.0-2.0µgat/l) for both the types of sites. At nondredged stations, there is evidently an increase of nitrite content as compared to the previous season. During the monsoon season, constancy of nitrite content prevails during the initial stage but towards the end of season gradual decrease was noted for dredged locations. At the nondredged sites, constancy was exhibited throughout the period.

In the bottom waters of the dredged site, the nitrite content in postmonsoon season showed higher range of variability (between 0.32 & 6.17µgat/l) while at the nondredged sites the nitrite concentration was low (< 0.78µgat/l). During the postmonsoon season, at the nondredged sites, the values gradually increased as season draws to a close. The range of values at these sites in premonsoon was between 1.75 and 4.79µgat/l. Corresponding values at dredged sites were still higher (1.28-6.29µgat/l). The observation during the monsoon season at the dredged locations indicated that nitrite concentration sharply reduced in bottom water by the end of season. A similar tendency was also prevalent at the nondredged areas.

Comparing the surface and bottom waters, at the dredged site, the features indicate that the bottom waters contained higher concentration of nitrite than the surface waters throughout the period of study. This increase obviously follows

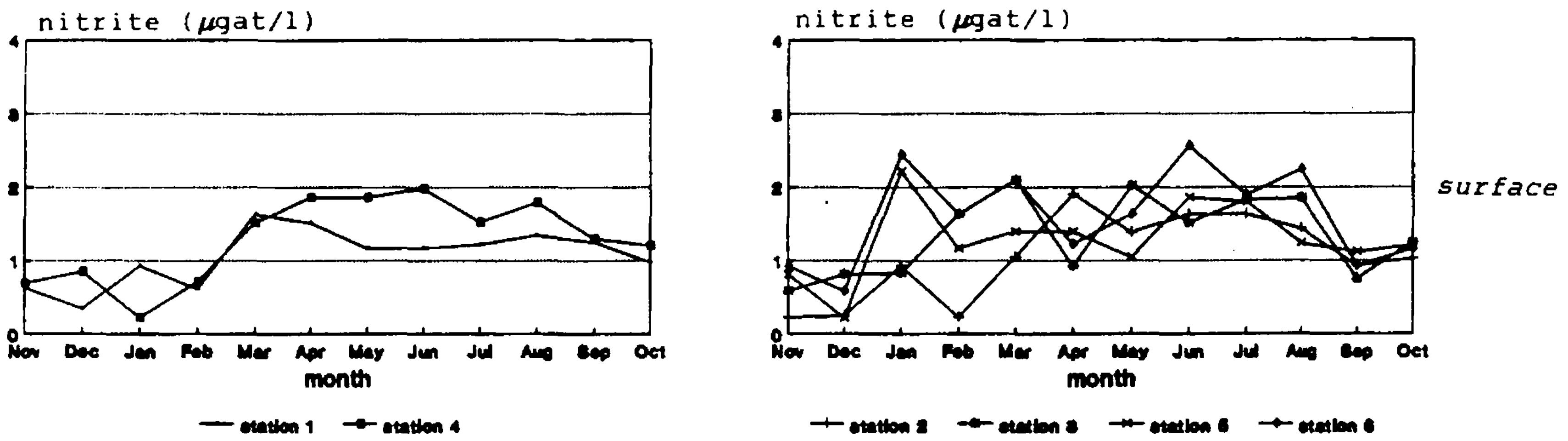
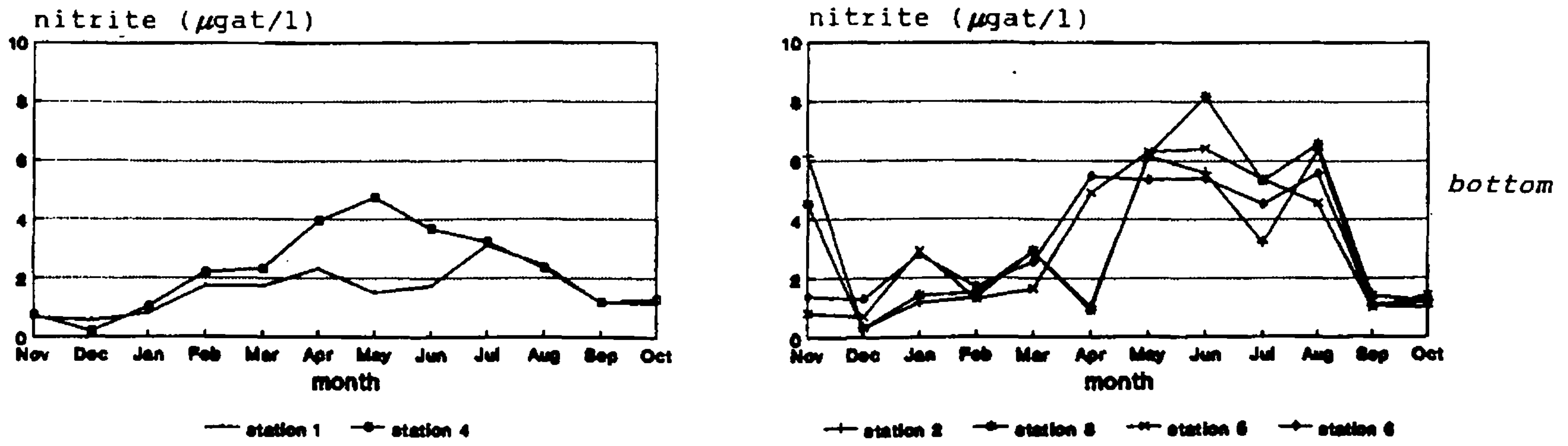


Fig. 10 Nitrite concentration at surface and bottom at nondredged (stations 1 & 4) and dredged locations (stations 2,3,5 & 6).



the sediment-water exchange gradient largely influenced by dredging action and turbulent movement in bottom waters which agitate the sediments leading to nutrient release. The consistently higher values of nitrite observed in bottom waters during the monsoon period coincide with large amounts of freshwater reaching the estuary which contain higher amounts of suspended solids. The deeper parts of the estuary - i.e., the dredged locations afford siltation processes whereby time scales favour quasi steady state nutrient exchange to result in higher concentrations compared to nearby nondredged sites of relatively lower content. Further, comparing the nondredged sites in both areas, more or less a similar trend was noticed but the contents were more in the bottom waters as expected. The postmonsoonal low coincides with the higher production in the estuarine waters. Noted are the trends at the dredged and nondredged sites which are similar; the perturbations in values at dredged locations are attributed to the desilting processes leading to nutrient release to water medium.

2. Phosphate

The phosphate concentration in the surface waters at the dredged sites during the postmonsoon of 1995 showed concentrations gradually decreasing as season advances (figure 11). But at the nondredged site (station 1) an increase in values occurred while at station 4, the tendency was as that of dredged sites. The observations at dredged locations during the premonsoon season (stations 2,3,5 & 6) showed non variability

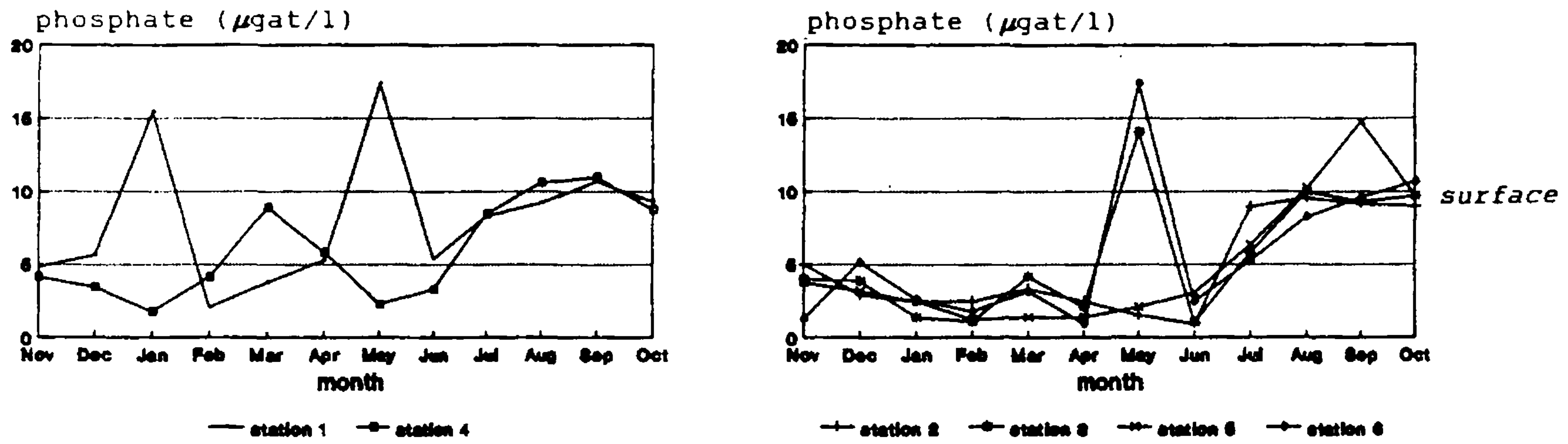
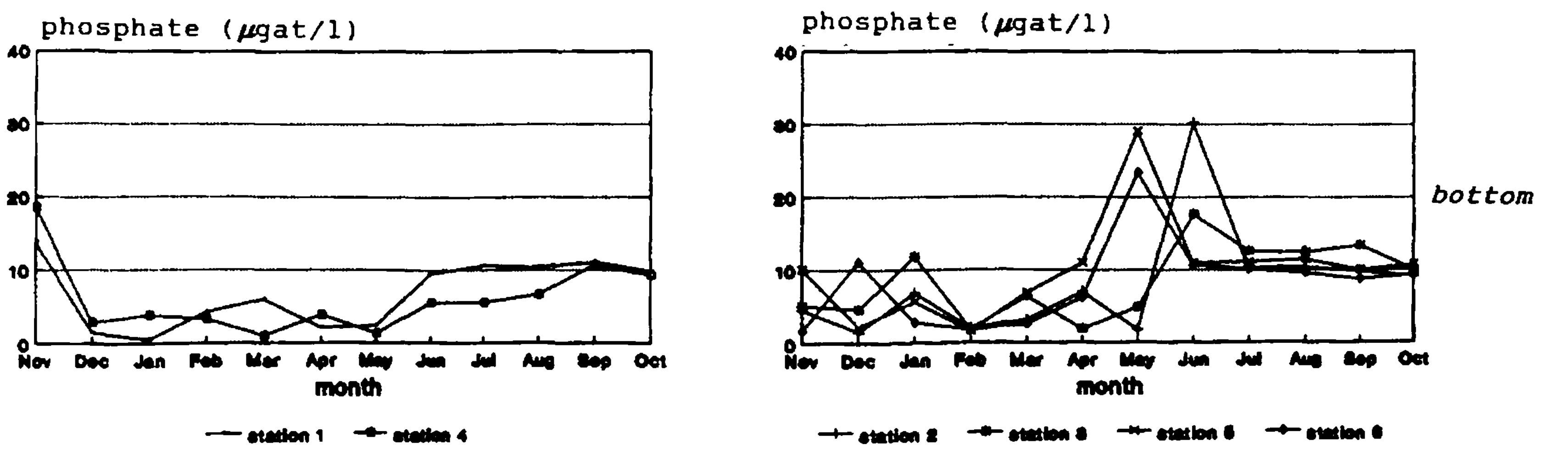


Fig. 11 Phosphate concentration at surface and bottom at nondredged (stations 1 & 4) and dredged locations (stations 2,3,5 & 6).



(1.32 to 4.17µgat/l) but there occurred a sharp increase in phosphate content in the last month of the season. At the nondredged site (station 1) a gradual increase was noted but at station 4, initially the content increased and thereafter showed a decline. During the monsoonal season, at the dredged location, a gradual increase of phosphate was observed (1.05 to 16µgat/l). A similar tendency was observed at the nondredged site also but the variability was restricted to 3.33 to 10.98µgat/l. This increase of phosphate concentration is attributed to the inputs into the estuary via rivers. The sharp reduction of phosphate just after the monsoon months indicate the consumption by way of enhanced productivity (Joseph, 1974; Nair & Balchand, 1993).

The bottom waters at the dredged site during the postmonsoon period of 1994 indicated more or less a constant range of values (< 12µgat/l) while that at the nondredged sites a decrease occurred as season advanced. During the premonsoon season, phosphate content showed a gradual increase at the dredged site followed by a tendency to largely increase. The content was low and non fluctuating at the nondredged sites. During late monsoon, bottom layers at dredged sites showed a constant value (9.58 to 12.56µgat/l) but at the nondredged site, a slight increase of value was noticed. The phosphate content does not however indicate wide changes in concentration between surface and bottom layers and trends at both depths are very similar.

A large increase of phosphate was observed at the both areas during the month of May 1995 which may be due to higher local inputs from municipal sewage or industrial wastes. In monsoon season. the surface phosphate content is more or less completely controlled by freshwater derived from the river systems ultimately reaching the estuary and as season advances, biological influence predominates in regulating the nutrient concentrations. The effect of dredging is however not very much evident in bring about release/adsorption of this category of the micronutrient.

H. CHLOROPHYLL

Microalgae constitute a major group of primary producers of any aquatic ecosystem. Quantification of these organisms often is a good estimate of the fishery potential of an aquatic system indirectly. Also studies on the seasonal and spatial variations of the biomass of these tiny plants would be recommendable for the assessment of man made alteration of particular ecosystem in question, that may result in considerable economic losses.

Studies on the biological parameters of Cochin estuary have already been carried out; such as plant pigments (Qasim and Reddy, 1967), light penetration (Qasim et.al., 1968), Nutrient cycle (Sankaranarayanan and Qasim, 1969; Manikoth and Salih, 1974; Joseph, 1974, Lakshmanan et al., 1987), seasonal abundance of phytoplankton (Gopinathan, 1972), spatial and temporal distribution of phytoplankton (Joseph and Pillai, 1975) and benthic microalgae (Sivadasan and Joseph, 1995). But practically no work has been done so far on the microalgal abundance in this estuary in relation to dredging and its effect on the environment.

1. Chlorophyll a

The analysis of chlorophyll a for a period of 12 months (November 1994 to October 1995) indicated that its concentration at nondredged locations (stations 1 & 4) showed typical seasonal variations, the highest values being recorded during the monsoon period (figure 12). The characteristic pattern of chlorophyll a distribution stands altered by dredging activities at dredged sites (stations 2,3,5 & 6) while at the nondredged stations distribution and magnitude in the chlorophyll a concentration at surface and bottom was more or less the same. Generally bottom samples were greatly affected by dredging than surface samples. The increase of microfloral biomass was indicated from chlorophyll a values as observed from bottom samples of dredged sites in comparison with nondredged sites. Slight decrease of chlorophyll a content was particularly noted for surface values of dredged site in comparison to bottom values. However, at all the dredged stations, it is noted that a seasonal monsoonal peak of chlorophyll a concentration in bottom samples occurred which may be due to the replenishment of bottom water with benthic microflora. Bottom samples generally gave higher values

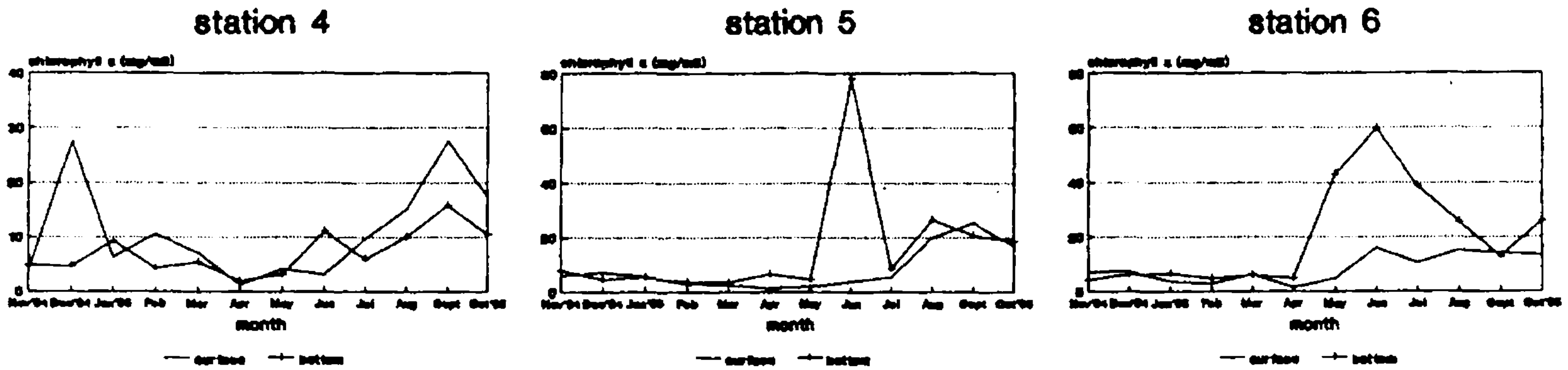
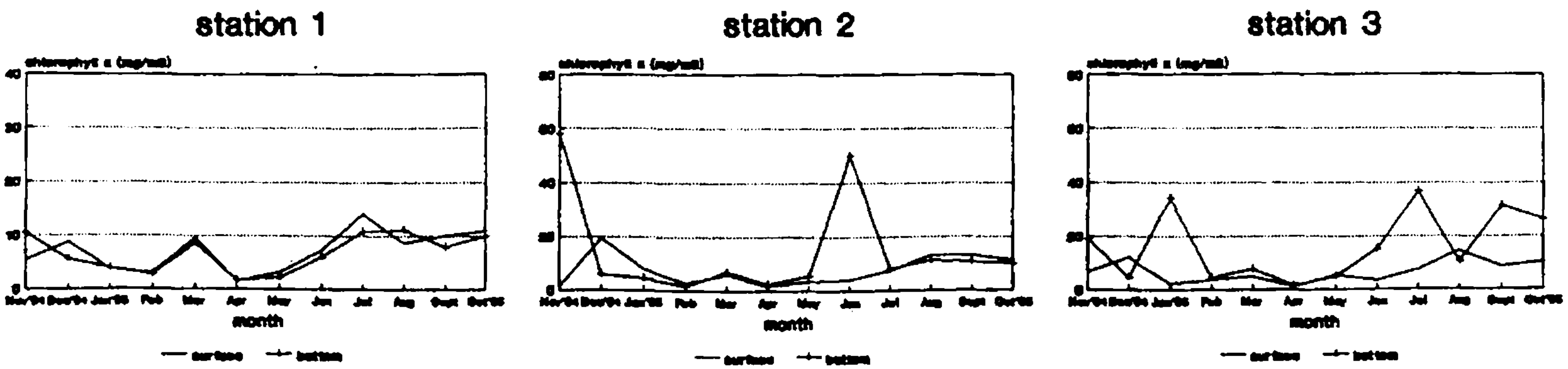


Fig. 12 Distribution of chlorophyll a (mg/m^3) at surface and bottom from November 1994 to October 1995 at stations 1 to 6.



(in mg/m^3) irrespective of nature of sites as is evidenced in the next paragraph.

Chlorophyll a in surface waters showed that, the average value at the nondredged site was a minimum (3.61) in the month of May 1995 and the maximum value was 18.90, observed during the month of September 1995. At the same type of location, seasonwise minimum value was noted during the premonsoon season (5.01) and the maximum was noted during the monsoon season (11.94). The annual average value was 9.15. At the dredged locations, the averages read as follows: minimum value was noted during April 1995 (1.38) and maximum value was noted during August 1995 (15.64) for surface. The seasonwise average minimum was noted during the premonsoon of 1995 as a value of 3.27 and the maximum was noted during monsoon season of 1995 (11.27). The annual average of the surface waters at the dredged location was 7.70.

In the bottom waters, the area greatly affected by dredging activities showed peculiar features. The average values of the nondredged sites, indicated that the minimum occurred during February 1995 (3.47). The maximum value was noted during the month of November 1994 as a value, 60.04. The seasonwise minimum was noted during the premonsoon period of 1995 (3.70), which was a period of intensive dredging activities. The maximum value was noted during the postmonsoon period (20.57). The annual average was calculated as 15.88. At the dredged locations, in the bottom waters, the average minimum value was noted during the month of February 1995 (3.59) and the maximum value (50.76) was noted during June 1995. The seasonwise minimum was noted during the premonsoon of 1995, the value bring 6.96 and maximum value in monsoon period (27.58). The annual average value worked out as 16.54, all above values in units mg/m^3.

2. Chlorophyll *b*

Chlorophyll *b* concentrations recorded at six stations were significantly less compared to that of other pigments (figure 13). Also significant differences were observed for pigments of chlorophyll *b* between dredged and nondredged sites. Bottom samples, gave clear monsoonal peaks at all dredged stations. Notably chlorophyll *b* bearing flora was most greatly affected by dredging and the effect was predominant in bottom waters.

Chlorophyll *b* content (again measured in mg/m^3) averaged in the surface waters of the nondredged site showed minimum values (below detection limits) during the months of December 1994, July and September 1995. The average maximum value was noted during October 1995 (3.75). The seasonwise average minimum value was noted during the monsoon period (0.44) and the maximum value was noted during the postmonsoon of 1994 (2.33). The annual average was accounted as 1.45. At the dredged stations, the average minimum was noted in during July 1995 (0.15) while maximum was noted the month of June 1995 (3.97). The seasonwise average minimum was noted during the monsoon period (1.29) and the maximum value was noted during the premonsoon period (2.18); the annual average was calculated as 1.72.

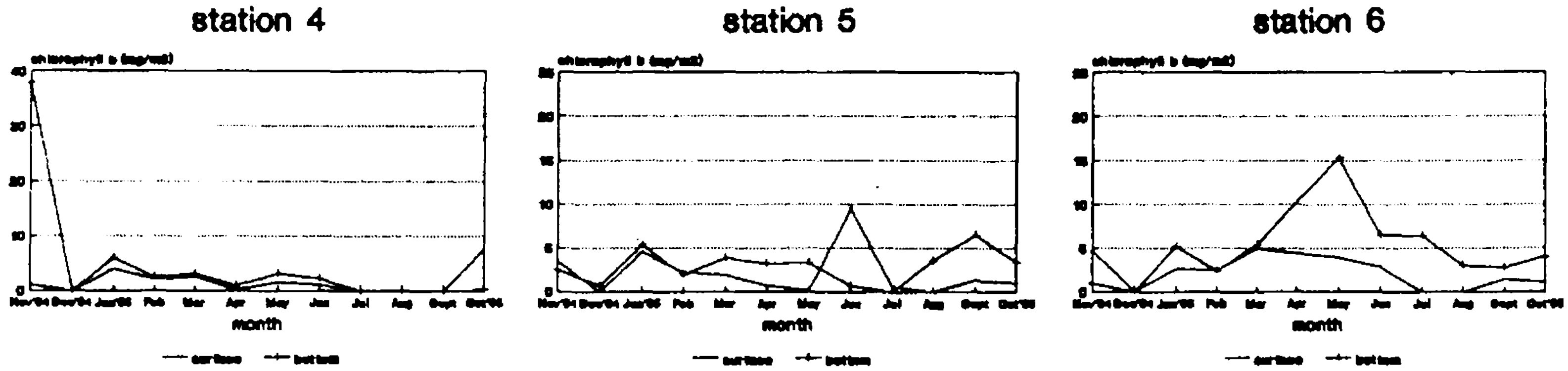
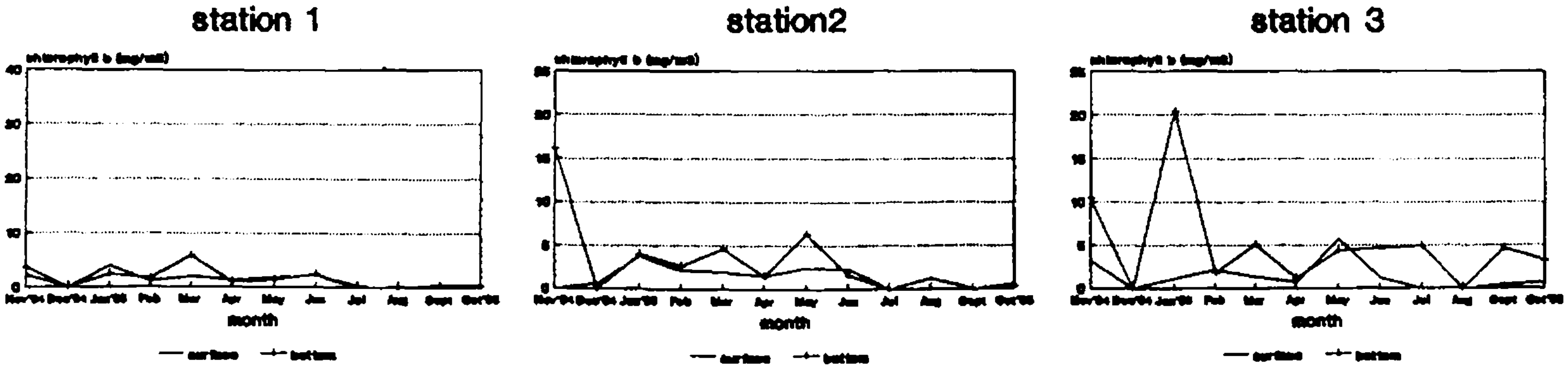


Fig. 13 Distribution of chlorophyll b (mg/m^3) at surface and bottom from November 1994 to October 1995 at stations 1 to 6.



In the bottom waters, averaged for the nondredged sites, the minimum value (below detection limits) was noted during the month of December 1994 and August 1995. The maximum value was noted during the month of November 1994 (20.85). The seasonwise minimum value was recorded during the monsoon season of 1995 (0.65) and the maximum value was noted during the postmonsoon period (6.33). The annual average was 3.13. At the dredged locations, the averages were as follows: minimum value was recorded during July 1995 as a value, 1.59 and the maximum was noted during the month of June 1995 (21.09). The seasonwise average minimum was recorded during the premonsoon season (4.02) and the maximum value was noted during the monsoon season (6.95). The annual average value was 5.25.

3. Chlorophyll *c*

Chlorophyll *c* is the less affected pigment due to dredging than chlorophyll *b* as studied from both surface and bottom samples of dredged and nondredged sites (figure 14). The content of chlorophyll *c* was mostly less than 15mg/m^3 except for occasional peaks during certain months and also it indicates that diatom flora was not influenced by dredging activities. The concentration of chlorophyll *c* was always higher than that of chlorophyll *b*. Higher value of chlorophyll *c* at both dredged and nondredged sites indicate substantial contribution of diatom from flora.

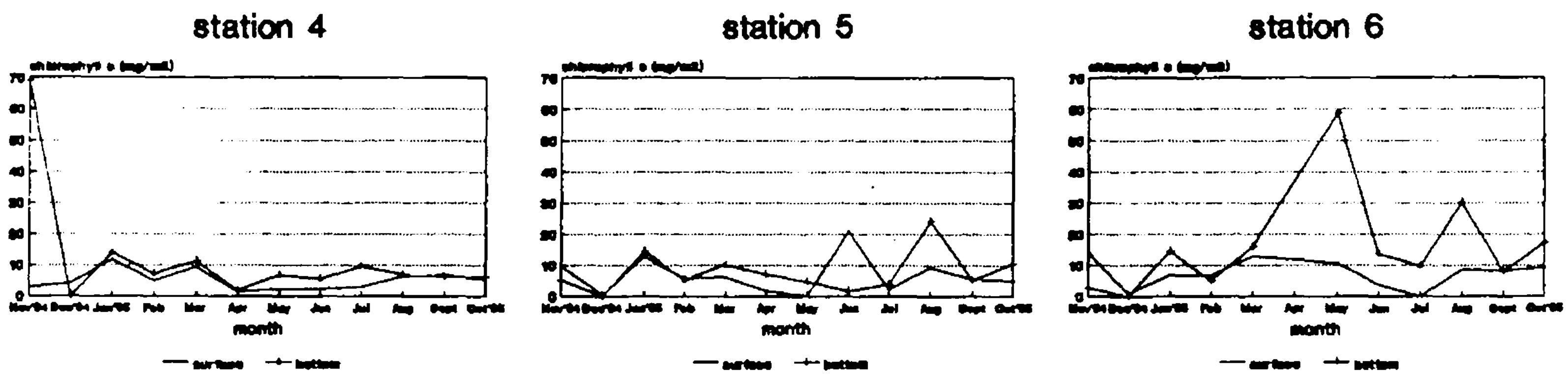
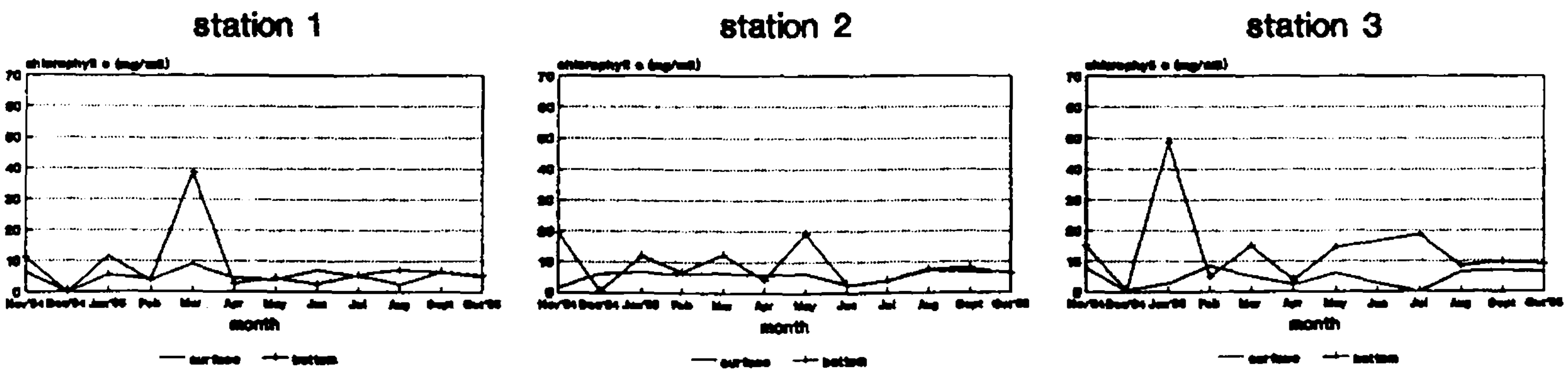


Fig. 14 Distribution of chlorophyll c (mg/m^3) at surface and bottom from November 1994 to October 1995 at stations 1 to 6.



In surface waters, average value(s) from the nondredged locations indicated that minimum occurred in the month of December 1994 (2.05) and the maximum value in the month of January 1995 (11.45). The seasonwise average value showed the minimum value (4.82) during premonsoon period while postmonsoon period recorded the maximum value as 5.81. The calculated annual average value was 5.18. At the dredged stations, minimum was noted during July 1995 (1.51) and the maximum value was noted during the month of November 1994 (8.18) being the averages of monthly surface values at stations 2,3,5 & 6. The seasonwise minimum was noted during the premonsoon period of 1995 (5.79) and the maximum value was noted in the postmonsoon period (6.00). The annual average was computed as 5.89.

The study based on the monthly averages of the bottom waters of the nondredged site indicated that the minimum value was (below detection limits) observed during December 1994 and the maximum value was noted during the month of March 1995 (24.89). Seasonwise minimum was noted during monsoon season as a value of 6.18 and maximum was noted during the postmonsoon of 1994 (13.95) while the annual average was 9.88. Averages from the dredged sites indicated that the minimum occurred during December 1994 (0.24) and maximum in May 1995 as a value of 24.26. Seasonwise minimum was noted during the postmonsoon of 1994 (8.27) and the maximum value was noted during the premonsoon period (11.76). Annual average works out to be 10.83, all above values represented in mg/m^3.

4. Chlorophyll *c*/Chlorophyll *a*

Computation of chlorophyll *c*/chlorophyll *a* have been attempted and when the values are less than unity, it is an indication of rather a healthy crop. Sivadasan and Joseph, 1995 have opined that in estuarine waters the ratio of Chlorophyll *c*/ Chlorophyll *a* is often an indication of the crop activities and also points to the environmental health under condition of external stress. During the dredging period (moderate to intensive) the values above unity is thence an indication of rather unhealthy crop as read for surface waters. The bottom waters, of the dredged site too showed the values were above unity (>1.5) during such times of intensive dredging. When comparing the chlorophyll *b*/chlorophyll *a* ratio to the above it was noted that chlorophyll c bearing flora significantly contributed to the standing crop of the investigating area than pigments of chlorophyll *b* linkage. *In situ* bioassessment of dredging at Toronto harbour had approached the problem by considering the ratios of planktonic abundance inorder to differentiate the relative effects of desilting (Munawar et al., 1989)

I. BOTTOM FAUNA

The macrobenthic organism was selected for study because they are permanent inhabitants of the sediments with low mobility and good indicators of the conditions prevailing in the area being studied. In addition they are also an important source for estuarine food chain (Jones and Candy, 1981). Bottom fauna spend most of their life within the substratum. The physical and chemical characteristics of the sediments and its change may be of great significance while studying the bottom fauna (Damodaran, 1973). During dredging operations, the substratum get disturbed, thereby affording a chance for the inhabitants to migrate into deeper layers or nearby areas or they may face mortality.

The studies by Rosenberg (1977) and Jones and Candy (1981) had suggested that the benthic fauna of dredged areas differs from that of the nondredged areas with respect to species composition and diversity. Jones and Candy (1981) also narrated the variation of sediment texture during dredging. Long term studies on dredging conducted by May (1973) had indicated that it may cause a variety of ecological changes depending on the area and the extent of dredging.

Polychaetes were the dominant group during the study period (Table 5). Altogether eight species were identified upto the genera named as Amphinome Sp, Maldanid family, Nephthys Sp, Neries Sp, Prionospio Sp, Rhamphobrachium Sp, Lumbriconeries Sp and Glycera Sp. Crustaceans ranked second which include Prawn juveniles, Amphipods and Isopods. Nematodes were also observed during the study period at some stations in few numbers. It may be noted that, Table 5 includes monthwise data from November 1995 to October 1996 at stations 1 to 6 excluding monthly results of the preceeding year. In many an instance, organisms were not

Table 5
Number of organism per 0.05m2 during 1995 to 1996

Month ->	November 1995						December 1995						January ' & February 1996				
Stations ->	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5
Species																	
A. Annelida - Phylum																	
Polychaeta - Class																	
Amphinome SP	-	-	-	-	-	-	-	-	-	-	-	-					
Maldanid (Family)	-	-	-	-	-	-	-	-	-	-	-	-	organism				
Nephthys Sp	3	1	-	-	-	-	-	1	1	1	2	-	not observed				
Neries Sp	-	-	-	-	-	-	4	-	-	-	-	-					
Prionospio Sp	-	-	-	8	-	-	4	-	4	-	-	-					
Rhomphobrachium Sp	-	-	-	-	-	-	-	-	-	-	-	-					
Lumbriconeries Sp	-	-	-	-	-	-	-	-	-	-	-	-					
B. Crustaceans																	
Prawn (juveniles)																	
Amphipod	1	-	-	2	-	-	-	-	-	-	-	-					
Isopods	-	-	-	2	-	-	-	-	-	1	-	-					
C.Nematode	-	-	-	-	-	-	1	-	-	-	-	-					
Total ->	4	1	-	12	-	-	9	1	5	2	2	-	-36				

Month ->	March 1996						April 1996						May 1996
Stations ->	1	2	3	4	5	6	1	2	3	4	5	6	
Species													
A. Annelida - Phylum													
Polychaeta - Class													
Amphinome Sp	-	1	-	-	-	-	-	-	-	-	-	-	organism
Glycera Sp	-	-	-	-	-	-	-	-	-	-	-	-	not observed
Maldanid (Family)	2	1	-	3	-	-	-	-	-	-	-	1	
Nephthys Sp	2	2	-	2	1	-	2	2	1	-	-	2	
Neries Sp	2	1	-	3	-	-	-	-	-	-	-	-	
Prionospio Sp	2	2	-	2	2	-	1	3	-	-	-	-	
Rhomphobrachium Sp	-	-	-	-	-	-	-	1	-	-	-	-	
Lumbriconeries Sp	-	-	-	-	-	-	-	-	-	-	-	-	
B.Crustacean	-	-	-	-	-	-	-	-	-	-	-	-	
Prawn (juveniles)	-	1	-	-	-	-	-	-	-	-	-	1	
Amphipod	-	-	-	-	-	-	-	-	-	-	-	-	
Isopods	-	-	-	-	-	-	-	-	-	-	-	-	
C.Nematode	-	-		-	-	-	-	2	-	-	-	-	
Total -->	8	8	-	10	3	-	3	8	1	-	-	4	45

(con't...2)

Number of organism per 0.05m2 during 1995 to 1996

Month ->	June 1996						July 1996						August 1996					
Stations ->	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Species																		
A. Annelida - Phylum																		
Polychaeta - Class																		
Amphinome Sp	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	1	-	-
Glycera Sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maldanidae (Family)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-
Nephthys Sp	-	-	-	-	-	-	4	-	-	-	2	-	4	-	-	9	-	-
Neries Sp	-	-	-		-	-	11	-	-	-	-	-	-	-	-	1	-	-
Prionospio Sp	-	-	-	-	-	3	-	2	-	-	-	-	-	3	-	-	-	-
Rhomphobrachium Sp	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Lumbriconeries sp Sp	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
B.Crustacean	-	-	-	-	-	-		-	-	-	-	-						
Prawn (juveniles)	-	2	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
Amphipod										-								
Isopods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	2	-
C.Nematode	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total -->	-	2	-	-	-	6	16	2	-	-	3	-	4	6	-	23	2	--> 64

Month ->	September 1996						October 1996						
stations ->	1	2	3	4	5	6	1	2	3	4	5	6	
Species													
A. Annelida - Phylum													
Polychaeta - Class													
Amphinome Sp	2	-	-	-	-	-	-	-	-	-	-	-	
Glycera Sp	-	-	-	-	-	-	-	2	-	-	-	-	
Maldanid (Family)	-	-	-	-	-	-	-	-	-	-	-	-	
Nephthys Sp	4	-	-	2	-	1	-	-	2	2	-	-	
Neries Sp	-	-	-	-	-	-	1	2	11	2	-	-	
Prionospio Sp	-	3	-	2	-	-	-	12	4	5	-	-	
Rhomphobrachium Sp	-	-	-	-	-	-	-	-	-	-	-	-	
lumbriconeries Sp													
B.Crustacean													
Prawn (juveniles)	-	-	-	2	-	-	-	-	-	-	-	-	
Amphipod	-	-	-	-	-	-	9	-	-	-	-	-	
Isopods	1	-	-	-	-	14	2	-	-	17	-	-	
C.Nematodes	-	-	-	-	-	-	-	-	-	-	-	-	
Total ->	7	3	-	6	-	15	12	16	17	26	-	-	--> 102

observed or were scanty at the dredged locations. From the nondredged locations the species identified falls in the species group given above.

In November 1995, the dominant group was Polychaetes which were observed at the non dredged site of station 1 & 4. The Crustaceans ranked the second. In studies held at dredging area, only one Polychaete belongs to Nephthys genera was observed. The species diversity was greater at station 4 (0.87) compared to station 1 (0.56) (Table 6). No species were present at stations 2,3,5 & 6 located in the dredging area. The reduction of the number of organism at the dredging site may be due to inhibition caused by dredging activities (increase of turbidity) which would disturb the entire bathymetry of the navigational channels.

During the month of December 1995 also, Polychaetes were dominant over other groups of very low representation from Crustaceans and Nematodes. The Crustaceans and Nematodes were represented by only a single specimen each. The dredged site showed a slight increase in number of organisms especially in Polychaetes which indicate the onset of colonization at the dredged site. In station 1 of the nondredged site, an increase of number was noted while station 4 showed a decline. Higher species diversity was noted at station 1 (0.96) followed by station 4 (0.69) and station 3 (0.50). No species were present at stations 2, 5 & 6 of the dredging sites.

Table 6: Species diversity during 1995 to 1996

Month -->	November 1995	Decmeber 1996	March 1996	April 1996	June 199
stns	S.I.*	S.I.*	S.I.*	S.I.*	S.I.*
1	0.56	0.96	1.38	0.64	-
2	-	-	1.73	1.32	-
3	-	0.50	-	-	-
4	0.87	0.69	1.37	-	-
5	-	-	0.56	-	-
6	-	-	-	1.04	1.01

Month -->	July 1996	August 1996	September 1996	October 1996
stns	S.I.*	S.I.*	S.I*	S.I.*
1	0.78	-	0.96	0.72
2	-	0.69	-	0.74
3	-	-	-	0.49
4	-	1.27	1.09	0.99
5	0.6	-	-	-
6	-	-	0.24	-

* S.I. (Shannon Index)

During January and February 1996, no organisms were observed at any of the stations (of both sites) which leads to indicate the inhibition of organism growth/propagation or mass destruction, reasons beyond the comprehension of this investigation.

During March 1996, Polychaetes dominated at both types of sites. Members from Maldanid family, Nephthys and Prionospio species were dominating. The Crustaceans were represented by a single juvenile prawn. At the dredged sites (stations 3 & 6) no organisms were observed. The dredged sites (stations 2 & 5) showed a less number of animals compared to the nondredged sites of stations 1 & 4. The species diversity was greater at station 2 (1.73) than station 1 (1.38) followed by stations 4 (1.37) & 5 (0.56).

In the month of April 1996, Polychaetes were dominant. The juvenile prawn and Nematodes also were observed during this month and are represented each by single specimen. Of particular interest is that the dredged sites showed an increase in number of animals compared to the nondredged sites which indicate rapid recolonisation of organisms due to the stoppage of dredging. The species diversity indices also showed higher value (1.32) at station 2 than station 1 (0.64). Station 6 gave a value of 1.04.

During the month of May 1996 no organism was observed at any stations which is likely linked to the extensive dredging activities of the previous month. Also this may be due to the acute anaerobic bottom conditions that rarely develop in the estuary or may be due to the migration of organism due to unfavorable conditions such as sudden fluctuations in salinity or temperature.

During the monsoon season, generally the dredging activities are largely intermittent or stopped due to bad weather conditions: the channel (maximum) depths do not shallow off during monsoon season due to presumably less extent of siltation in higher runoff conditions in the inner two channels. The intensive dredging just prior to the monsoon season often causes reduction in number of organisms. It is also noted to change many bio-geo-chemical characteristics of the estuary. As far as the physical features are concerned the salinity stratification, temperature, suspended load as bed material and that in suspension and current structure change in accordance with the river inputs and tidal conditions. Large inputs of freshwater entering the estuary through rivers have a definite influence on the change in the sedimentation pattern (Sundaresan, 1989). The stability of the substratum also changes due to wave action and current pattern leading to the formation of a nepheloid layer(s) (Chandramohan, 1989; Rasheed et al., 1995a). During the month of June 1996, at the dredged sites (3 & 5) and nondredged sites(1 & 4) no organisms were observed, but at stations 2 & 6 of dredged sites the presence of polychaetes and Juvenile prawns were noted. The species diversity was observed only at station 6 (1.01) of the dredged location.

During July 1996, Polychaetes dominated the estuarine locations. Higher number ($16/0.05m^2$) of organisms were observed at station 1. Among this, Neries were represented by a total of 11 individuals. This indicates the recolonisation after the substratum failure. But at station 4 of the nondredged site no animals were present. The dredged sites of station 2 & 5 showed the presence of Polychaetes. Obviously higher species diversity was observed at station 1 (0.78) followed by station 5 of the dredged site.

At the nondredged sites, in August 1996, the presence of large number of organisms including Polychaetes and Isopods were noted. The number of organisms were large compared to the previous month of monsoon. The nondredged area at station 4 showed slow recolonisation after the substratum failure. The higher species diversity was obtained at station 4 (1.27) followed by station 2 of the dredged site.

September 1996 exhibited presence of Crustaceans, dominating among the bottom fauna. The dredged site showed an increase of organisms than the nondredged site a time when dredging has to recommence after monsoon break. Isopods were observed at station 6, and they numbered 14. But the species diversity was higher at station 4 (1.09) followed by station 1 (0.96). The dredged site of station 6 gave a diversity index of 0.24.

Studies in October 1996 indicates a condition of maximised benthic growth prior to the commencement of dredging activities.

The observations were made just before the commencement of dredging. The Polychaetes ranked first and Isopods & Amphipods second. The observation indicates that the colonization was maximum prior to dredging. At stations 5 & 6 however no organisms were observed. A higher species diversity was observed at station 4 (0.99) followed by station 2 (0.74) and station 1 (0.72). The above conditions are to revert back to a situation often observed during postmonsoon seasons when dredging activities will intensify in the harbour area.

CHAPTER 4

SHORT TERM SYSTEMIC CHANGES

This chapter incorporates the results on the studies conducted in the estuary to cover three aspects, all of them related to short time scales and impacts thereof due to dredging. This include the development of turbidity maxima during a salt silt wedge in one of the channels, the short term impacts of dredging by means of few selected parameters and a special study on capital dredging. Discussion on the above aspects are also included in this chapter.

A. SALT SILT WEDGE AND TURBIDITY MAXIMA

1. INTRODUCTION

The study on sedimentation in Cochin harbour is reckoned as important for the uninterrupted marine traffic operations; in this context, sediment characteristics and development of turbidity maxima in the estuary (Balchand et.al., 1991) has special significance. The development of turbidity maxima composed of suspended particulate matter (SPM) have been studied in several estuaries by earlier workers like Officer and Nichols (1980); Officer (1981); Uncles and Stephens (1993). According to Uncles and Stephens (1993), who had conducted surveys in the Tamar estuary and noted that the tidal currents and runoff have key roles in controlling the turbidity maxima. The suspended solids content and its distribution in Cochin estuarine harbour widely varies according to tides and seasons. According to Gopinathan and Qasim (1971) during the pre and postmonsoon months, the total material transported from the sea into the backwaters amounts to approximately 900 tonnes/day. They have also stated the possibilities of the transportation of suspended solids into the sea from the backwaters during the monsoon months as suspended solids. Anto et al. (1977) has described that the main source of silt to the outer harbour comes from the backwaters and the offshore regions. Seawater driven by tidal currents and outgoing river water often interact at the Cochin estuarine harbour inlet, and the development of suspensate as a turbidity maxima have wide implications in traffic operations vis-a-vis dredging activities (Sundaresan, 1989; Shibu et al., 1990). A study was conducted in the Ernakulam channel near Dufferin point on 12/04/94 on R.V. Nautilus equipped with a Savonious current meter, temperature-salinity bridge and turbidity meter. The parameters selected were tide, salinity, turbidity and current, sampled at an interval of 10mts from 9 a.m. to 6.40 p.m. at the surface (1m), middle (4.5m) and bottom (9m) at a location where station depth was 11m.

2. RESULTS

The study was conducted during the premonsoon period. According to Joseph and Kurup (1989) & Balchand and Nair (1994) the fresh water influence at Ernakulam channel is a minimum during the premonsoon period. The fresh water discharge increases by the onset of monsoon from June onwards and decreases by the end of monsoon (September) during most years. The figure 15 gives the observed tide profile during the time of the survey. The variation of salinity, turbidity (suspended solids) and current during the flood phase, slack period and ebb phase are also given in this figure.

The study showed that the surface salinity value gradually increased throughout the flood phase, then attains a constant value and starts to decrease during the ebb phase. The observation further indicated that the middle and bottom salinity values were slightly higher in the initial flood phase than the surface value but reached a constant value (32.0) as that at the surface during slack period. Finally during the ebb phase the surface salinity gradually reduces but the middle and bottom values more or less remain a constant as observed from the figure. The minimum salinity value observed at the surface, middle and bottom were 18.2, 22.2 and 22.6 while that of maximum was 32.1, 32.2 and 32.2 respectively. This indicates that the development of partially mixed conditions in and around the vicinity of observation area in this estuary.

This study confirmed that the distribution of suspended solids during the period of study at the surface was more or less the same (figure 15). The middle and bottom content however showed an increase during the propagation of high tide. Immediately after the high slack, suspended solids showed no significant variations which is evidenced in the above figure.

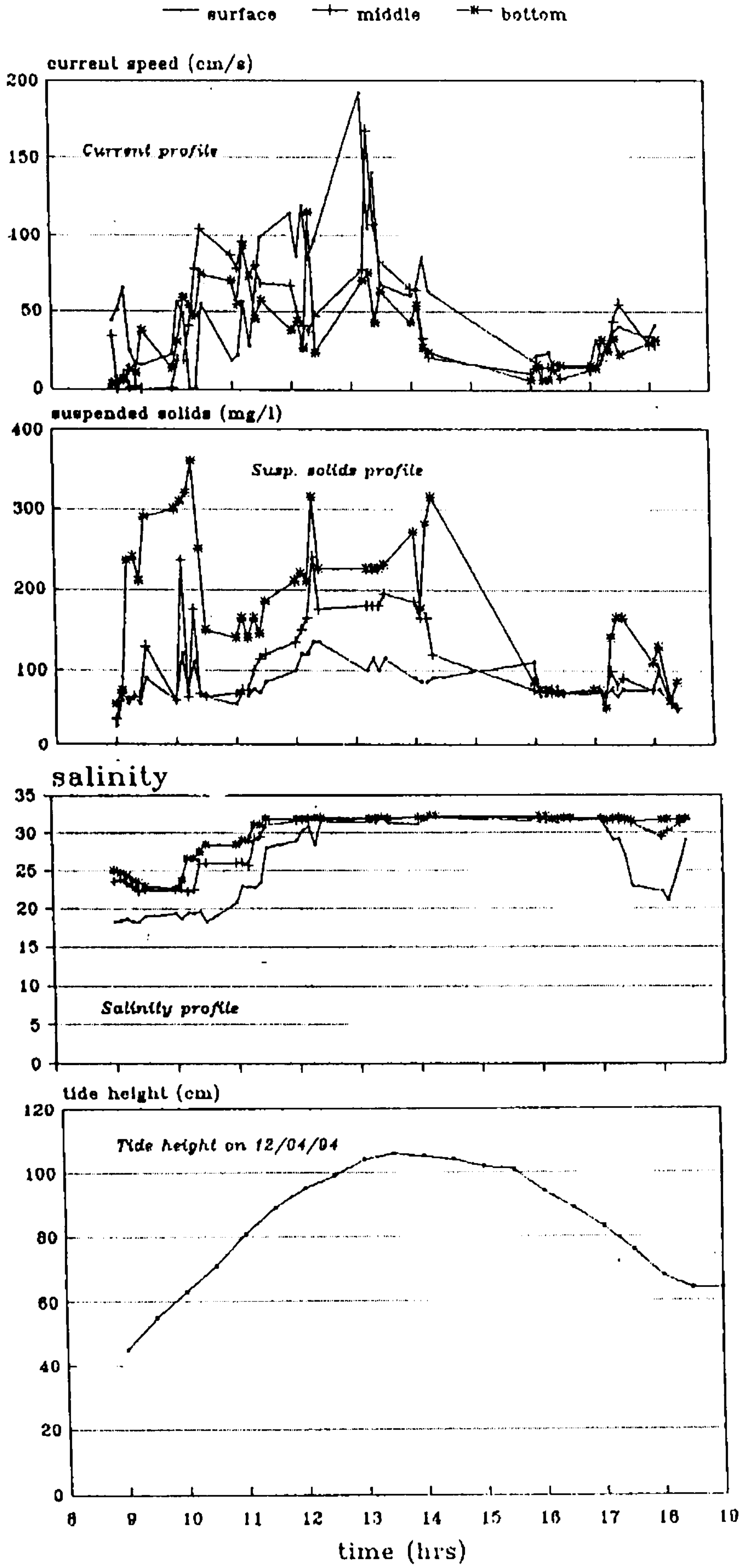


Fig. 15 Observed tide profile, salinity, suspended solids and current speed on 12-04-94 at surface, middle and bottom.

The maximum value of suspended solid content was observed at the bottom (300-360mg/l) during the high tide phase and this feature affirms that the turbidity maxima development is partial from the seaward contribution of particles and that trapped from riverine origin. On reversal of tide to low, the material is transported out to the sea and the suspended solid content dropped to very low value. The study of the current profiles also showed features in tune to that of suspended solids (figure 15). Comparing the current vectors with that of suspended solids and salinity, the development of salt silt wedge is well represented diagramatically. The incidence of high tide brings an increase of salinity and suspended solids at the middle and bottom and the salinity values reduces under the influence on freshwater derived from the land origin during the ebb phase.

From the above study it is concluded that siltation in Cochin harbour would likely take place just at and after the high slack during the premonsoon season. The incoming suspended solids from the seaward side traverse upstream of Ernakulam channel and suspended solids content remains a constant at surface and middle layers while increase at bottom during the high slack period towards the upstream regions of the channel as observed during the study (figure 16). Further it may be noted that part of the seaborne material would settle within the estuary whereas the rest of the sedimenting solids may be of riverine origin subjected to seasonal changes influencing input quantities and state of stratification in the estuary.

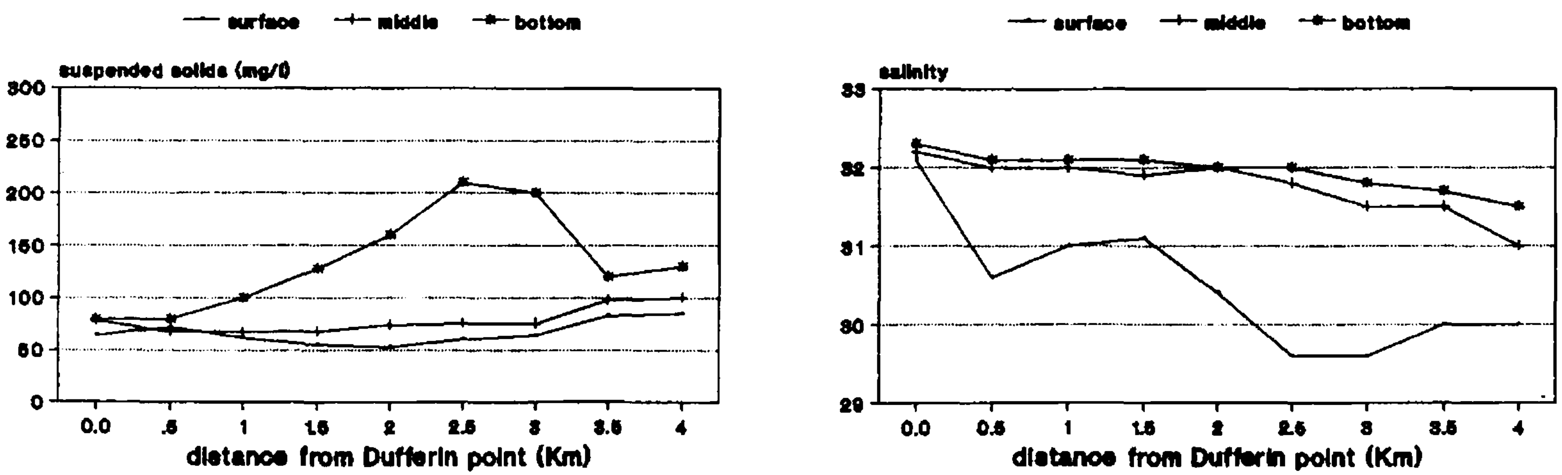


Fig. 16 Distribution of suspended solids and salinity upstream of Dufferin point in surface, middle and bottom.

B. SHORT TERM IMPACTS OF DREDGING

The main objective was to prepare a short term impact assessment of dredging which would reflect on environmental responses in a short time scale. For the above purpose, nine stations were selected within the Mattancherry ohannel and eight parameters were thoroughly monitored before, during and after dredging (see figure 2). The dredging operations were held at station 5 and at its very immediate vicinity. This site was chosen considering the fact that dredging operations were not held at or in the larger vicinity since more than three weeks affording the scope of this study. The parameters monitored were current speed and direction (at 2m interval in the vertical), salinity (surface, middle and bottom), turbidity (at 2m interval in the vertical), transparency, nutrients (surface and bottom), chlorophyll *a,b,c* (surface and bottom) and bottom fauna.

1. CURRENTS

The short term impact of dredging was studied during the ebb phase of the tide during premonsoon. The observed current vectors during the study period is shown in table 7. The surface current speeds prior to the commencement of dredging (09/01/96) was high compared to the bottom values at almost all the stations. The bottom of all the stations indicated low current speeds (< 20 cm/s) which points out to the penetration of the tide along the bottom and flow at the surface was directed seaward. The current

Table 7 Values of current vectors at 2m interval at stations 1 to 9 selected for short term impact study.

		09/01/96		10/01/96		11/01/96	
stns	depth(m)	vel. (cm/s)	dirn.[x]	vel (cm/s)	dirn.[x]	vel. (cm/s)	dirn.[x]
	0	18	235	28	014	36	328
	2	3	230	19	023	12	013
1	4	6	041	12	027	8	012
	6	5	336	8	216	15	040
	8	9	087	14	218	15	192
	10	10	100	16	200	13	216
	0	16	012	14	346	23	004
	2	16	035	13	326	13	011
2	4	5	070	5	336	13	061
	6	9	241	5	273	18	166
	8	14	129	11	247	22	192
	10	14	114	5	225	20	197
	0	52	138	26	039	24	048
	1	18	106	-	-	-	-
3	2	16	070	12	331	13	051
	3	19	109	-	-	-	-
	4	16	124	14	302	14	069
	5	16	154	-	-	10	085
	6	-	-	14	272	15	026
	8	15	155	15	208	17	028
	10	16	154	12	206	18	023
	0	21	016	16	050	24	322
	1	14	044	-	-		-
4	2	7	063	8	307	22	330
	3	7	067	-	-		
	4	12	100	15	128	21	084
	5	11	104	-	-	15	060
	6	-	-	12	264	13	098
	8	13	105	12	270	15	060
	10	15	106	16	307	20	100
	0	19	012	12	341	25	323
	2	12	020	16	335	12	035
	4	14	034	17	284	17	069
5	6	11	028	16	285	18	103
	8	19	084	14	264	15	340
	10	4	232	13	305	15	045

(con't..2)

stns	depth(m)	vel. (cm/s)	dirn.*	vel (cm/s)	dirn.*	vel. (cm/s)	dirn.*
	0	11	096	19	228	24	026
	2	11	091	31	257	13	071
6	4	11	006	13	286	24	191
	6	11	300	34	311	26	194
	8	14	236	141	271	29	226
	10	13	236	22	239	22	219
	0	25	035	34	186	21	112
	2	12	338	16	220	23	206
7	4	7	320	17	232	28	209
	6	7	256	23	228	22	200
	8	15	191	23	278	20	188
	10	17	178	17	271	21	170
	0	12	046	14	180	16	008
	2	7	073	18	220	14	335
8	4	11	219	15	210	19	214
	6	18	205	18	206	5	269
	8	12	201	16	227	8	207
	10	15	175	14	225	10	210
	0	13	007	10	220	12	034
	2	10	003	10	240	10	318
9	4	13	243	17	228	23	246
	6	12	233	13	232	25	217
	8	11	226	9	229	23	224
	10	12	237	7	227	12	217

(* direction in degrees)

vectors are multidirectional when viewed from surface to bottom due to the inward and outward flow of estuarine waters.

During the time of dredging (10/01/96), the tide was in the same phase as that of the previous day. The current vectors indicated more or less similar features as that of the observations made before dredging (previous day). Almost at all the depths, low (1 to 20cm/s) and intermediate current vectors (21 to 60cm/s) were observed. Along the bottom, the range of current speed was minimum almost at all the stations (<15cm/s) compared to the higher surface values.

After the dredging operations, observations were made on 11/01/1996, when the tidal conditions were once again very nearly similar to the two prior days. The surface current vectors showed a slight increase in values, but at all other depths, current speed gradually decreased with increase in depth. The direction of vectors were again multidirectional due to the prevailing ebb tide conditions.

2. SALINITY

Salinity was also measured along with currents before (09/01/96), during (10/01/96) and after (11/01/96) the dredging operation. The salinity values during the study period is given in table 8. The changes in salinity was very limited in the context of dredging operations. Before the dredging operations the surface salinity at all the stations showed high values (>27.0) except at station 7 where it was 21.0. The mid depth

Table 8

Salinity values before, during and after dredging

station	location	9/1/96	10/1/96	11/1/96
	surface	30.0	33.0	32.5
1	middle	31.5	33.0	32.5
	bottom	32.0	33.0	32.5
	surface	32.0	29.0	32.0
2	middle	34.0	30.0	33.0
	bottom	35.0	32.0	33.5
	surface	33.5	29.0	33.0
3	middle	33.0	30.5	33.0
	bottom	32.0	31.5	33.0
	surface	33.0	30.0	33.0
4	middle	33.5	31.0	33.0
	bottom	33.5	32.0	33.5
	surface	33.0	27.0	34.0
5	middle	33.5	29.5	34.0
	bottom	34.0	31.0	34.0
	surface	32.0	26.5	31.5
6	middle	32.0	28.0	33.0
	bottom	32.0	31.5	34.0
	surface	21.0	28.0	35.0
7	middle	27.0	30.0	34.0
	bottom	33.0	32.0	33.0
	surface	30.0	28.0	28.0
8	middle	32.0	30.0	30.0
	bottom	34.5	31.0	33.0
	surface	27.0	29.0	30.0
9	middle	29.0	30.0	31.0
	bottom	31.0	32.0	31.5

salinity values gradually increased (31.5 to 34.0) except at station 7 (27.0). At the bottom layer, salinity gradually increased from 31.0 to 34.00. At the time of dredging, the observations were made at the ebb phase of the tide and no appreciable changes in salinity was observed but at station 1, salinity was constant with depth. The day after dredging, the observations on salinity showed no conspicuous changes - the salinity distribution maintained the same pattern as the days before and during dredging. At this estuarine harbour, salinity fluctuations are the resultant of tidal-freshwater interactions, seasonwise.

3. TURBIDITY

The most commonly observed changes in water quality during dredging is the rapid increase in turbidity. This aspect is very important in estuarine and coastal waters as the tropical estuaries receive and store large amounts of suspended load from perennial rivers. Likewise, Cochin estuary also receives large amounts of river inputs from Periyar on north and Muvattupuzha on south and Pamba, Manimala, Meenachil, and Achankovil on a seasonal basis which leads to siltation at the harbour region. Previous studies had indicated that the natural turbidity in the surface waters of this harbour was less than 30mg/l (Gopinathan and Qasim, 1971). Of course, in monsoon, the load content may go upto values like 100-120mg/l or more.

In order to study the short term impact on turbidity due to dredging, at station 1, the observations before the commencement of dredging showed that turbidity do increase with increase in depth (surface < 5mg/l; middle 20-30mg/l and bottom 30-40mg/l). But during the time of dredging, the turbidity showed a sharp increase which is clearly observed from figure 17. The turbidity values at certain depths were more than 100mg/l, which is generally detrimental to the aquatic organisms. After the stoppage dredging, the turbidity values showed a decrease to normal values. At station 2, similar features and range of values were observed - even higher values like 300mg/l at the time of dredging. At station 3, during dredging the surface turbidities increased to more than 120mg/l; however at bottom, a decrease of turbidity was observed during the same time. During dredging, turbidity increased towards the bottom with peak values at certain subsurface layers at station 4. At stations 5 & 6, turbidity sharply increased with depth during the time of dredging and most of the values were above 60mg/l. Interestingly, station 7, located upstream of the dredging site did not show an increase in turbidity during the time of dredging. At station 8 an increase of turbidity up to 4m was noted during the time of dredging but no change was noted for greater depths. An increase of turbidity was noted at all depths except at surface during the dredging time at station 9. The facts points out to upstream stations (7 to 9) not being affected due to the stage of tide, i.e. ebbing phase.

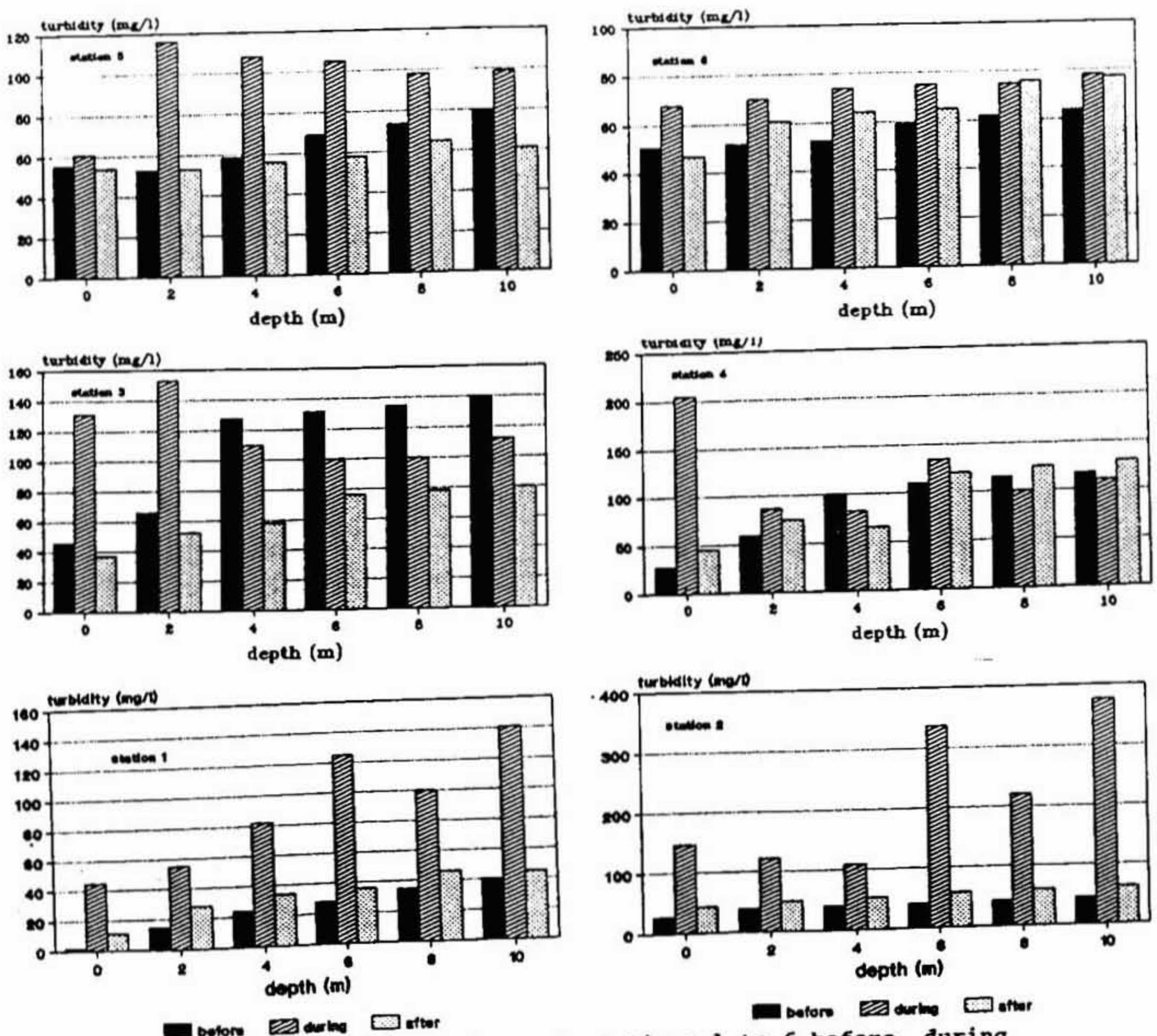


Fig. 17 Turbidity values at stations 1 to 6 before, during and after dredging (Con't...)

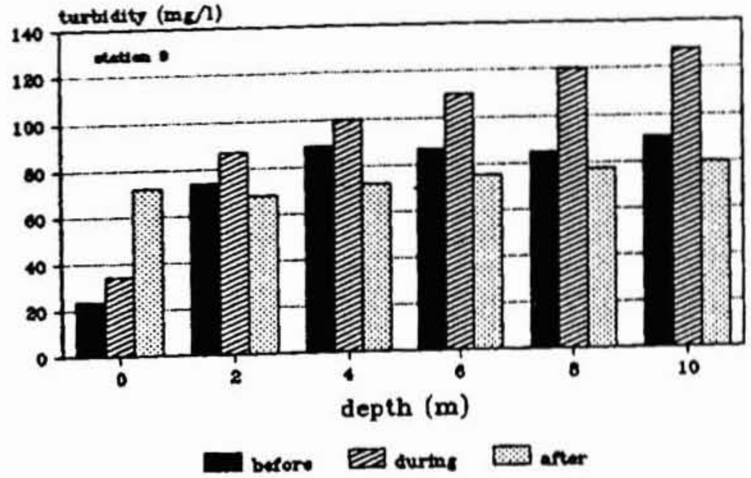
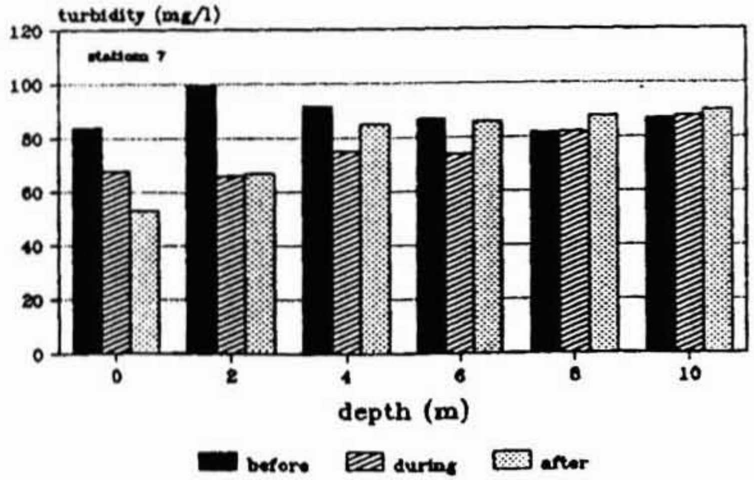
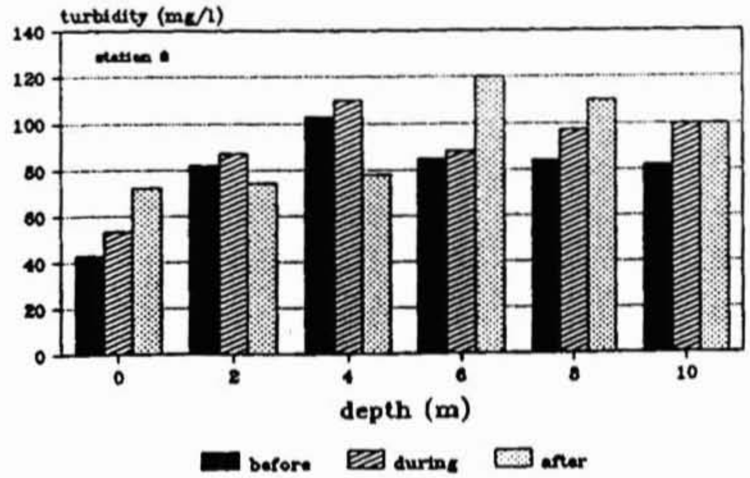


Fig. 17 Turbidity values at stations 7 to 9 before, during and after dredging





From the above results, it is ascertained that change of water quality due to dredging will not have a permanent impression. The turbidity change were transient and localized. But the main concern will be as to know how it affects the biota. Certain earlier studies have revealed that some of the estuarine and coastal organisms (may have) adapted to a small change of turbidity but rapid changes of above nature in a particular range may have highly detrimental effect to the propagation of organisms, especially on its growth and reproduction (Sherk, 1971). The increased turbidity will also adversely affect the production of phytoplankton as it reversely interferes with photosynthesis by limiting light penetration. These facts have been documented earlier (Bray, 1979, Johnston Jr., 1981) but is not attempted as part of this study. The benthic algae are particularly susceptible to inhibition due to decreased light intensity (Windom, 1976) and the increase of turbidity probably will affect fish gills by its clogging action and it can also clog the membranes of filter feeding organisms (Bray, 1979).

4. TRANSPARENCY

The short term impact on transparency/extinction coefficient at the dredging site were also conducted for three days, i.e before (09/01/96), during (10/01/96) and after (11/01/96) dredging operations. The variation of extinction coefficient during the period of study is as shown in figure 18 as 2D plots made at 0.5 interval. The values are also provided in the table

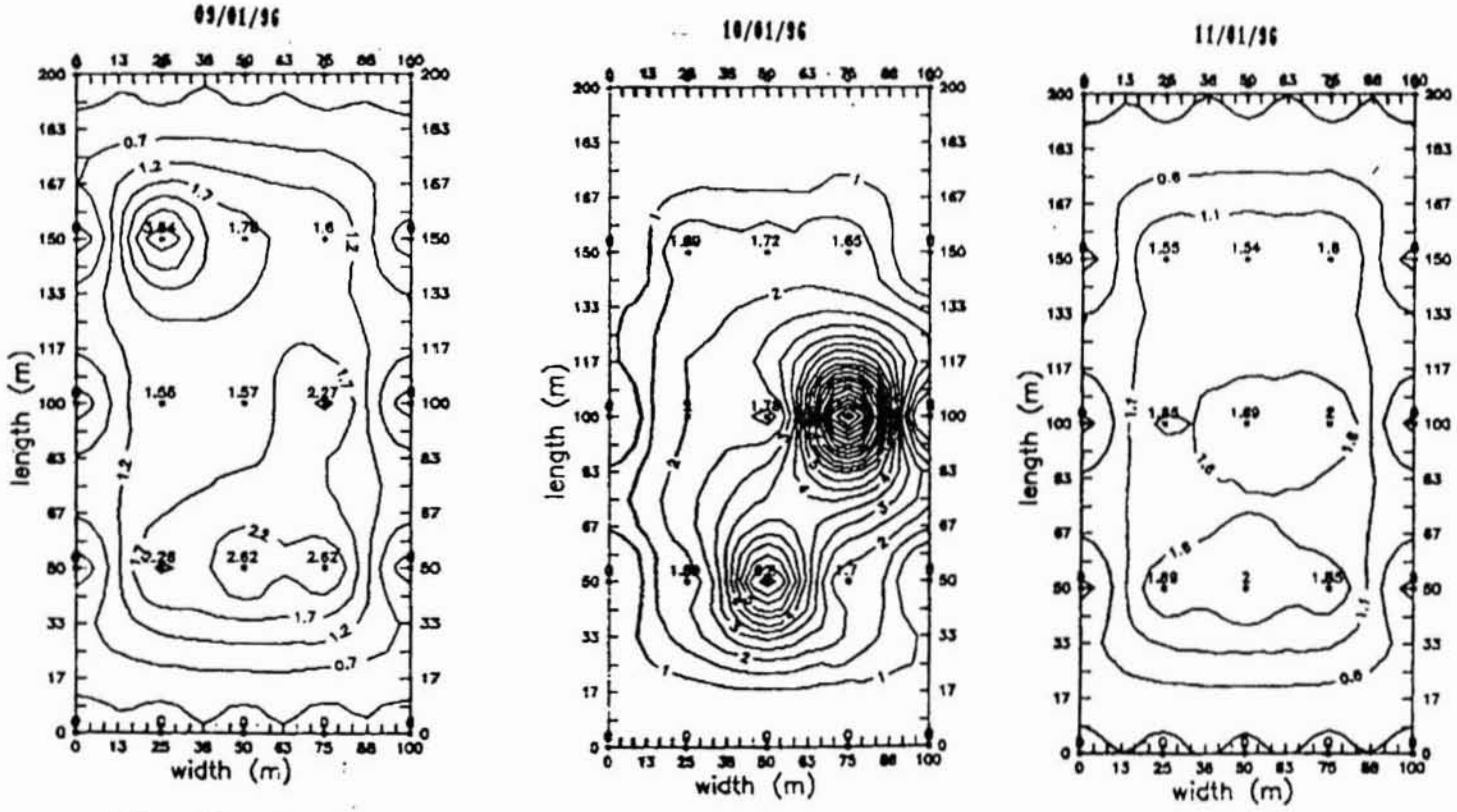


Fig. 18 2D plot of extinction coefficient on three days.

Table 9: Extinction coefficient before, during and after dredging

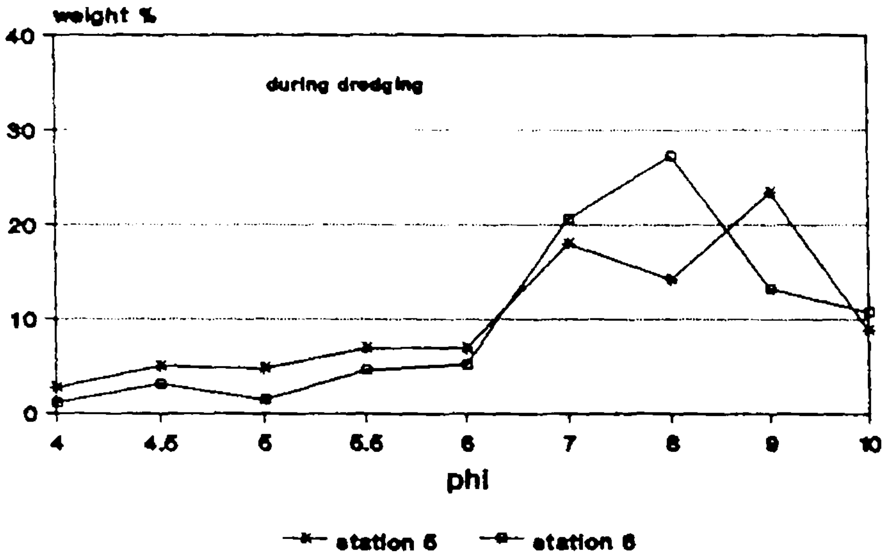
stns ->	1	2	3	4	5	6	7	8	9
09/01/96	2.26	2.62	2.62	2.27	1.57	1.55	3.54	1.78	1.60
10/01/96	1.89	2.80	1.70	2.33	1.78	2.00	1.89	1.72	1.65
11/01/96	1.89	2.00	1.85	2.00	1.89	1.65	1.55	1.54	1.60

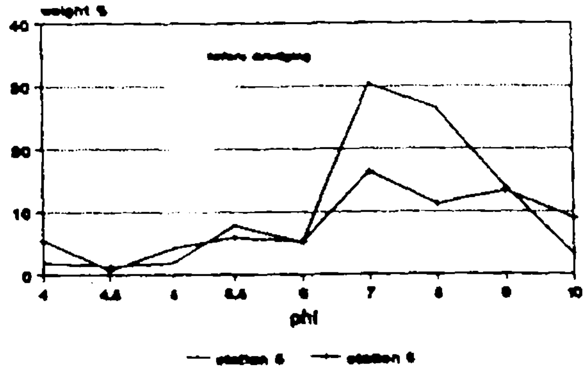
9. Just prior to dredging, the transparency was high giving low values of extinction coefficient (1.55 to 2.62) which indicate the presence of clear waters before the dredging operations. The exception was the high extinction coefficient value (3.54) observed at station 7 indicating the presence of turbid waters due to some probable local action.

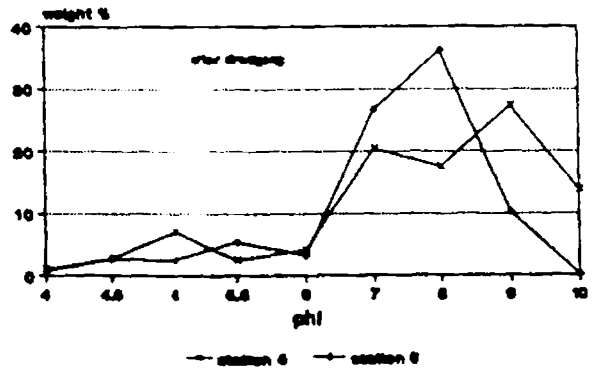
During the time of dredging, the extinction coefficient was very high (11.3) at station 4 followed by 6.8 at station 2 indicating the presence of high turbidity in the surface waters. The 2D plot showed two pools of high extinction coefficients at stations 2 & 4. Observations made aftermath of dredging operations indicated high transparency with low extinction coefficients. No closed isolines were observed at any of the stations which indicate that there exists a trend in the turbidity to gradually attain a normal set up in the estuarine regions soon after stoppage of dredging.

5. SEDIMENT TEXTURAL CHARACTERISTICS

The analyses of samples collected before the day of dredging at stations 5 and 6 indicated that fine silt played a dominant role. Coarse silt was very low compared to clay fractions as observed from the figure 19. At station 5, the values on standard deviation, skewness and kurtosis showed that the sediment was poorly sorted, very fine skewed and very leptokurtic but the sediments at station 6 showed very poorly sorted, coarse skewness and platykurtic.







Figs. 19 Weight percentage vs phi values at stations 5 & 6 before, during and after dredging.

The analysis of sediments collected during dredging showed that very fine silt mixed with the clay fractions were of higher percentage when compared to the observations of the previous day. At station 5, the sediments were poorly sorted, near symmetrical and mesokurtic and at station 6, the sediments were poorly sorted, fine skewed and mesokurtic.

After the stoppage of dredging, the next day, very fine silt fractions dominated the sediment texture in the study area. The sediments at station 5 were poorly sorted, near symmetrical and mesokurtic. At station 6, sediments were poorly sorted, fine skewed and very leptokurtic. Also there was an increase in the percentage amounts of very fine silt and clay size ,sediments when compared to the dredging time samples. At station 6, very fine silt increased from 27 to 37% whereas clay fractions increased from 14 to 18%.

6. NUTRIENTS

The nutrients carried to the sea by rivers are involved in the role of the principal agent for maintaining the fertility of the oceans. Within estuaries, the continued inflow of nutrients via the rivers must frequently be assessed for their importance in maintaining productivity especially since many a rivers carry some amounts of pollutional loads in addition to elements leached from the land sites. The annual contribution of nutrients by all the rivers of the world appears to provide only a small part to the total marine productivity. Emery et al.

(1955) estimated that the annual rate of use of nitrogen and phosphorous by phytoplankton is only about 1% of the reserved within the oceans but even so the use is about 100 times greater than the amount contributed by rivers and rain annually.

The circulation in the estuaries is frequently characterized by a two-layered flow with the surface layers diluted by river water, escaping seaward and the salt water entering along the bottom. The estuary may be fertilized by the seawater countercurrent, since in many cases, the sea water is drawn from the depth below the euphotic zone in the ocean (Lauff, 1967), when the concentrations of nutrients has not been depleted by the growth of phytoplankton. This effect may further be augmented by a process which Redfield (1955) has termed as the biochemical circulation. Organisms grown in the surface layers of the estuary may sink to counter current depths where decomposition releases the nutrients which will then be returned again for reuse within the estuary. Nutrients can thus become trapped within the estuary and built up to unusual high concentrations. Recent studies have thrown to better light on nutrient transformation in coastal waterbodies (Matsukawa and Sasaki, 1986; Matsukawa, 1989; Gopinathan et al., 1994; Gouda and Panigrahy, 1995) and on recycling within estuaries (Thornton et.al., 1995; Kronkomp et al., 1995).

a) Nitrite

According to Windom (1976) both polluted and unpolluted fine grain sediments of coastal and estuarine areas contain high concentrations of soluble nutrients (phosphorous and nitrogen). This may be due to the accumulation of organic detritus which decompose to regenerate nutrients. The study conduoted by Windom (1975) in Intracoastal waterway maintenance dredging analysis showed that no increase of nutrients (ammonia, nitrite and phosphate) were found. May (1973) also found similar results for phosphorous in Mobile bay. However, in some instances nutrient release mechanisms do not favour increase of nitrite or phosphate on dredging.

To study the short term impact of dredging on dissolved nutrient content, observations were made before, during and after the dredging operations. The results indicated in figure 20a; points out that analysis before start of the dredging at surface showed that the maximum concentration of nitrite was 1.87μgat/l at station 6 followed by 1.83μgat/l at station 7. The minimum value was observed at station 1 as 0.71μgat/l.

During the time of dredging, the sediments (rich in nutrients) on resuspension to the surface waters released nutrients in the dissolved form and its presence was noted as an increase in the content in the water column. The maximum value was 2.37μgat/l at station 6 followed by 2.35μgat/l at station 9.

A day after the dredging, the observations showed that the nitrite content persisted slightly enhanced at station 8

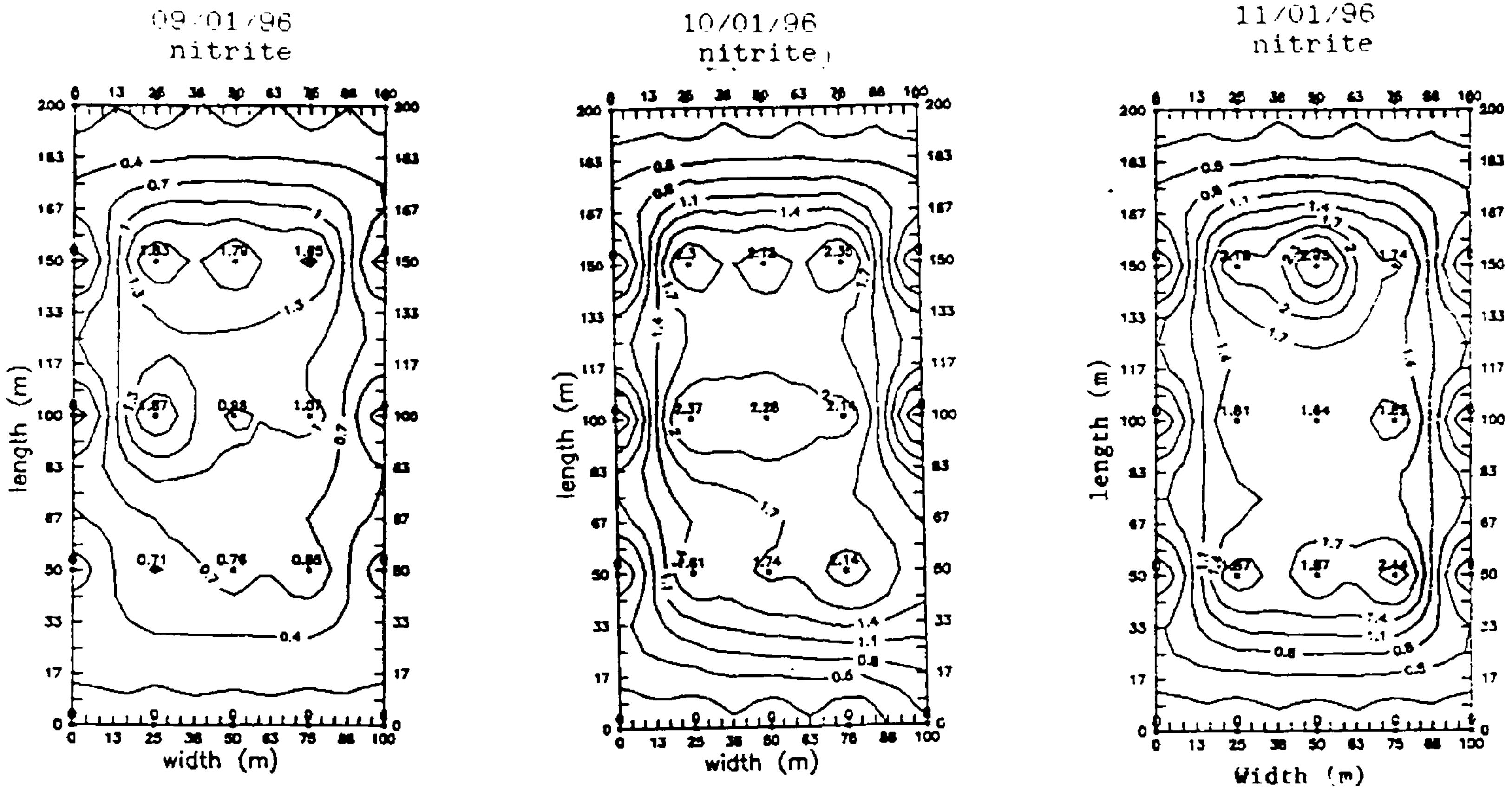


Fig. 20a 2D plot of nitrite at surface during three days of investigation.

(2.95µgat/l) which indicate the continued release of nitrite to the upper water column. At most of the other stations, values showed a gradual decline. This decrease may probably be linked to the uptake of nutrients by the phytoplankton or the adsorption onto the particulate matter.

In bottom waters, prior to dredging , nitrite showed still a higher value at station 7 (3.3µgat/l) and minimum at station 4 (0.66µgat/l) [figure 20b]. Comparing these values to that of surface, the nitrite content was more or less enriched in concentration to a comparable level though appearing to be on the higher side. During the dredging time, the substrata is totally disturbed and release of nutrients to the bottom waters enhance the content of nitrite. The values of nitrite showed a sharp increase at all stations; the maximum value was observed at station 4 (5.4µgat/l) followed by 4.4µgat/l at station 9. Two close isolines are quite evident for its appearance at station 4 & station 8 in figure 20b. After dredging operations, the next day, the peak values had shifted to stations 1 & 7 as 3.58 & 3.47µgat/l in concentration. Two close set of isolines appear around these stations. The results indicated that normal values of nitrite are not attainable after one day of dredging and the mechanism of nitrite uptake and release may be a slow process.

b) Phosphate

The variation of phosphate in surface waters before, during and after dredging is shown figure 21a. In the surface waters,

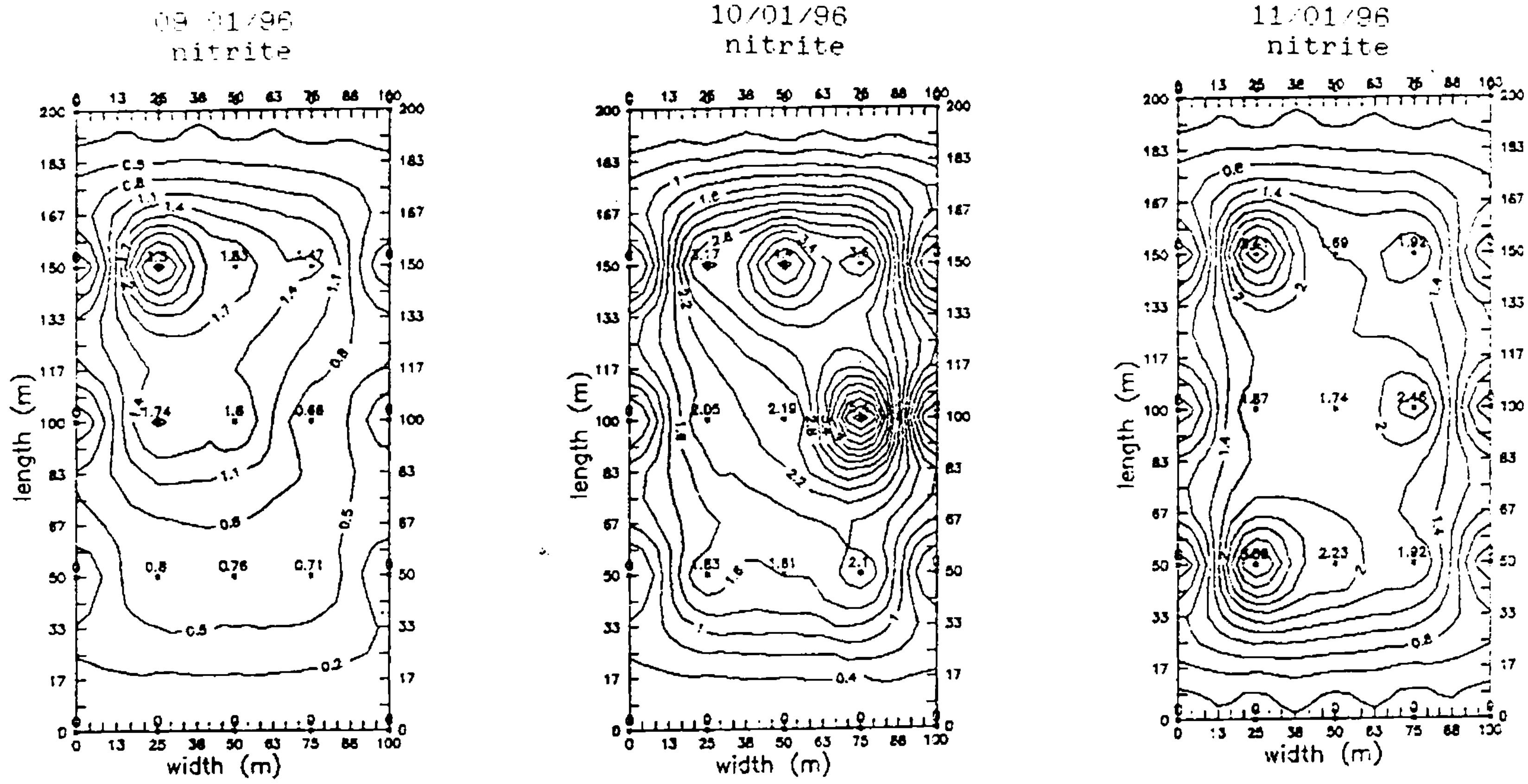


Fig. 20b   2D plot of nitrite at bottom during three days of investigation.

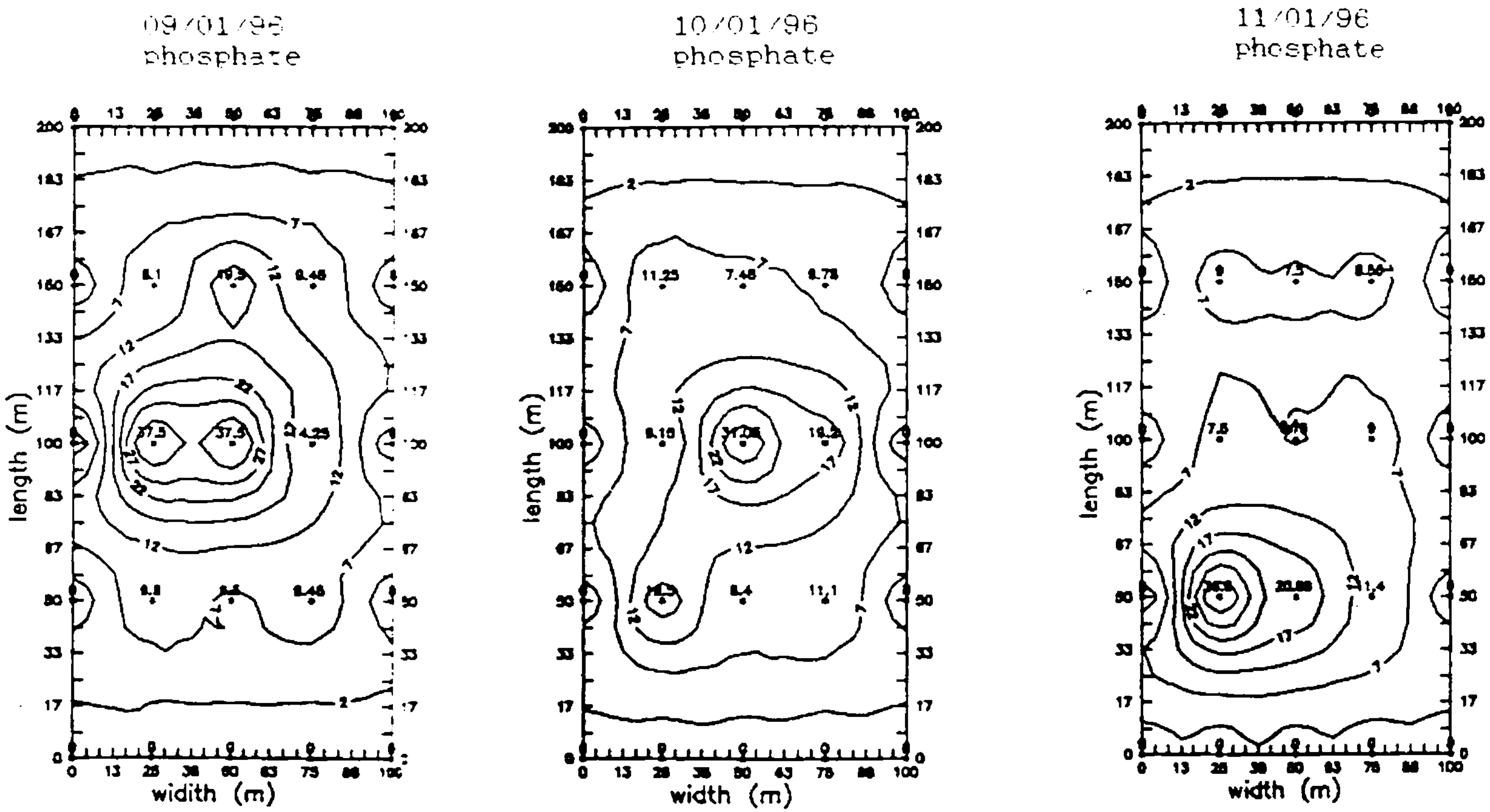


Fig. 21a 2D plot of phosphate at surface during three days of investigation.

before commencement of dredging, considerable content of phosphate was observed which revealed that this estuarine region may act as a sink or source for presence of phosphate as a nutrient. The concentrations observed at stations 5 & 6 fall in the range 37.5µgat/l as indicated by rapidly closing isolines of proximity at these locations. The content showed a decrease at other stations. During dredging time, the surface values drastically reduced; the highest value was noted at station 5 as 31.05µgat/l. One day after the dredging, (11/01/96) no consistent increase or decrease could be observed except at but station 5, where the value drastically reduced. The highest value was observed at station 1 as 36.00µgat/l .

The change of phosphate content in the bottom waters during the three days of study is shown figure 21b. The results obtained on study of bottom waters before dredging showed that higher values occurred at all the stations compared to surface values. The highest value was observed at station 9 (63.05µgat/l) which is evidenced by the pattern of isolines at that station. During the time of dredging, still higher values were observed at station 6 (79.50µgat/l) which is indicated by the close isolines nearby the station. After the stoppage of dredging, no drastic changes were noted but the values may gradually reduce compared to that observed during dredging. It may be indicated that the adsorption/absorption of phosphate onto the resuspended particulates and geochemical control would play an important role in the distribution of nutrients. Unlike nitrite, absolute

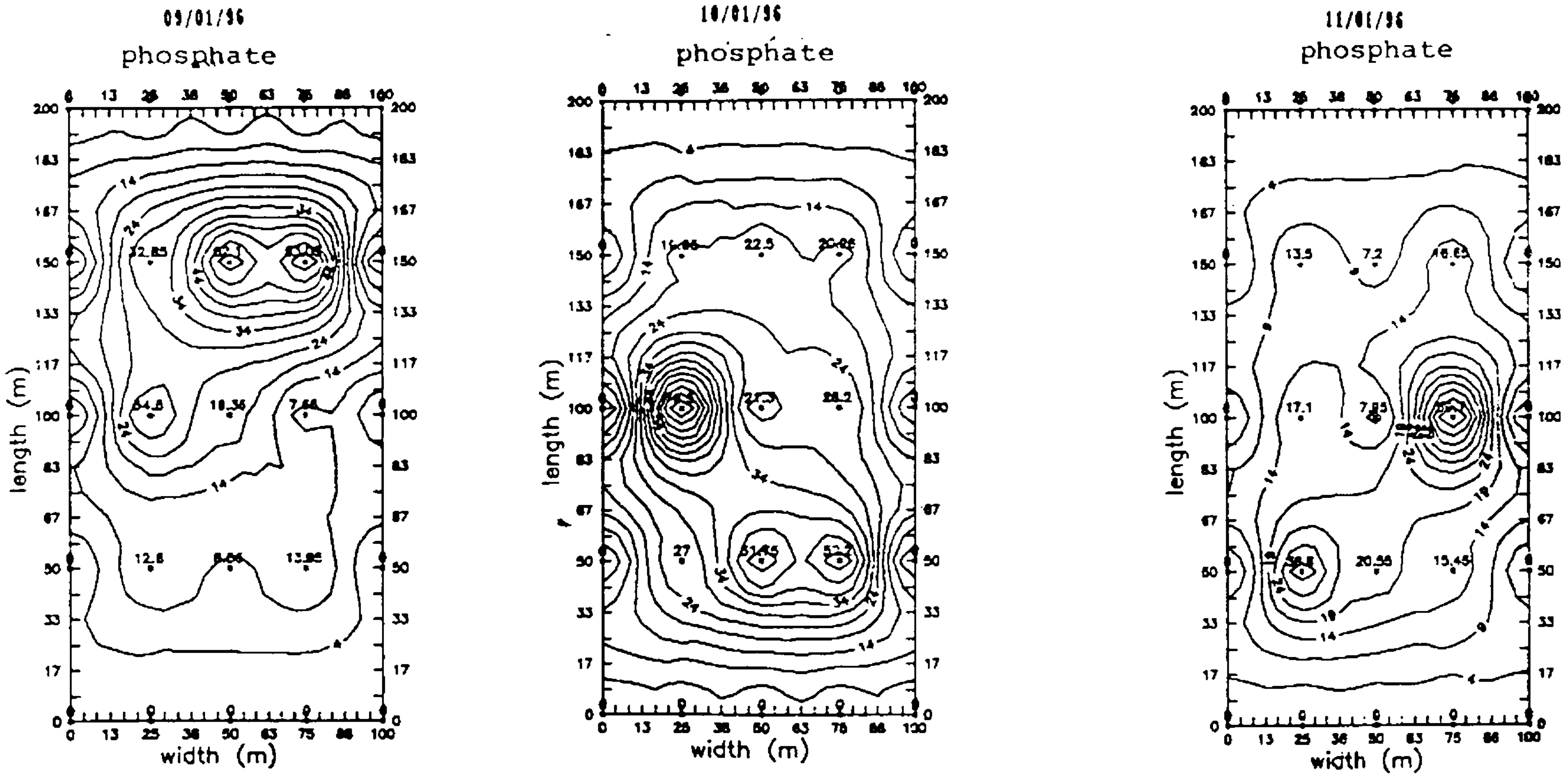


Fig. 21b 2D plot of phosphate at bottom during three days of investigation.

values of phosphate do not indicate release mechanisms but change in content (increase/decrease) play a dominant role.

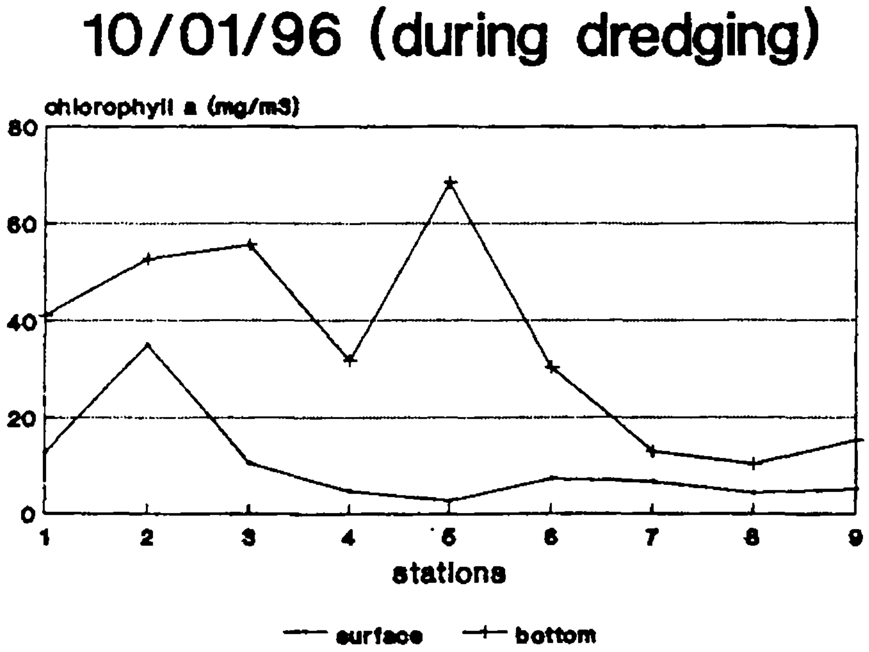
7. **CHLOROPHYLL** *a,b,c*

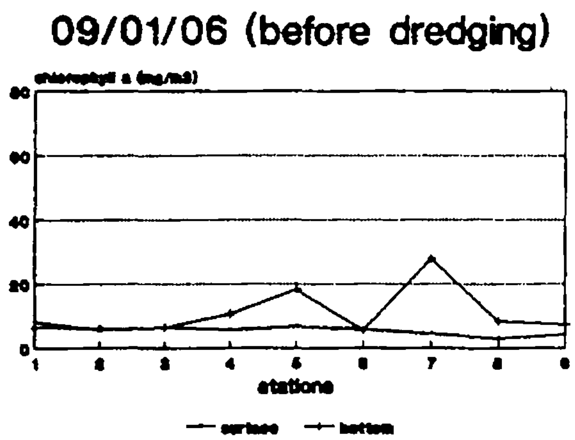
a) Chlorophyll ***a***

Analysis of chlorophyll *a* before, during and after dredging showed that higher values were observed in bottom waters compared to the surface waters. Before dredging, the surface samples contained < 10mg/m^3, but bottom values at four stations (stations 4,5,7 & 8) showed > 10mg/m^3 (figure 22a). Investigation continued during dredging on 10/01/96 gave surface values higher than 10mg/m^3 only at stations 1, 2 and 3. With regard to bottom waters all stations except station 7, 8 and 9 gave values higher than 20mg/m^3 and peaked around the main dredging site (stations 4, 5 & 6). Study conducted after dredging, indicated that the surface waters regained the original status on the very next day (11/01/96). The bottom waters also showed similar tendency as that of surface waters except at station 2.

b) Chlorophyll ***b***

Before dredging, in surface waters, the values of chlorophyll *b* was below detectable limits at some locations. In bottom waters it was around 10mg/m^3 (figure 22b). During dredging, surface waters showed < 10mg/m^3 except at stations 2 & 4. In bottom waters its content showed > 20mg/m^3 except at stations 7,8 & 9. Both in surface and bottom waters, chlorophyll





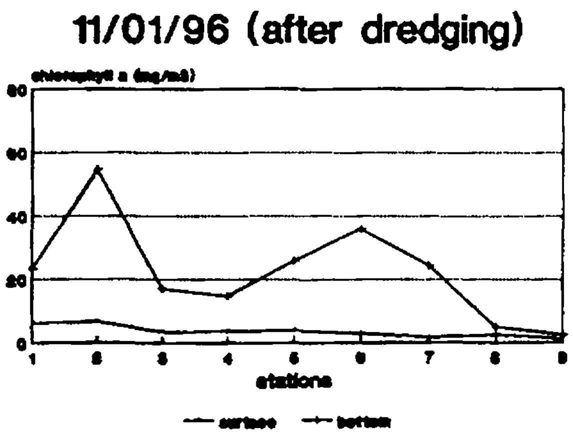
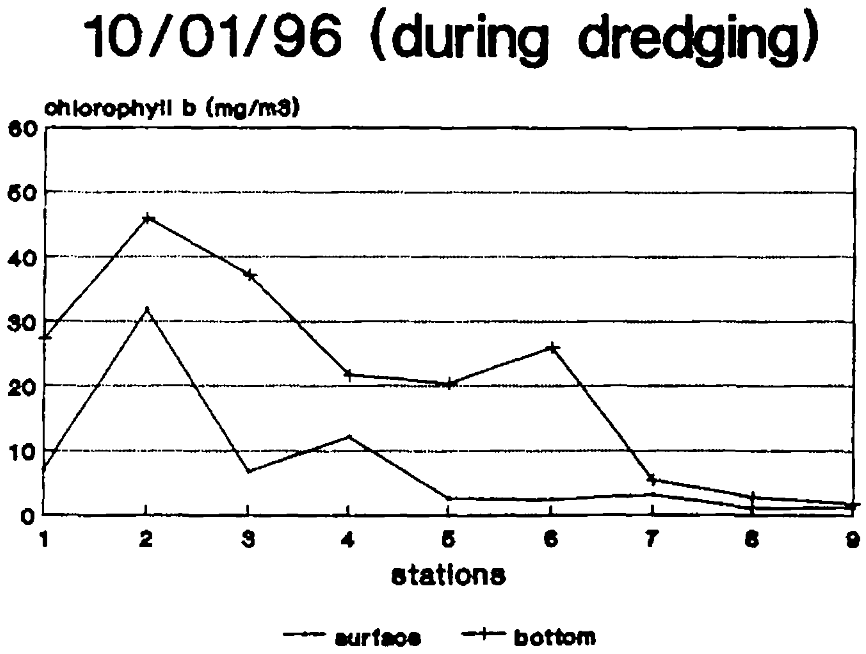
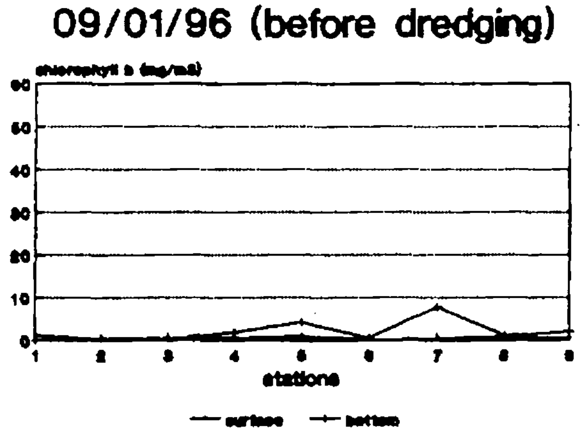


Fig. 22a Surface and bottom variation of chlorophyll a (mg/m^3) before, during and after dredging at stations 1 to 9.





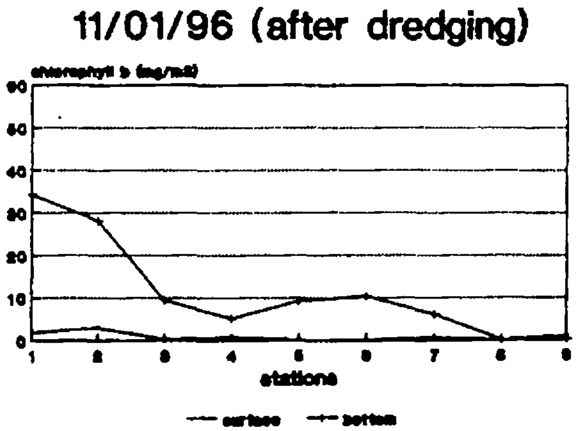


Fig. 22b Surface and bottom variation of chlorophyll b (mg/m^3) before, during and after dredging at stations 1 to 9.

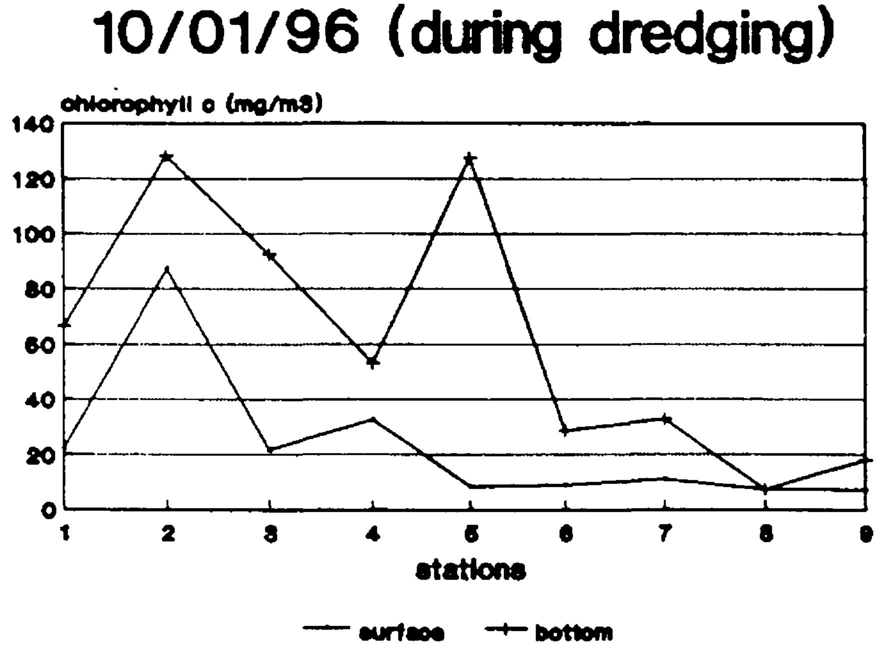
b gave peak values at station 2. After dredging operations, the surface waters readily regained the condition prior to dredging while bottom waters particularly station 1 & 2 did not reach the ambient conditions prior to dredging.

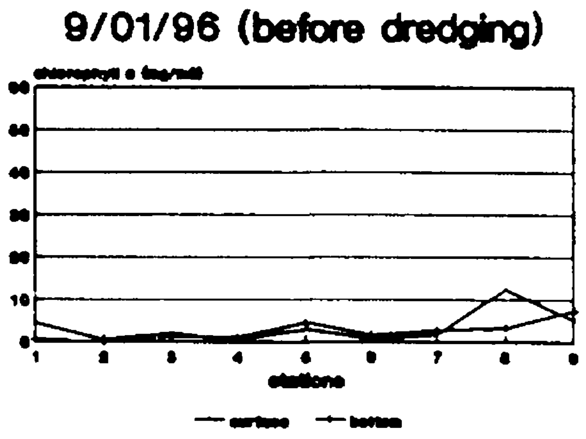
c) Chlorophyll *c*

Chlorophyll *c* also showed near similar tendency as that of chlorophyll *a*, but the values were found to be a little on the higher side than that of chlorophyll *b*. Before dredging on 09/01/96 the values generally showed the surface and bottom waters to contain < 10mg/m^3 (figure 22c). During dredging, on 10/01/96, chlorophyll *c* content showed that in the surface waters the values gradually increased and a peak was observed at station 2; but in bottom waters values were above 30mg/m^3 except at stations 8 & 9, followed by higher values at stations 2 & 5 (> 120mg/m^3).

The observation after dredging indicated decrease in values towards the riverine side. The surface values were below detection limits except at stations 1 & 2. Bottom values showed content greater than > 10mg/m^3 except at stations 7, 8 & 9. The maximum value was observed at station 1.

The higher values of chlorophyll *a*, *b* & *c* in bottom waters may be due to the introduction of benthic flora into those particular locations by the churning up action due to dredging. The higher values in the surface waters may be due to the





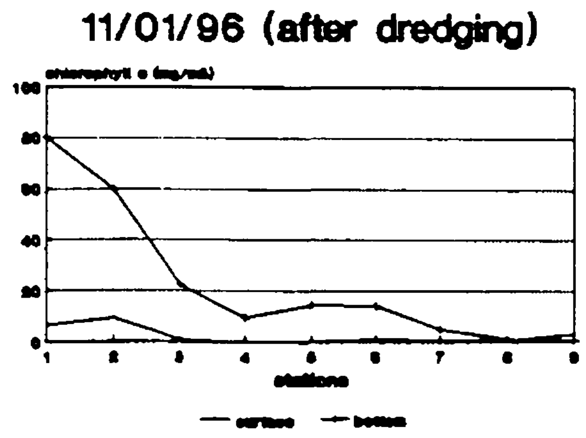


Fig. 22c Surface and bottom variations of chlorophyll c (mg/m³) before, during and after dredging at stations 1 to 9.

influence of bottom waters on moving towards the surface during dredging time.

The increase of chlorophyll *a* supported by changes in nutrients may bring about higher productivity but this will not likely happen in reality due to decrease of light penetration by increase in turbidity. The other two types of pigments, namely chlorophyll *b* & *c* exhibited increase during dredging time compared to values prior to start and after stoppage. Established relationships between primary production and chlorophyll *a*, *b* & *c* are well documented elsewhere (Uye et.al, 1987).

8. BOTTOM FAUNA

The short term impact on benthic fauna reveals that before dredging, polychaete was the dominant group (tables 10 & 11) especially at station 1 (45 Prionospio Sp was observed). At stations 3 & 6 single specimen of polychaete were noted. A total of 49 organisms were observed and the species diversity at station 1 was 0.21. At stations 2,4,5,7,8 & 9 no organisms were observed.

During dredging, the polychaete was the dominant group but the number of organisms detected was very less; crustaceans ranked second. No organisms were observed at stations 1,4,6,7,8 & 9 of the dredging locations. The species diversity was 0.69 at station 5 and 0.67 at station 3.

Table 10 : Number of organism per 0.05m2 before, during and after dredging

	(Before) 09/01/96									(During) 10/01/96									(After) 11/01/96								
stations ->	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Species																											
A. Annelida - Phylum																											
Polychaeta - Class																											
Nephthys Sp	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Neries Sp	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Prionospio Sp	45	-	1	-	-	-	-	-	-	-	4	-	-	2	-	-	-	-	1	-	-	-	-	1	4	3	-
lumbriconeries Sp	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	-	-	-
B.Crustacean																											
Amphipod	1	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
C.Nematodes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Total ->	47	-	1	-	-	1	-	-	-	-	4	5	-	4	-	-	-	-	2	-	-	1	-	1	6	4	
Gr.total	49									13									14								

Table 11: Species diversity before, during and after dredging

sites	Before (09/01/96)	During (10/01/96)	After (11/01/96)
1	0.2	-	0.6
2	-	-	-
3	-	0.6	-
4	-	-	-
5	-	0.6	-
6	-	-	-
7	-	-	0.6
8	-	-	0.5
9	-	-	-

The observations made the next day of dredging (11/1/96) showed that polychaetes ranked first followed by crustaceans and nematodes. A higher number of organisms were observed at station 7 of the dredging site. A few more organisms also appeared at stations 1,4,6 & 8 of the study area. At other stations, no organisms were observed. The species diversity showed a higher value at station 1 followed by station 7 (0.64) and station 8 (0.56).

The results indicate that there is a likelihood of inhibition or reduction of bottom fauna to occur immediately after dredging but this aspect is also controlled by many other factors and is species selective too. A drastic reduction of organisms were noted in the case of Prionospio. Another interesting result associated with aftermath of dredging was that the species diversity index increased compared to timings prior and after the desilting operations.

C. SILTATION STUDY AT A CAPITAL DREDGED SITE

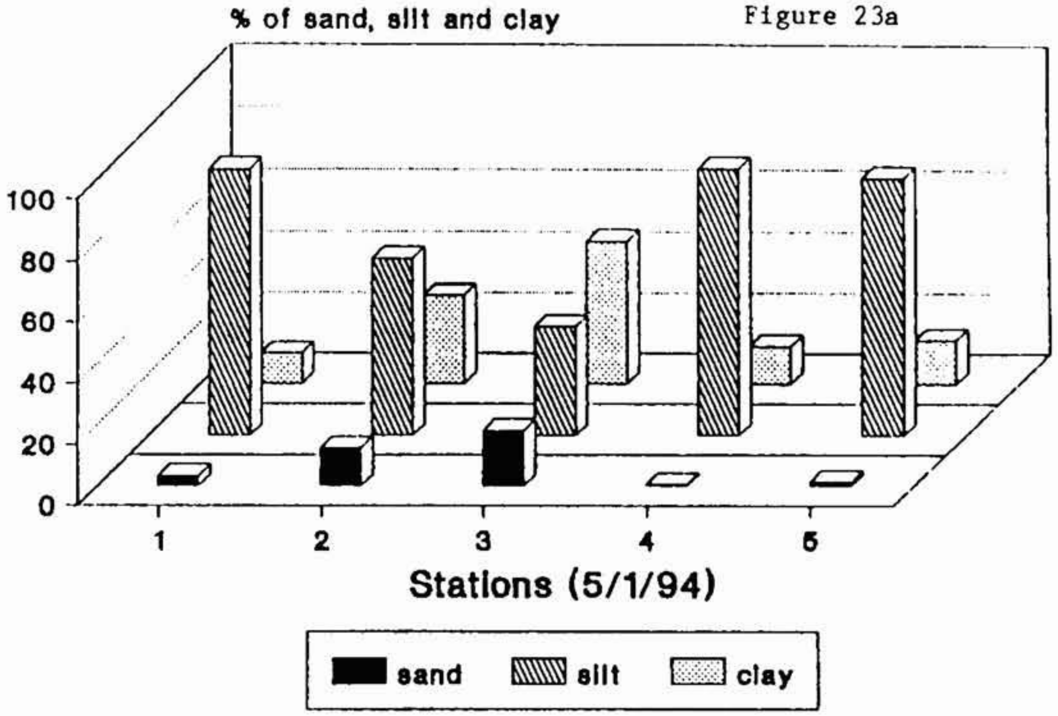
1. INTRODUCTION

Dredging is an art projecting human skill in shaping the coastal environment by way of escavation of material from the bottom of the sea, estuary or sea so as to achieve desirable navigational depths (Mahon, 1979, Rasheed and Balchand, 1995). It is a high cost, high risk business involving powerful and expensive equipment. It involves the removal variable material from different substratum in adverse conditions to achieve other declared objectives like adjacent land reclamation, waste land coverage, construction of bund, damming etc. This study was conducted upstream of the inner channel of Cochin harbour (see figure 2). Study mainly concentrated on either side of the Mattancherry bridge which was constructed in early 1940's. Tides of 1m range greatly influences this particular. Wave action at these area is meager due to protective nature of the harbour. This, being a shrinking estuary, receives perennial river discharge along with large amounts of suspended solids which eventually settles at the estuarine bottom affording quite favourable locations for siltation. The sedimentation and reclamation activities and its consequences are well documented by Gopalan et al., (1983). More details on environmental setting is available elsewhere (Anto et al., 1977; Udaya Varma et al., 1981; Joseph and Kurup, 1987 & 1989; Balchand et al., 1990 and Ajith & Balchand, 1994).

Dredging was performed in order to reclaim land for road traffic on the southern part of the Willingdon Island by spoil transfer. Dredging operations were performed by means of cutter suction dredger and pipeline disposal technique. Due to this activity, a large area of the upper Mattancherry channel was disrupted including fisheries harbour functions. The survey elucidates information on dredging and concurrent siltation at sites of interest as given below.

2. RESULTS

Dredging started at the site by the end of postmonsoon season of 1993 (December). The survey was first attempted on 05-01-94 and later continued. The bottom sediments were collected at five stations in the study area and lead/echo sounding also was performed. Station 3 is located at the capital dredging site with stations 1 and 2 on the southern part and two more stations on the northern part (stations 4 & 5). The analysis showed that the sand proportion gradually increased towards the dredged area, but further northwards, its presence decreased (figure 23a). However the silt concentration (%) showed a gradually decreasing tendency towards the dredged area, thereafter, it was distributed uniformly. The clay concentration showed an increasing tendency towards the dredged site and later showed similar features as that of silt. Investigation continued at the site on 01-03-94 after a one week pause in dredging (figure 23b). The relative sand percentage showed remarkable



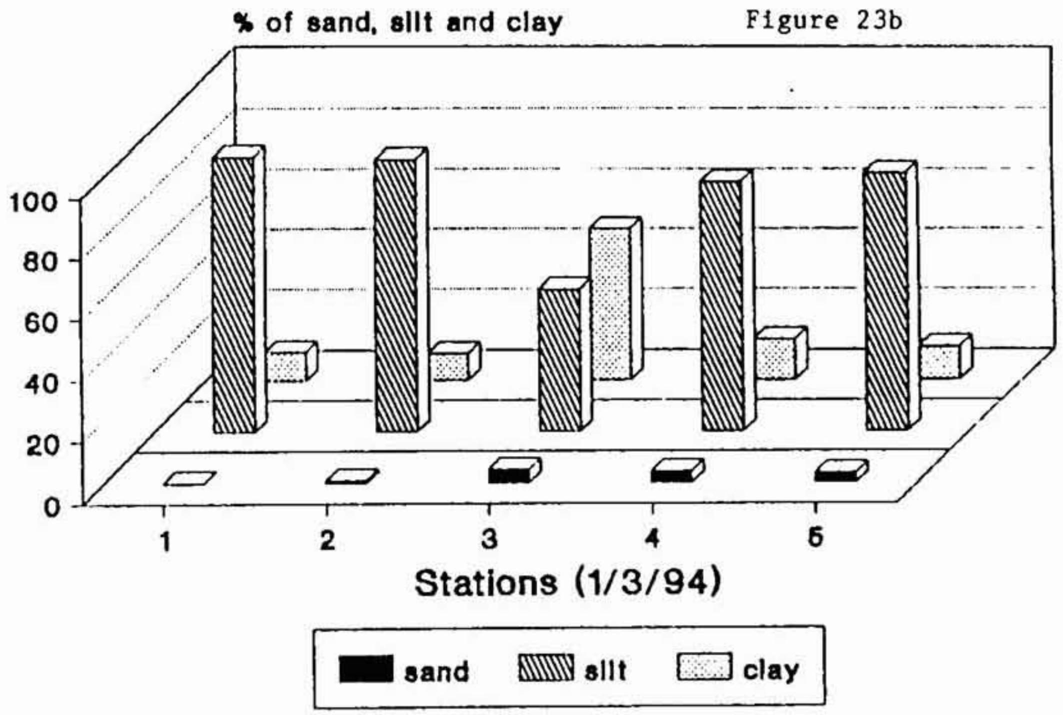
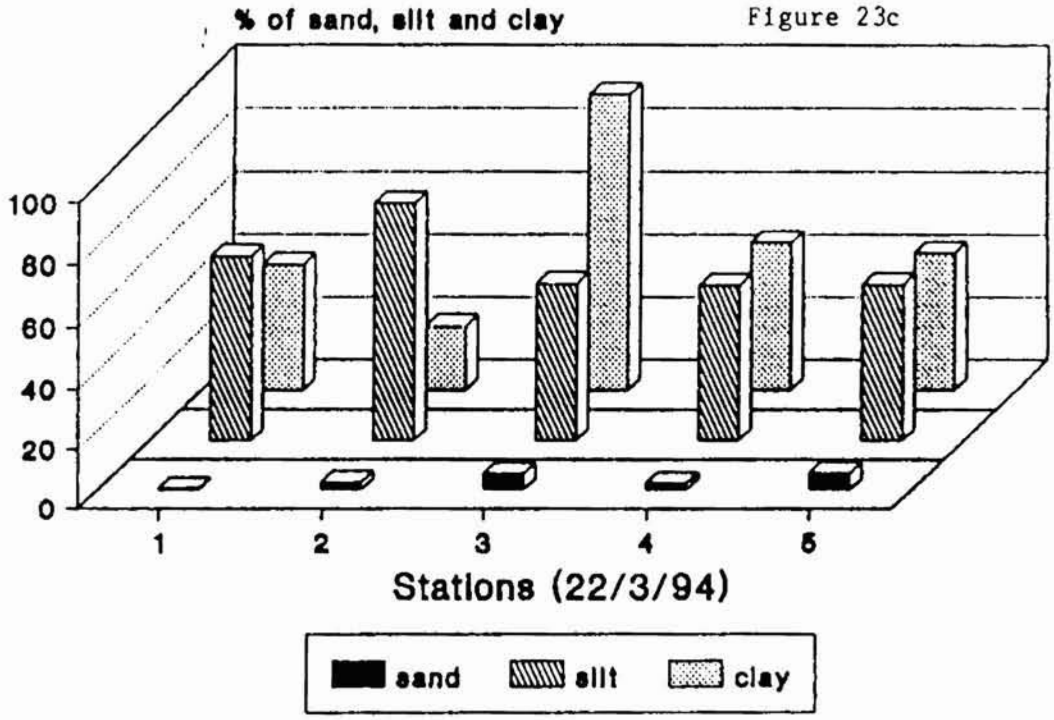


Fig. 23a & b Percentage distribution of sand, silt and clay at stations 1 to 5 on 05-01-94 & 01-03-94.

decrease in abundance but silt concentration a marked similarity on either side of the dredging site. Clay percentages were equally matching to that of silt and was in far higher proportions at the dredged site compared to other stations. This feature clearly indicated that fine material was selectively deposited at the subsurface layers or occurrence of sedimentation processes (river borne/sea borne). These aspects were further probed in subsequent surveys.

The survey continued in the same month (22-03-94) on completion of one month of continuous capital dredging. The study gave results on the presence of very minor portions of sand (figure 23c), which was more or less same as that of the previous survey. The silt concentration marginally reduced giving way to the deposition of clay material at stations 3,4 & 5. These observations leads to the conclusion that more finer material than silt is either sedimented or translocated on the seaward side of the dredged site. This factor also excludes the possibility of river borne material to reach the dredged area under diminished low river discharge rates during premonsoon season (February - April).

After a gap of one month, collection was again held on 20-04-94 which indicated practically little presence of sand but extensive proportions of silt material. The percentage of clay at stations 1 to 5 varied between 10 to 25% which was less than those values observed in the previous collection (figure 23d). The pattern of percentage distribution of sand, silt and clay



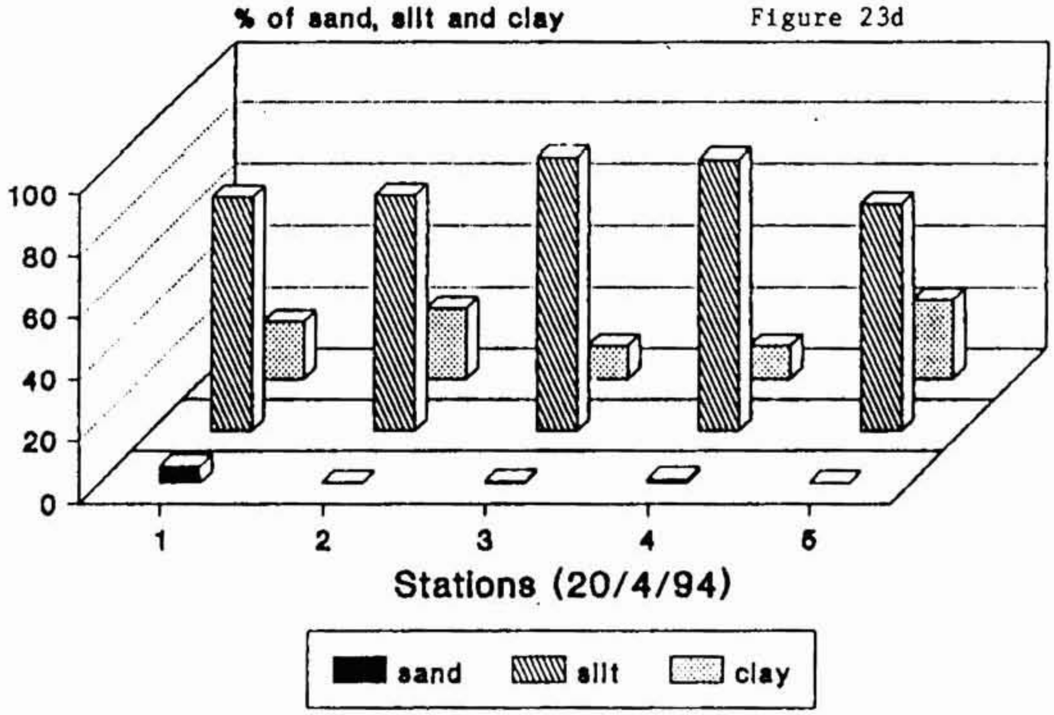
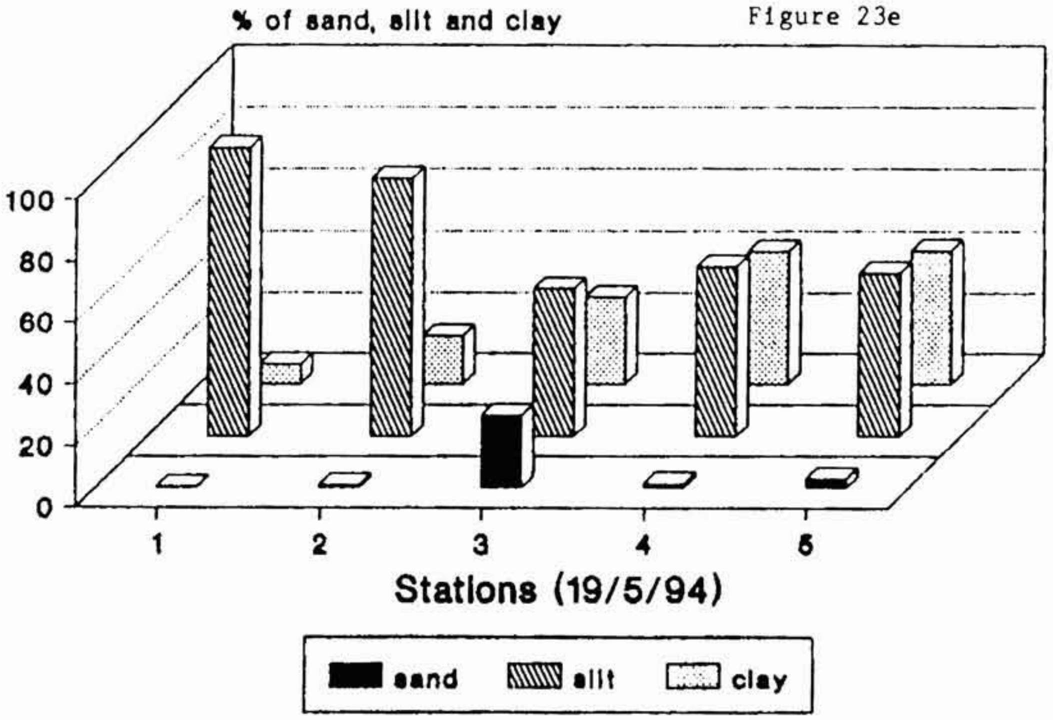


Fig. 23c & d Percentage distribution of sand, silt and clay at stations 1 to 5 on 22-03-94 & 20-04-94.

fractions during this month suggests substantial sedimentation of material which caused shallowing of dredged site and its neighbourhood as observed from the topography map (see paragraphs below). The position of turbidity maxima was often noticed during premonsoon period to be either at the barmouth or within the channels (Rasheed et al., 1995a).

The results of the survey held on 19-05-94 revealed a remarkable change. On commencement of dredging after three months of stoppage, the dredged area indicated the presence of comparatively higher proportions of sand whereas the neighbourhood stations lacked the presence of this grade of the constituent (figure 23e). Stations 1 & 2 on the southern part of the dredging site contained more silt in comparison to stations 4 & 5 on the down estuarine regions. This also coincides with the onset of early monsoon leading to the likelyhood of bed load movement plus discharge of river borne materials. Selectively, this implies the filling up of deeper portions of the channel which had earlier been dredged containing denser materials.

During the month of June 1994, the dredging operations were intermittent. The survey held on 25-06-94 indicated that relative sand concentration increased only in slight amounts towards the dredging site (figure 23f). Silt concentration showed mild irregular distribution, but finer material at end member stations on either side of the dredged site was occupied by more than 40% of clay.



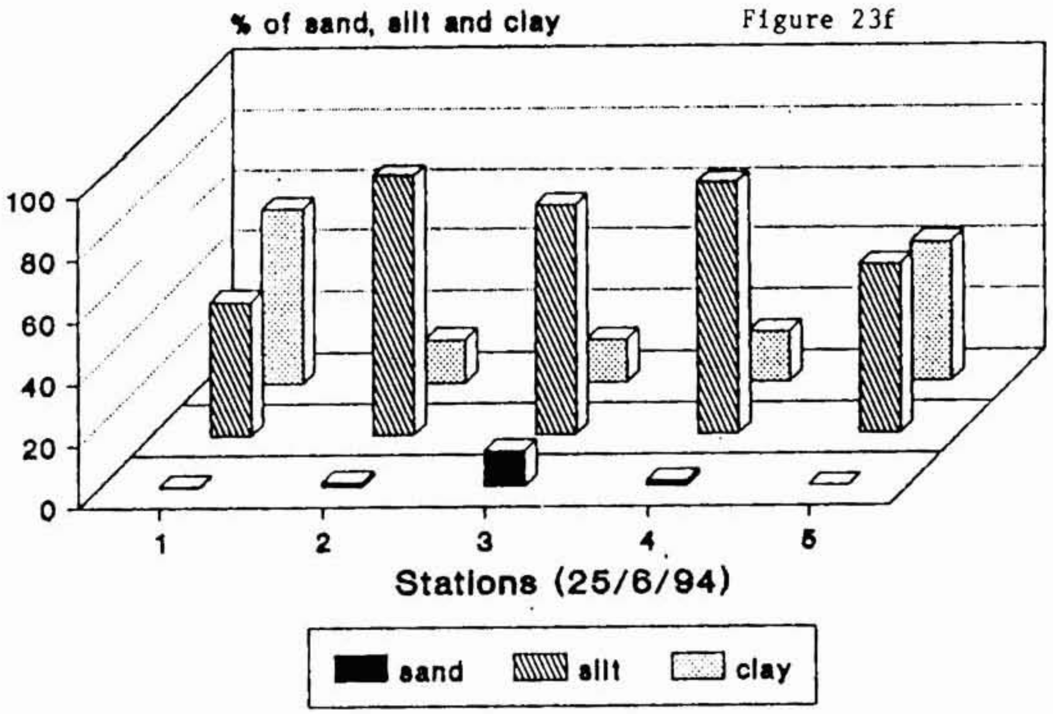


Fig. 23e & f Percentage distribution of sand, silt and clay at stations 1 to 5 on 19-05-94 & 25-06-94.

The last survey held on 24-08-94 after a gap of two months showed very low percentage of sand, but equal shares of silt and clay distributed irregularly, between stations 1 & 5 (figure 23g). The inference from the last two surveys revealed the presence of finer material being transported in suspension and siltation to occur in the proximity of Mattancherry channel - a field of divergence and sluggish water currents. The overall picture indicate the trend to attain near level ground which suggests the fill up of dredged site by composite material, predominant in silt in the long run.

At the capital dredging site, the bottom topography was closely monitored apart from the sediment textural characteristics. Figure 24a represents isobaths at the dredged site which was investigated on 05-01-94. The contours in this figure as well as the figures 24b and 24c (subsequent dates) indicated moderate depths (3.2-5.4m) in the region of study. The survey held on 20-04-94 reflects depths varying from 2.8 to 3.8m (figure 24d). A remarkable change in the bottom topography consequent to prolonged dredging (figure 24e) showed most of the region to be at depths varying between 3 to 5m but presence of two deep pools of depths 11m and 15m lying adjacent towards the northern parts of the study area where most of the dredging operation was concentrated. This is the result of direct consequences of material being dredged out continuously from an area to reclaim adjacent land leaving little or no time for natural suspended or bed material to replace the excavated

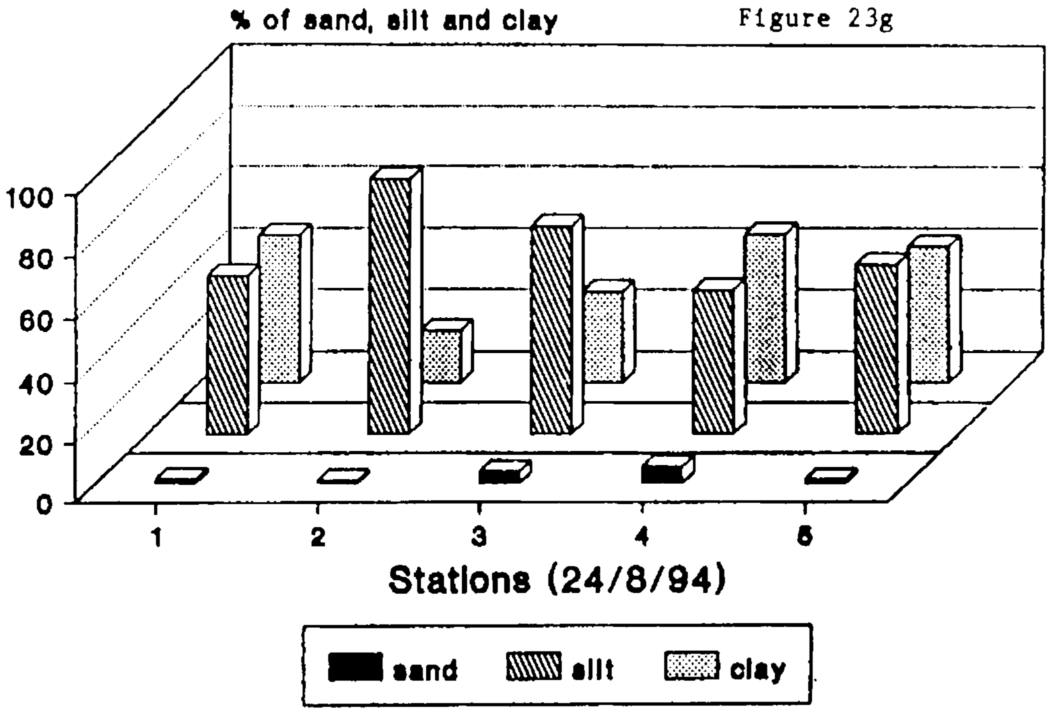


Fig. 23g Percentage distribution of sand, silt and clay at stations 1 to 5 on 24-08-94.

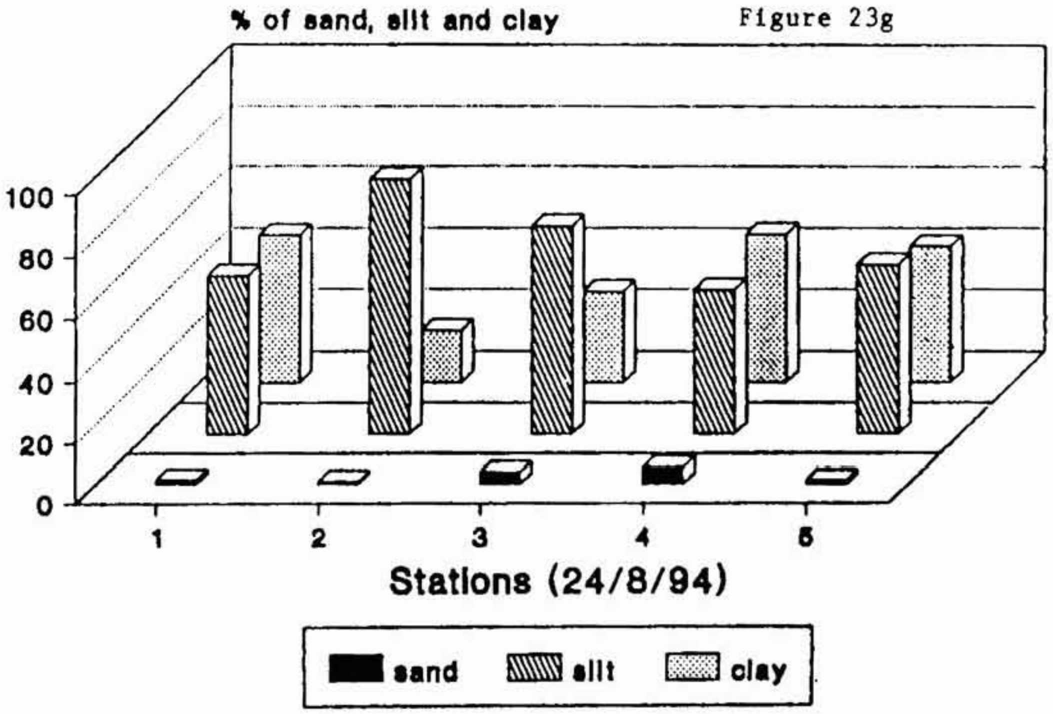


Fig. 23g Percentage distribution of sand, silt and clay at stations 1 to 5 on 24-08-94.

Fig. 24a,b &c 2D plots of isobaths at the study area for the dates of investigation 05-01-94, 01-03-94 and [illegible]-03-94.

Figure 24a

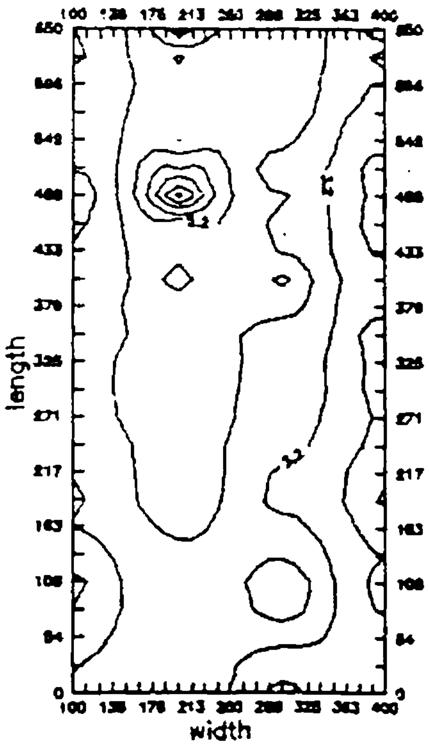


Figure 24b

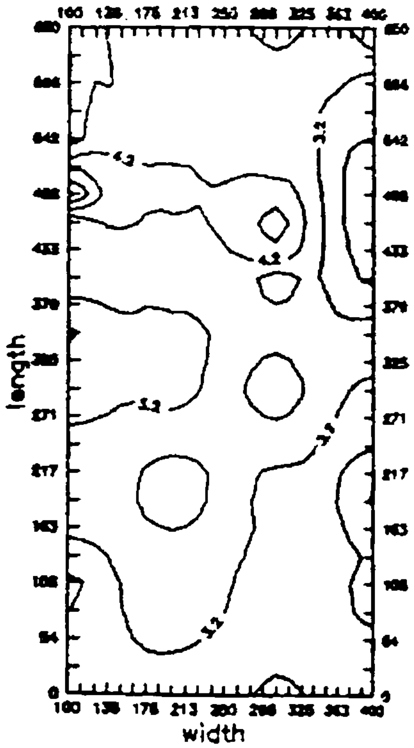


Figure 24c

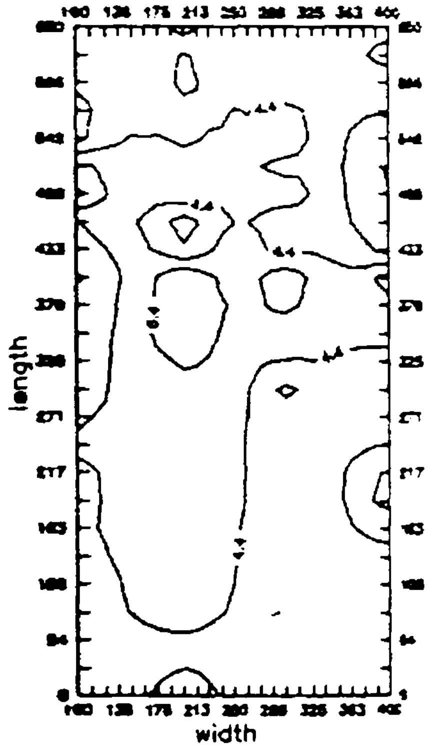


Fig. 24d,e,f & g 2D plots of isobaths at the study area for the dates of investigation 20-04-94, 19-05-94, 25-06-94 & 24-08-94.

Figure 24d

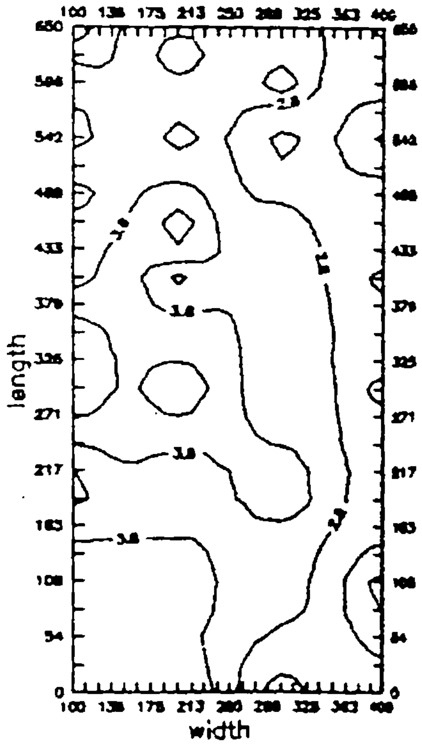


Figure 24e

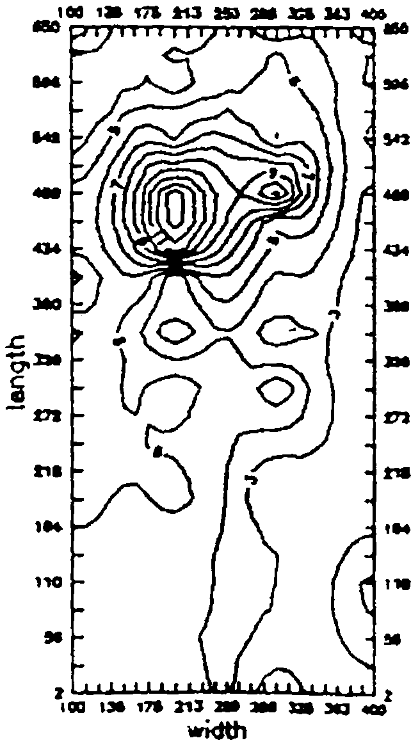


Figure 24f

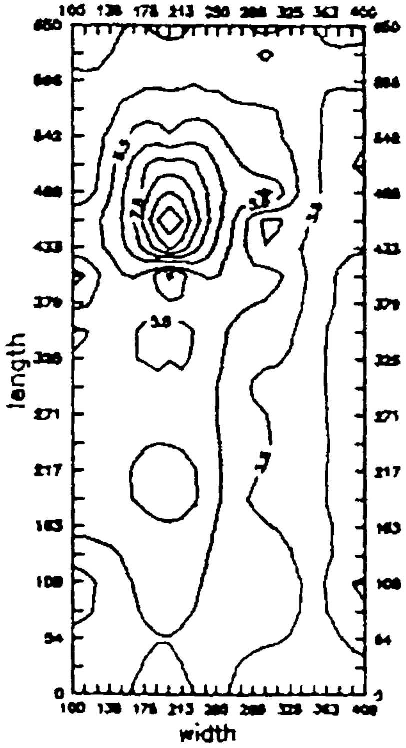
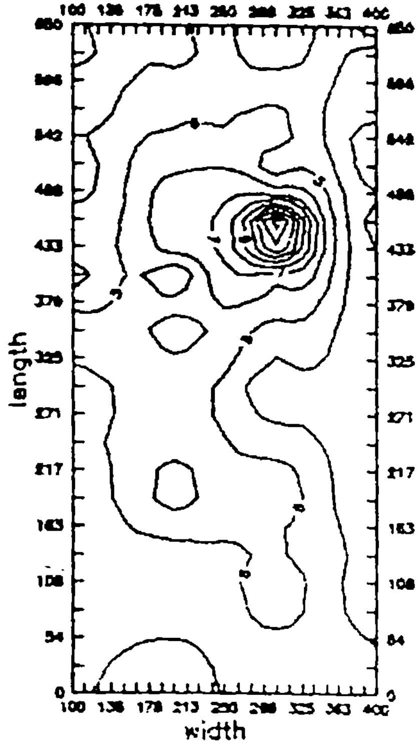


Figure 24g



quantity. During the ensuing monsoon months, the topography of the area indicated filling up of the pools resulting in shallowing to depths around 9.5m. This directly coincides with the monsoonal inputs transporting material to the down estuarine sites. The impacts of intermittent dredging are quite projected in figure 24g. On a survey held on 24-08-94, the presence of a single pool was noted which stood shifted to the right of the deeper area as seen from the previous figure 24f. The influence on isobaths due to overflow from the nearby reclaimed land did add to the features in figure 24g.

3. DISCUSSION

Using the surfer software applying trapezoidal method, the amount of material dredged and that sedimentated at the study site was computed. The volume of material dredged between the first and second survey was derived as 2,31,153m^3. The amount the sediments dredged between 01-03-1994 to 22-03-1994 was 27,550m^3, followed by the next phase of observation which indicated the contribution to be 1,00, 982 m^3. The difference in volume between 20-04-1994 to 19-05-1994 was 88,053m^3 and that between 19-05-1994 and 25-06- 1994 was 1,75,217m^3, this being the material that gradually filled up in the dredged area. The net amount removed stood up at 2,31,153m^3 and aggregate volume sedimenting totaled 3,91,801m^3. Estimates could not be arrived to include the results of the last survey held on 24-08-1994 as land overflow and runoff lead to non-point sources of material driven into the study area.

Calculation also included the per day deposition rate in Mattancherry channel, between days of observation as 1300m^3/day in March 1994, 3500m^3/day from March end to mid April period followed by a rate of 3,000m^3 up to mid-May 1994 (low river flow but dominant salt/silt wedge). The start of monsoon indicated deposition rate around 4700m^3/day (riverine inputs wash down terrestrial material in suspension and/or bed load movement). It may be noted that within the Mattancherry channel or in the nearby vicinity, dredging which would excavate nearly two lakhs m^3 of material from an area approximately 12,500m^2 to depths 10m below estuarine bed would be refilled by natural processes in about three months time, given that the event occurs before monsoon. In case, the contribution from increased riverine inputs are considered during monsoon alone, the deepened portions of the channel are subjected to rapid sedimentation leading to shallowing. This study at Cochin accounts for sediment budgets at a capital dredged site as stated above. A reasonably good picture of the sedimentation pattern within the channel has aided the study in depth variation after each dredging operations so as to arrive at the volume of material removed from the bottom; on stoppage of dredging operations, studies on the fill up procedure with time and space has lead to ascertain the amount of material inputs which settle and its textural distribution. A good appreciation of sedimentation - rate and texture of material filling up the dredged locations have been successfully attempted.

The observation during the study mainly indicates that the sediment characteristics and bottom topographic features will be restored after a period of intermittent dredging. The tidal flushing characteristics and river discharge plus material inputs helps the dredged site to return to its initial status. These aspects have added significance in view of the tropical environmental setting and the extent of maintenance form of dredging that is currently practiced at Cochin Port elsewhere in the channel to ensure uninhibited traffic operations around the year. The influence of seasonal monsoon(s) and the input of material, requisite better scientific management lower recurring cost of operations, in light of planned development of super container berth(s) at this port.

CHAPTER 5

DREDGING IMPACT ASSESSMENT

In the context of this thesis, DIA is designed to identify, assess and predict the impact(s) on the biogeophysical environment of Cochin harbour, in particular and followed by a comprehence discussion on the operational procedures (process) and impact assessments. Whereas several choices are in vogue, the decision/policy makers do not fully rely on attempts to prepare and review impact assessments with adequate interest on environmental quality upkeep. Though it has now been recognised that impact assessments should form an integral part of all major environmental actions leading to a study on the pros-and cons-, which would bring out adequately the positive and negative impacts of projects, the same is nevertheless contemplated for an already existing, ongoing project. With growing awareness on environmental, ecofriendly processes, existing engineering feats do attract our attention where the original objectives, goals and ultimate results now stand redefined, necessitating the study of alternatives including that of ongoing actions. Impact assessment have now to be conceived as an activity, continuum in time scales, to cover mid term and long term outcome-predictions of impact(s) and attempt to gather sufficient knowledge of the magnitude and importance of the environmental aspects/concerns already standing exposed. Impact assessments have had the following success: increased public awareness, evolution of effective environmental protection techniques and opening up of new avenues for research (Munn, 1975; Holling, 1978) but on the side of failure, lighthearted approaches in unrealistic time frames, rescheduling of places and programmes, lack of coordination and poor research design plus unethical practices (Rosenberg et al., 1981) such affords have brought about catastrophic results. In the present context, a conceptual framework for EIA deals with orchestration of resources and people, a process that integrates talents and concerns and also includes more modern approaches like artificial intelligence so as to achieve desirable results (Buschek, 1994). To summarise, all efforts are basically performed to significantly improve the quality of the human environment and to preserve and develop the surroundings and resolve the issues falling within any given project by means of an internal mechanism.

Dredging activities are not a relatively new enterprise of man. Gower (1968) has brought out an article on history of dredging as well as other scientists have discussed the cause and effects and the resultant general scenario arising out of such activities from time to time. The Corps of Engineers (U.S.A.) are known to maintain over 30,000 Km waterways and about 1000 harbours by means of dredging operations (Boyd et al., 1972). United States and number of other nations have formulated a sound environmental policy which require the preparation of environmental impact statements for such activities like dredging too (Munn, 1975). India too now insists on comprehensive dredging impact assessment in the upkeep of environmental quality and wholesomeness.

The DIA comprises the effects on the environment by various dredging operational methods, objective linked engineering activities aimed at wide scenario modifications and such other activities necessarily constituting beneficial or other manifestation on communities which have direct relevance to social setup and economic values. In many cases, impact studies have pointed out various negative effects which result on deliberate damage to the environment to achieve a desired goal. Dredging, of course, is attempted mostly in coastal zones, the major interface between oceans and continents and a place where mostly high productive areas of the marine environment is located. The fragile coastal environments, a complex system is comprised of many subsystems where equilibrium conditions exist, highly susceptible to irreversible degradation. The alterations due to dredging which include both direct and indirect effects in the short and long term duration may be partly beneficial or detrimental or may have no appreciable effects. Under the umbrella of a realistic DIA concept for the coastal zone, which recognises human presence as an integral component of the system, impacts due to dredging shall not lead to impoverished conditions which would have otherwise induced irreparable modifications to the regime. Consequently, technologically manipulated living conditions of the existing human race may fail to take off; hence the concepts shall be zonal protection, conserved approach which would pursue a balance between the extent of attentions vis-a-vis needs, satisfying and adequately protecting the operations providing beneficial effects to the environment and man. The necessarily damaging, degradation factors are as listed in succeeding paragraphs and these require close attention and augmented remedial care.

Dredging impact assessments are site specific and case specific; it would permit to draw out strong conclusions on reliable evaluation of direct and indirect effects. The main difficulties often encountered are the complexity of the ecosystem and correct readings of signals already emphasized earlier, multiple interconnections and the state of equilibrium of many subsystems of the coastal zone. Dredging has to be understood as one such activity which shall teem its influence on natural ecosystems and artificial subsystems of anthropogenic domain such as industry, fisheries, agriculture etc. Findings of this research study attempts to encompass qualitative and quantitative information and evolve a criteria incorporating pertinent assessment techniques in bringing out an open matrix in the perspective of process - outcome - assessment - impacts relation for any dredging site. The prime objective of this exercise includes the selection of parameters which would lead to the description of the process -> impacts and the parameters themselves which would lead to the assessment of the process. The DIA matrix is given in flow chart 2.

The process has been designated as dredging leading to an outcome such as sediment removal, navigation, mining, beach nourishment, reclamation and construction. At a glance, the listed outcome(s) all appear to be beneficial in attaining declared objectives at the chosen sites. However, each of the above have also inherited objectionable effects which may leave a permanent impression on the (coastal) zone features. Literature reviews offered by Boyd et al., (1972), Oosterbann (1974) and Lee and Plumb (1974) have highlighted the advantages and drawbacks of the expected outcome.

As regards the assessment of dredging processes, nine sensitive parameters have been chosen for the coastal zone which would help to identify the relevant impacts due to dredging. Depending on the operational status, the geographical response and the depth of demands vs benefits, the impacts may be viewed as positive and/or negative in the context of developmental scenario. A network analysis of dredging and potential environmental impacts affording description of the said impacts are provided by Sorensen (1971) in an earlier attempt. Massoglia (1977) has attempted the preparation of research projects dealing with impacts of dredging and guidelines in evaluating the said impacts considering the importance of the topic. General material reading is available with Lehmann (1979) addressing worldwide research on dredging and its impacts. In a more recent DIA review, covering water resources projects also, subject review has paid due attention to global implications in light of the benign environment (Canter, 1985).

To present a detailed note on the impacts which would include advantageous effects and the opposite, the following list is self explanatory.

According to Herbitch (1975), the exclusive advantageous effects of dredging are

1. Dredging could be used to remove polluted bottom sediments for safe storage and/or treatment.
2. Conducive to harbour operations
3. Dredging could reoxygenate the sediments
4. Dredging would increase the overall water column content by mixing
5. Dredging brings about release of nutrients to the water column and make them available to suspension feeders
6. Dredging could remove the dissolved and particulate adsorbed pollutants from the water column and tie them up in bottom sediments
7. Regulates the amount of material available at the nearshore regions and
8. Material made available for land reclamation for a growing metropolitan city

and

according to the same author, the deleterious effects are,

1. Increase of turbidity
2. Removal of habitats

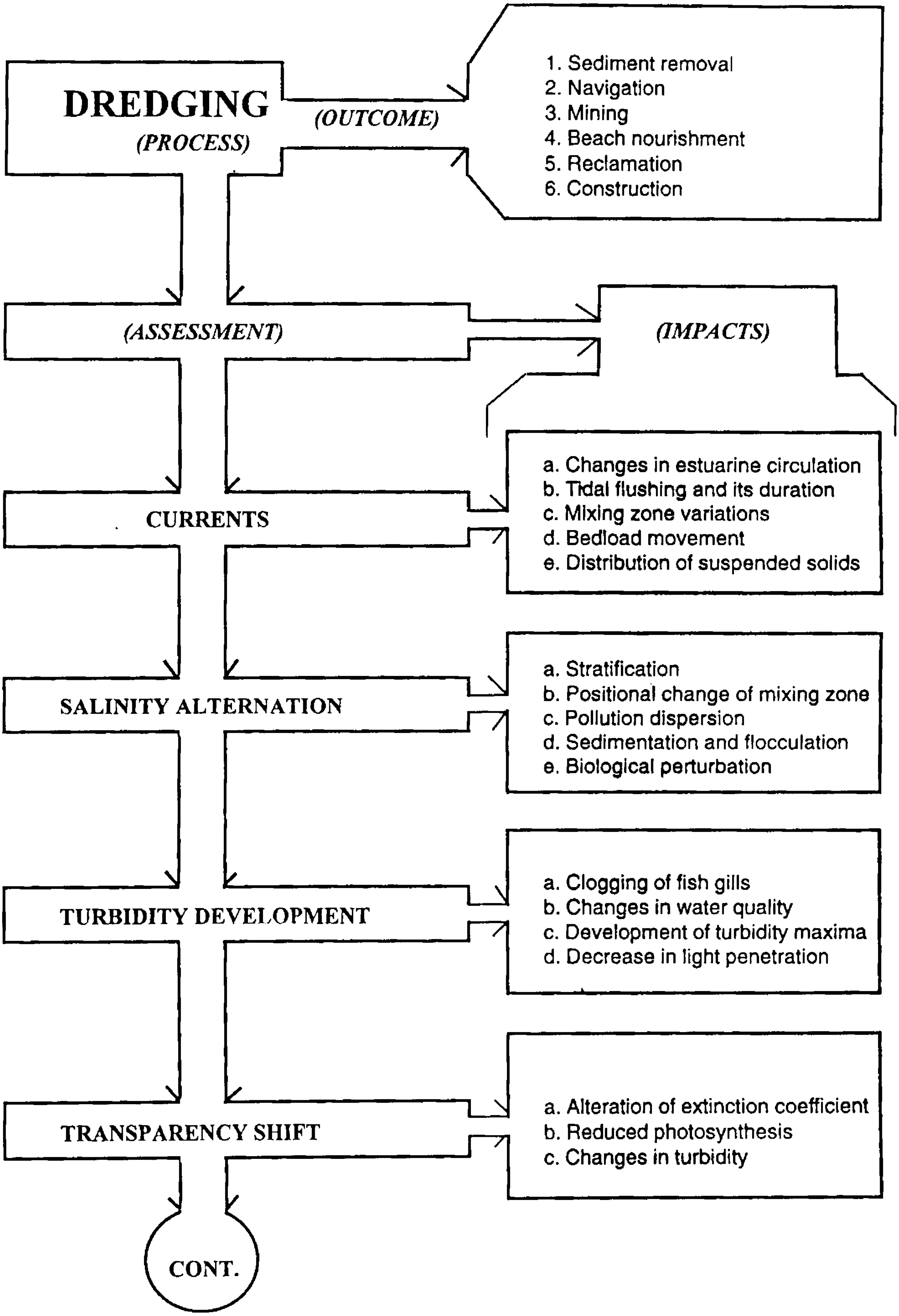
3. Resuspension of polluted sediments, thus causing increase in toxicity
4. Causing physical damage to organisms
5. Creating a barrier to the movement of fish to other sites of marine life.
6. Mortality due to burial of habitat
7. Change of flow patterns
8. Causing turbidity which affect marine life and
9. Consequently affecting directly the marine life, by removing them from the food chain and eventually affecting the food supply to survivor.

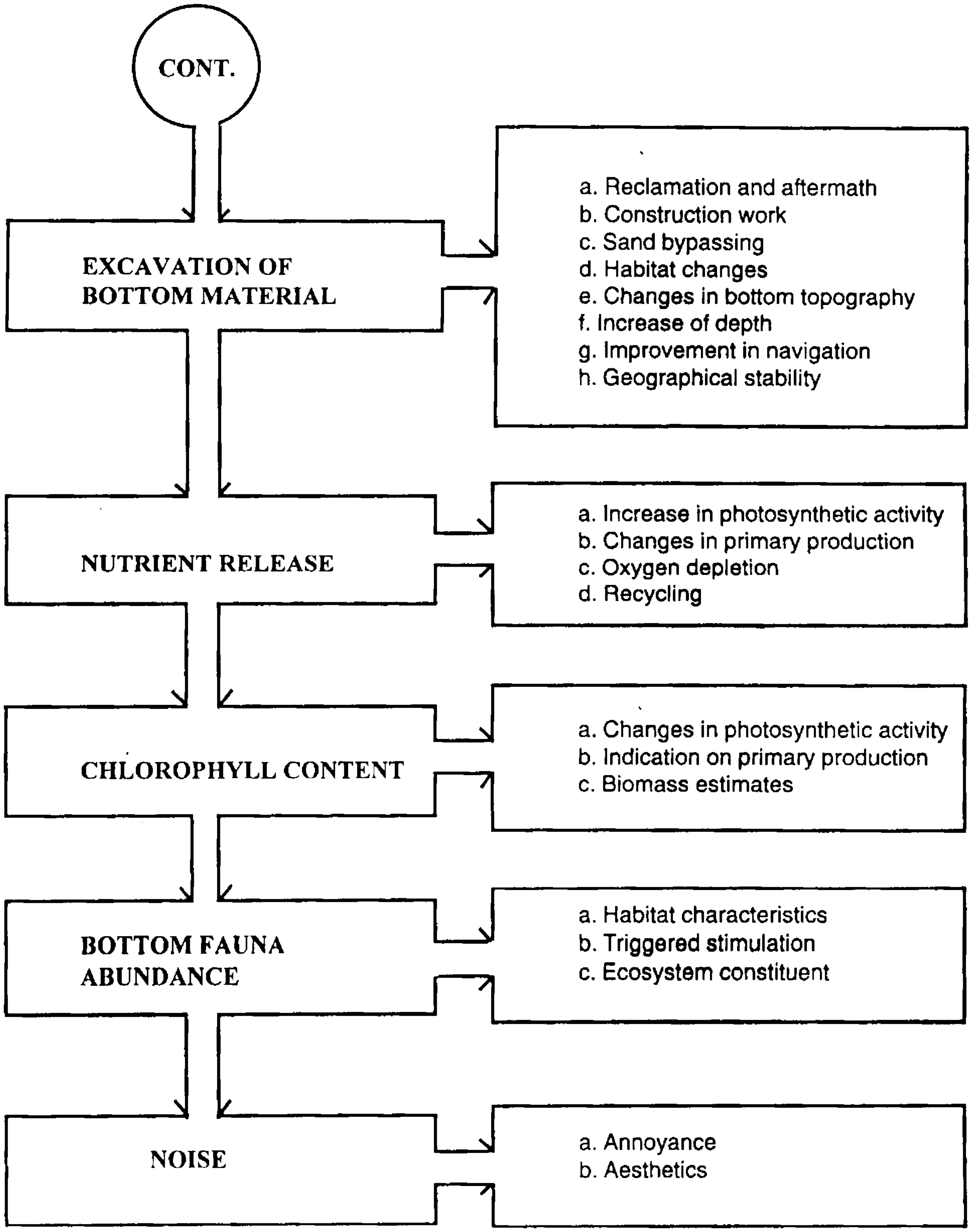
Environmental aspects of dredging in the coastal zone has also been generalised by Windom (1976), PIANC (1977), Bouwman and Noppen (1996) and Burt and Fletcher (1997).

The following discussion is based on the results of investigation presented in chapters 3 and 4 which are dealt in tune with the DIA matrix (flow chart 2). The impact aspects, whether positive or negative, are dealt herein, under different sub-headings.

1. Currents

Field observations indicate that the estuarine circulation at Cochin harbour is an esoteric phenomenon. Feeble currents (1 to 20cm/s) were observed during the slack period at most instances. During the flood phase, the current vectors were


DREDGING
(PROCESS)
(OUTCOME)
1. Sediment removal
2. Navigation
3. Mining
4. Beach nourishment
5. Reclamation
6. Construction
(ASSESSMENT)
(IMPACTS)
CURRENTS
a. Changes in estuarine circulation
b. Tidal flushing and its duration
c. Mixing zone variations
d. Bedload movement
e. Distribution of suspended solids
SALINITY ALTERNATION
a. Stratification
b. Positional change of mixing zone
c. Pollution dispersion
d. Sedimentation and flocculation
e. Biological perturbation
TURBIDITY DEVELOPMENT
a. Clogging of fish gills
b. Changes in water quality
c. Development of turbidity maxima
d. Decrease in light penetration
TRANSPARENCY SHIFT
a. Alteration of extinction coefficient
b. Reduced photosynthesis
c. Changes in turbidity
CONT.



Flow chart 2: DIA matrix in the perspective of Process-Outcome-Assessment- Impacts at dredging site.

directed upstream, mainly along the bottom layers of the harbour region; the extent of intrusion was dependent on the stratification features which is a seasonal phenomenon. As already stated the monsoon period exemplifies a time of strong stratification in this estuary when the presence of saltwater is restricted to the mouth of the estuary partly covering the seaward section of the Ernakulam and Mattacherry channels. Observation further showed that the postmonsoon was a transitional period when low to intermediate current speeds were noticeable, but it was during the premonsoon period that strong current vectors were observed in this waterway. The premonsoon period are the months when well mixed homogeneous waters were noticed at the harbour region. The tidal flushing action has to be well reckoned at this time of the year, when minimum river discharge permit tidal currents to intrude upto the farthermost regions of this vast backwaters. Within the above mentioned seasonal cycle, this study has helped to elucidate a clear circulation pattern in the deeper portions (dredged location) of the harbour region. This refers to currents of near equal magnitudes often encountered in the dredged locations.

The impacts of dredging, assessed in terms of current vectors, indicate that a definite change in estuarine circulation could be perceived in the harbour region. The extent of tidal flushing and its duration appears to be more dependant on river inflow rates and its interaction within the estuary as expected. It may be again summarised that the seasonal estuarine features which may alter from a well mixed to highly stratified condition is definitely a function of tide versus river discharge and consequently the mixing zone variations is also functioned by such changes. However, dredging may have a definite influence in modifying the magnitude of the tidal currents due to deepening of channels at the estuarine river mouth (Ajith and Balchand, 1996). This aspect plays an important role during the premonsoon season; the deepened portion of the channels helps to bring out improved conditions of mixing of seawater with river water (especially during the flood time) thereby causing seawater intrusions to befall further upstream into the estuary. On the other hand, the deepened portions are occupied by seawater under the less dense overlying fresh water of riverine origin bringing about stratified conditions (in monsoon). The mixing zones are thus modified by the action of dredging at Cochin harbour which aid the development of periodic seasonality in estuarine circulation. Apart from this direct consequence of dredging, the presence of water currents may have two functions: modifying the suspended solids distribution at all times of dredging (well evidenced from the results of short term impact studies) and causing bedload movement including resuspension of the unconsolidated particles from the bottom. As shown by this study, the deeper portions of dredged channel is a region where marginal bedload movements are likely to occur due to the differential topographic features; the presence of currents also give positive indications of nepheloidic layer appearance. The above statements are validated by studies on suspended loads within the harbour region and its vertical distribution; the bottom topographic features, time to time, were cross examined to consider aspects related to water currents speeds and translocation of unconsolidated silt and clay from the vicinity of dredged locations. Experience from elsewhere suggest that North American and North European ports are constantly being filled up by sediments and in order to counteract the ill effects, moderate to substantial scale of dredging is being performed. Bryant (1980) reports on the bathymetric changes in three estuaries of the Central New South Wales coast highlighting the influences of currents generated by tides to such extents that suspended load distribution and bedload movements are coincident with the boundaries of marine sand intrusion of the estuary and seawards fluvial transport. At Broken Bay, bathymetric changes are linked to wave climate, in turn related to currents, which may bring about considerable bottom erosion. An excellent study in connection with Jabel-Ali port in Dubai involve channel dredging and the pronounced littoral movement of sediments under the influence of currents. Project proposals involved even modifications in channel orientation, depth factors and break water construction as important requisites to inhibit erosion on the downdrift sector (Loewy et al., 1978). In India, sedimentation problems encountered at Mopla Bay was related to drift movement and partly wave climate (Pillai, 1989). Annual dredging was found to be economically not viable for such a small harbour where offshore sources were identified as partially significant. The currents in the region had a dominant role on the quantity of littoral drift, bed load movement and distribution of suspended loads. Predictive studies consider bathymetric modifications so as to overcome unfavourable sedimentation across the harbour entrance. The role of currents, its assessment and impacts have been well documented as a part of EIA for ports in Thailand by Teetakaew (1986). The incorporation of role of currents in modifying the nautical depths in ports and channels in model studies as well as in real time has been highlighted by Blaauw et al. (1982).

It is now concluded that development of currents especially in the deeper locations of the Cochin harbour contribute to the development and strengthening of the stratification, influence the extent of mixing zone and the processes within, giving rise to formation of turbidity maxima and also play a role in translocating bottom material.

2. Salinity

The direct inference related to salinity alterations point out pronounced seasonal variability in the estuarine characteristics which are helpful in delineating the climatic hydrological features. The results of this survey are in tune with earlier findings on (1) a stratified condition in monsoon (2) salt wedge to partially mixed condition - transitional in postmonsoon and (3) well mixed during premonsoon. The above estuarine features are mainly resultant from the interaction between river discharge and tidal forcing from the seaward side, a fact already stated above and made quite evident from previous studies (Please see Chapter 1, 3. DIA at Cochin Port). Processes such as dredging have had a significant role in bringing about salinity alterations by way of hydrographic changes, thereby causing biological perturbations, significant positional changes of mixing zone and again, close relation to stratification features; effects on sedimentation and flocculation. Features on seawater - fresh water mixing and even deciding the fate of pollutants and their dispersion in the estuarine regions are factors linked to hydrographic changes. The extent of above impacts have been noticed as pronounced in lower estuarine regions where moderate scales of dredging would lead to considerable consequences as reported elsewhere (Tavolaro, 1984; Richards, 1985; Rijn, 1986; Tent, 1987; Amson, 1988; Nichols et al., 1990). As regards the Cochin harbour which is situated in the lower estuarine regions, the dredging activity substantially contribute to the development of stratification at Cochin gut and the adjoining two channels within the harbour area. Deepening of the channels from time to time would bring about associated changes in pollution dispersion, sedimentation-flocculation processes and salinity related biological perturbations. These factors are corollary to the findings on distribution in suspended solids and studies related to benthos. The salinity variations in an estuary is also helpful in deciding the region where formation of turbidity maxima could be noticed; the location is generally in very low salinity regions (0.20) to low/medium salinities (8.00) whereupon seawater when mixing with fresh water leads to the development of a high turbidity zone for reasons explained by Bewers and Yeats (1977), Morris et al.(1982), Esima (1993), Balchand and Nair (1994). In this particular case, during monsoon prolonged stratification is conducive to the formation of turbidity maxima apart from the fact that the river inputs would contribute to the high load of suspended particulate matter. In light of these two facts, the scope of dredging related impacts that would contribute to strengthening of the stratification (obviously due to salinity alterations) will also lead to the presence of an additional quantity of material brought from inland in the runoff plus a fraction locally generated by flocculation processes to locate itself in the channel region. Short term study indicated to a reasonable extent, even the movement of particulates from the seaward side (origin of which may be terrestrial or seaborne) towards upstream. With every dredging activity, there invariably occurs, an associated change in hydrography resulting from deepening of the channels which in turn influence the position of the mixing zone.

3. Turbidity

Field observation on turbidity (suspended solids) around Cochin harbour helps to enhance our understanding on the upper, middle and bottom layers of the estuarine waters, abundantly holding fine to very fine material in suspension. A simple fact relates to the surface (0.0 to 2.0m) which is relatively less turbid irrespective of dredged or nondredged sites considering all seasons except for isolated cases. The subsurface layer (2 to 6m) occupied by moderately turbid waters is linked to many factors-turbulence, estuarine flocculation, river inputs, resuspension from bottom - compounded by dredging processes. In dredged area, the bottom waters indicated sharp increase in the content of suspended solids where the formation of a turbid substrata of loose mud is present. During the postmonsoon season and the following premonsoon, the occasions when intensive maintenance form of dredging was held at Cochin harbour, have lead to the outcome of quite high turbidity prevalence in the estuarine waters by bottom stirring. This fact is, of course, expected and forms part of an indispensable impact factor when dredging is performed for desilting material of fine texture from shallow waters. The vertical and longitudinal extent of turbidity zones will be then decided by turbulent factors, the circulation features brought about by currents and to some extent, by salinity stratification in estuaries as noted for Cochin harbour described in chapter 3 & 4. The particle size also plays an important role in deciding the time scales for resettlement as well as formation of aggregates. The observation during monsoon period revealed high turbid waters in vertical at the harbour region which is a result of land derived sources through run off plus flocs. At Cochin harbour, generally, during monsoon when purpose oriented dredging has to be undertaken, the impacts stand isolated for this season alone and development of nepheloidic layers is seldom conspicuous. The impacts arising out of turbidity development are of mostly direct which include quite evident changes in water quality, presence of turbidity zones which would lead to a decrease in light penetration factors and to an extent, brings about clogging of fish gills. As regards to polluted sediments, even beneficial objectives by way of removal of such hazardous material is not devoid of detrimental factors such as release of toxicants to the overlying waters and associated ill effects. Containment of turbidity development is one such arena when assessment of impacts takes priority. A number of instances have been quoted in literature (Walsh, 1977; Hubbard and Herbich, 1977; Bohlen et al., 1979; Collins, 1980; Holton et.al., 1984; Bailard, 1985; Jarrett, 1985; Vellinga, 1987; Busch, 1989; Kagan, 1991) highlighting the negative impacts arising out of bottom material churn up. In this instance, short term studies have well illustrated development of turbidity zones around activity sites and related changes in water quality along with decrease in light penetration. A few other case histories where from similar examples could be drawn refers to Baltimore harbour tunnel (Siefring and Hart, 1982), Saint John harbour in Canada (Wildish and Thomas, 1985), Ems river (Franzius, 1986), New York Harbour, (Pierce, 1982), Kobe harbour (Morioka, 1981), Port of Bristol (Foy, 1982), Thames

Estuary (Rowlatt and Limpenny, 1987), Coos Bay/ North Bund, Oregon (Muretta and Price, 1982) and Port of Humburg (Tent, 1987).

4. Transparency

Transparency is the property associated with light penetration in the upper layers of the water column measured in terms of extinction coefficient in the context of studies related to assessment and impacts due to dredging. As stated earlier the seasonal aspects are well noted for this parameter too at Cochin harbour. The premonsoon period indicated variation in extinction coefficient to follow a zig zag pattern whereas high values denote monsoonal features due to increase of turbidity. During the postmonsoon period, dredging brings about large influences in conditions of transparency of the water column, otherwise more clear waters are present at surface. In another context, the study also brings about near uniform characteristics in transparency conditions at dredged locations but seasonal geographical influence control the extinction coefficient values at non dredged sites.

Coincident with turbidity development in estuarine waters, the transparency of the water column is reversely affected under conditions of turbulent upsurge of bottom material to surface. Studies have indicated (Smith et al., 1976; Sustar et al., 1978; Munawar et al., 1989) reduction in rates of photosynthesis along with changes in conditions of turbidity thereby altering the status of the ecosystem to some degree or the other. In many a cases (Zhaosen, 1981; Parker, 1981; Herbich, 1985; Nichols et al.,1990) there follows a restorative mode of action on return of turbidity values to normalcy, upon stoppage of desilting, whereby the original photosynthetic activity may continue. However, in very sensitive ecosystems, the assessment on impacts have led to conclusive evidence of a definite amount of damage that would have occurred due to the disturbance in transparency conditions (Rosenberg, 1977; Smith, 1981; Wildish and Thomas, 1985; Teetakaew, 1986; Amson, 1988;). This parameter thus serves as an adjunct in studies related to turbidity development and to delineate zones of particle cloudiness.

5. Sediment textural characteristics

In the context of sedimentological studies for an estuarine region, excavation of bottom material is bound to bring about textural changes in recently settled sediments. The results from such an investigation would also help in understanding partly the depositional tendencies as well as topographical modifications including mudsliding for such regions where unconsolidated material may be dislodged and translocated. Upon dredging, it is common that a slab of the top bed is removed exposing the substrata. With time, the site is either filled up (by sedimentation) or covered from the sites (mudsliding and bedload movement) or left intact. In a highly dynamic estuarine environment, excavated site often is susceptible to refill and the process, time dependent, could be well exemplified by thorough inspection. The limitation would be the extent of thickness that would have been excavated in comparison to a larger bulk of similar material held in the region as a result of long standing accumulating tendencies which is typically true for tropical estuarine harbours.

At Cochin harbour, the relative percentages of sand, silt and clay have not drastically varied in comparison to earlier observations by other workers (Josanto, 1971; Veerayya and Murthy, 1974; Sundaresan, 1991; Seralathan et al., 1993). Another aspect noticed relates to the fact that by the end of the monsoon season, clay fraction marginally increases in the port area at both dredged and nondredged sites. Comparing the dredged and nondredged sites, fine to very fine silt was noticed during the postmonsoon period in regions where dredging had taken place but medium silt and small amounts of fine silt and clay were observed at nondredged sites. A similar picture also was evolved by studies during premonsoon period too. During monsoon, the nondredged sites were dominated by fine silt compared to dredged stations; as season progressed and came to an end, prevalence of higher fractions were noted. At instances when dredging activities would be held at a more closer interval or on a daily basis, the textural studies turn out to be a handy tool to designate such areas which have been excavated and given longer time duration, conduct of similar studies would help to categorize the type of material and even rates of settled sediments could be rather postulated (Krone, 1978; Komar and Reimers, 1978; Martin et al., 1986).

6. Nutrients

In most estuaries, the sediments hold a certain quantity of nutrients (biostimulants) which otherwise would have remained dormant except in such circumstances that they would be released and made good use of as a result of such activities or processes, one being dredging. The outcome cannot be readily perceived for the simple reason that there are other dominating factors which control the cycling of nutrients in overlying waters. Definitely there have been studies which indicated the release/adsorption of nutrients, forming a part of the geochemical cycle and that dredging had played an important role in bringing about such complex reactions (May, 1973; Windom, 1974, 1975). Each constituent of the nutrient, depending upon their chemical reactivity, ionic valency state and tendency to involve in sorption processes decide the ultimate fate of chemical reactivity at the given location. Speciation studies have indicated more complex behaviour of typical nutrients like nitrite, nitrate and phosphate in estuaries and nearshore regions, whereupon, the abundance of a particular nutrient constituent would not be the deciding criteria to trigger higher production. The relative concentrations or even the essential presence of one or more species would work in favour of raising the productivity for the given location. Basically a dredged location, when compared with nondredged sites, should clearly exhibit alteration in nutrient status which may lead to changes in planktonic activity and primary production, even bringing about depletion in oxygen content and evidence (re)cycling of nutrients.

The results of this study evidenced the release - adsorption processes of nutrients due to dredging activities. A good enrichment factor was noted for bottom waters at the dredged site with slight enhancement during the monsoon season. A postmonsoon low in nitrite content was observed due to higher production. This particular variety of the nutrient species is helpful in identifying the extent of intensity of dredging which supported the release of nitrite from sediments to the overlying waters. The above mechanism also leads to enhance our understanding of controlled release of such favourable nutrients to cause higher production or supplement a given region deficient in vital food. The study on phosphate was one which did not clearly depict the release adsorption features due to its well known scavenging effects and speciation tendencies (Sterling and Wormald, 1977; Golterman, 1984 & Nair and Balchand, 1993a; 1993b; Balchand and Nair, 1994). At Cochin harbour, the seasonal aspects favour higher production during postmonsoon season (Sivadasan and Joseph, 1995) when either forms of the nutrients indicated low content in presence of continued dredging operations. This aspect in turn would lead to contemplate about the positive impacts aiding higher production.

7. Chlorophyll

Pigments estimated in a water media constitute excellent parameters which indicate the status of organic production; it involves a good expression of the significance of external forcing parameter(s) which may aid the development or bring about collapse of an ecosystem. Tropical waters of estuarine-nearshore regions are locations where biomass estimates made in terms of pigments (expressed as the content of chlorophyll *a, b & c*) lead to a clear understanding of the rates of biological activity and helps to ascertain directly/indirectly the role of processes like dredging and its impacts on the system(s). In a general sense it may be stated that a reduced chlorophyll content would point out to the reduction in primary production, disruption in the abundance of planktonic presence which could be related to changes in biomass (estimates) and invariably also refer to changes in photosynthetic activity. The pathway which brings about chlorophyll changes due to dredging is by the turbulent effect on churning up the medium thereby causing presence of turbidity which would counteract on the system in two ways - reduction in transparency inhibiting the faculties of light penetration and physically the presence of particulates in the media itself which alter the status of pigment production (Jones, 1981; Bokuniewicz, 1982; Landin, 1982; Tosswel and Webber, 1984).

The analysis of chlorophyll *a* for a period of 12 months (November 1994 to October 1995) indicated that its concentration at the nondredged locations showed typical seasonal variations; the highest values were noted during the monsoon period. The characteristic pattern of chlorophyll *a* distribution stands altered by dredging activities as studied at dredged sites compared to nondredged stations; the distribution and magnitude of chlorophyll *a* concentration at surface and bottom of nondredged locations were more or less the same in content. Generally, bottom samples are greatly affected by dredging activities than surface samples. It was particularly noted that a seasonal peak of chlorophyll *a* concentration in bottom samples occurred which may be due to the replenishment of bottom water with benthic microflora. The actual amounts of chlorophyll *b* was less than other pigments. Chlorophyll *b* bearing flora was greatly affected by dredging activities and the effects are predominant in bottom waters as noted from the content of this constituent; significant difference in chlorophyll *b* was observed between dredged and nondredged sites. Among the three types, chlorophyll *c* was the least affected pigment in both surface and bottom waters of dredged and non dredged sites. Ratioes of pigments would rather suggest a healthy condition of the media. During dredging, the ratio points out to unhealthy conditions which prevail in the waterway.

The three forms of chlorophyll have helped to deduce a better understanding of the waterway surrounding the Cochin harbour. The first form namely chlorophyll *a* helps to identify those regions of the harbour where dredging was held (as indicated by lesser contents of pigments). This aspect in comparison with chlorophyll b whose absolute values were much lower than the form "a", indicated predominant depletion in concentration, especially in bottom waters. At sites where dredging was performed, chlorophyll *b*, then would become an excellent parameter to quantify the ill effects, as well as demarcate the region where influence of dredging would have had more lasting impacts. Chlorophyll *c* on the other hand is a poor choice in asserting the impacts arising out of dredging in this estuarine waters. The concept of considering the ratio of forms of pigments was also useful in this study (Sivadasan and Joseph, 1995).

8. Bottom fauna

Considering that atmospheric inputs (direct) and terrigenous inputs (via rivers and streams), play a role in modifying the coastal environments, of paramount importance, often affording the role of a supportive parameter towards impact assessment from the rigid boundaries of an estuary, an important assessment factor is the bottom fauna. The above aspect in more simpler terms refer to the perturbations in estuarine bed which is often rich in presence of benthic organisms. As vital life forms, the estuarine watershed constitutes an integral part of the ecosystem occupied by benthic agglomerates probably under stress from a number of environmental factors; such as the physical nature of sediments, availability of food (organic detritus and nutrients), the temperature, latitudinal position, day length and biotopic instability (Fischer, 1961) plus a number of other factors (Wells, 1961; Phillips, 1977; Spies and Davis, 1979 and Lewis, 1982) going to influence the habitat of bottom fauna.

Most tropical estuaries exemplify a characteristic food web commonly involving benthic organisms. Any process which is likely to institute originative changes on the bottom life system of an estuary will particularly have long standing impacts on the ecosystem as a whole (Kurian et al., 1975; McCauley et al., 1976; Flint, 1984; Amson, 1988). In establishing the geographical boundaries of an estuary, the bottom bed is invariably one such rigid but ecosensitive plane where benthic fauna has established a way of propagation. The susceptibility of alteration could range from minute elements to destabilising conditions of major preponderance such that impact assessments by processes like pollutional discharges, material excavation, bottom current disturbances etc. would contrive definite signals (Rosenberg, 1977; Nichols et al., 1990). It may be noted that within a seasonal cycle of reasonable duration many environmental factors have been delineated for their extent of influence on the survival and propagation of benthos (Langton and Robinson, 1990). Another aspect reported and often to be reckoned with, is the fact that for a given set of environmental characteristics, a process such as dredging, would bring about an outcome wherein the process triggers a rapid growth and propagation of bottom fauna (McCall, 1977; Jones and Candy, 1981). Thus the study on bottom fauna in relation to impacts due to dredging processes would lead to the generation of good evidence on the role of human interference with natural ecosystems and help to identify the cause-effects for a major enterprise. The study in this direction generally deals with the predominant species in the area of interest. In the context of this study, the abundance of different species at dredged and nondredged site were attempted. Seasonal changes were bound to occur but marked alterations at dredged locations stand out predominantly. The low representation of certain species in dredged area and their tendency for recolonisation on suspension of operations are direct results of the investigation. Kaplan et al., (1975) and Metcalfe et al., (1976) have commended on the factors affecting the colonisation of a dredged channel in the context of impact assessments and have commended on the sediment- tidal current stresses in an area worth major studies in future. The concept of diversity has also some extent of application in this study where higher species density were noted at the nondredged location compared to dredged area but not without exceptions. However at a dynamic environment like that of Cochin harbour, the situation affords ample opportunities in recolonisation, under favourable conditions, a topic of study, vast in its own regime.

9. Other assessment parameter(s)

In toto, excavation of bottom material generally quantified by the term, dredging, has history from the earliest time to the modern 20th century (Gower, 1968) which on record may be placed as one of the proudest achievements of mankind, involving conceptual thoughts and ideas leading to the formulation of one or more scientific advancements; concurrently our understanding on impacts on the environment and their mitigation has not kept pace with development. Proven experience indicate the listing of impacts, mostly direct, from an assessment of bottom material excavation such as reclamation and aftermath, the concept of sand bypassing, habitat changes, bathymetric alterations, primary gains by way of improved navigation and those activities ensuring geographical stability (Flow chart 2). A close analysis indicate that large scale excavation operations are mostly linked with reclamation of adjoining land areas (practiced in Cochin) or towards protection and improvement of landscape or operations directed towards developing conducive facilities in harbours. For a set of given conditions, such activities may be viewed either to bring about negative or positive impacts; to emphasize, such activities will have to be judicially balanced so that reclamation and aftermath would substantiate reasonably the cause for conducive harbour operations or removal of toxic substances or benefit construction work or yet another positive impact factor. Among the known positive impacts, sand bypassing may regulate the amount of material available at the nearshore region. Proceeding a step further, it may be contemplated that a new habitat could be brought into existence within, in a time frame, adapting the technique of translocating certain sediments and caping certain other regions (not reported for Cochin). If successful, this has to be viewed as a positive impact. At the present level of technological growth, it is quite possible that optimally balanced dredging operations could be attempted without disturbing the geographical stability best recommended for Cochin harbour operations. Bottom topography may stand modified at the expense of material made available towards stabilising a growing metropolitan city, greater Cochin being an example for such a site. Parts of land holding resources have been exploited or large estuarine waterways has over the years witnessed changes in bottom topography in and around Cochin harbour. The adjacent landscape (local geomorphology) has existed in harmonious unison but not without negative impacts either of short term or long term duration. To a lesser degree but inviting critical comments is the area of noise pollution and low noise operation, on dredging, which willingly may quantify towards positive impacts when compared to the substantial gains in terms of economy and revenue. Annoyance and disturbance to local community has always been a concern in low ambient noise areas. For a metropolitan city like Cochin, dredging activities here would hardly be recognised and noticed by noise/sound in the midst of countless number of marine vessels plying along the waterways accompanied by heavy rail-road goods traffic within city limits. Added to this, industrial units, semi mechanical enterprises, construction activities add to the dreadful, hubbub pestering the common man. On the other hand, aesthetic values varying from person to person remains still an unquantified entity. In cases where the spoil is of black colour with a fishy oil smell, let out in the open, as part of land reclaim and allowed to dry in a few days time, those regions of human habitat do react and the procedure remains questionable in the light of aesthetic values of great relevance to inhabitants of Cochin. Another scenario is related to coastal dumping from dredgers directly into the estuarine surface waters which is marked by colouration and foaming; this is a thoroughly bad approach in disposal techniques. Another minor point noted on Cochin harbour is that dredging activities do not interfere with historical and archeological packages which adds up to other points under positive impacts but this is again site specific. On aspects related to short term impacts, three cases have been attempted in detail as given in chapter 4. These cases investigate three aspects namely (1) salt silt wedge formation (2) the investigation on short term impacts aimed at perceiving parametric changes before, during and after dredging and (3) occurrences at a site of capital dredging. Case number 2 has been bracketed with the long term studies, discussed earlier, whereas the objectives of cases 1 and 3 are specific and is for explicit purposes. The discussion on assessment- impact on these follows:

Case I. Salt silt wedge and turbidity maxima

The study on suspended solids (distribution), occurrence of turbidity maxima and source of sediments attempts to bring out estuarine features of salt silt wedge. In brief, surface and bottom salinity values indicated partially mixed conditions during premonsoon at the study location in Ernakulam channel. The propagation of high tide brings about higher suspended solids load along the middle and bottom layers of the channel. With the progress of high tide phase, turbidity maxima development has been confirmed; the source includes contribution from seaward side and particles of riverine origin trapped in the turbidity zone. Siltation is likely to occur at and soon after the high slack period in the channel.

The study helps to confirm the premonsoonal behavior of the estuary in terms of stratification. The role of tides, both during high and low, in modifying the distribution salt and silt could be picturised. The study served the objectives of quantifying turbidities in the lower estuarine reaches as well as the longitudinal extent along with vertical three layer differences. Comparing the concentrations of particulates in the wedge it is evident that additional sources will have to be accounted since the riverine inputs were far below those values recorded at the investigation site. The presumption that silt wedge would be composed of particles other than terrestrial origin along with seaborne material originally translocated from the inland sites gains acceptability in light of results given here for lower tropical estuarine reaches.

Case II. Short term impacts of dredging

Dredging operations are known to bring about both short and long term effects on the environment. The short term effects are very conspicuous noted in the some of the parameters of study which are of great concern (results given in chapter 4).

The observation indicated that the currents and salinity at the sites of study is part of the overall estuarine circulation. Transparency is directly linked to turbidity and has been a very useful tool in marking the zone of influence due to dredging activities. Yet another factor of variability is that related to sediment characteristics. Percentage amounts of different textural content, on comparison, proves that the degree of alteration of the features are noteworthy, rather than the absolute content of each type of the sediments.

Of prime interest to biologists and environmental management people are aspects on nutrient dynamics which poses thoughtful prepositions. In many an instance, the disturbance of a media leads the environment to act as a source or sink. The Cochin environment indicates that nitrites are released on dredging to the bottom waters and normal values are not attained within a reasonable time of one day of dredging. However, this does not apply in the case of phosphates which showed an estuarine variability under the influence of dominant chemical control. Short term variations are conspicuously noted when trends fail to reveal more categorical picture on cycling of phosphates as nutrients. Pigments are a different class of indicators which readily responded to dredging activities. Chlorophyll a & c increased in content at surface and often peaked in bottom layers. On stoppage of dredging, chlorophyll a & c showed tendencies to attain normal values. Chlorophyll b being lesser in magnitude, its variations were less conspicuous. Benthic fauna too is a high response category of indicator in study of short term dredging impacts. The loss of benthos in an ecosystem as against its necessary presence and continuance can readily be noted on desilting operations.

Case III. Siltation study at a capital dredged site

Apart from short and long term effects for a highly dynamic environment, capital dredging often provides special interest by way of increasing our understanding on nature's capability to partially or completely overcome anthropogenic impacts. A capital dredging site at Cochin, meant for aiding land reclamation, afforded opportunities to quantify the extent of suspended solids excavated and its distribution, rates on dredged pool fill up and link the features to aspects of seasonality. Bathymetric approach supported by textural changes elucidate sufficient information on estuarine processes aiding the refill of dredged sites on contrasting time scales and good estimates were made on per day depositional rates along the one inner channel at Cochin harbour under the influence of low to very high river inputs. The dredging operations also could be viewed as giving rise to positive impacts when material of reasonable quantity could be made available for alternate purpose such as land fill and low grassland development. Bank/beach nourishment and improved landscape could be achieved if the event is clocked timely with major climatic events involving terrestrial inputs to coastal plains via vast waterbodies and allowing settlement thereof in low estuarine reaches as a part of natural processes. An illustrative case of very recent times has been the successful construction of a dam by dredgers as a means to prevent coastal erosion at Eierland, Isle of Texel, The Netherlands (Rakhorst et al., 1997).

10. Critical assessment of dredging impacts

The DIA has been evolved based on systematic approach identifying the main impacts by a judicious selection of assessment parameters. Issues connected with impacts on the environment evidence long term cumulative effects on one hand and on the other, short term effects reflect relative severity of effects. Applying DIA concepts, both positive and negative impacts have been noted for Cochin harbour. A critical assessment of dredging impacts is attempted in the following paragraphs.

Results and conclusions indicate that negative impacts are quite evident on studies of assessment parameters, namely, turbidity, transparency, chlorophyll and bottom fauna. Current and salinity are two parameters which by themselves constitute the parts of the hydrodynamic and stability factors but appear to play a balancing role in control of physical forces in Cochin harbour. Their influence in the present context can not be independently isolated but forms an integral part of the geographical setting and the system, as a whole itself.

Parameters included in assessment studies, namely, nutrients and aesthetic values have varied impacts. The two are site specific and could alter in status depending on local characteristics. Lastly, but not the least, the textural features of the bottom material at Cochin appears to be affected only to a minor degree, though the selection of a such a parameter could otherwise prove highly beneficial under certain situations. The study also reckons the importance of the positive impacts which mainly include improved facilities for harbour operations and guaranteed navigational facilities (as reported by means of study on a number of selected parameters). During many instances, the spoil excavated serve as landfill material or is applied for reclamation purposes within the harbour region. The dredging activity also plays a role in regulating the amounts of material made available to the nearshore region, manipulating the beach stability on either side of the channel region in the proximity of the ocean boundary and may also be a favourable factor in lowering the pollution loads accumulating in the bottom sediments plus nutrient release to the overlying waters. The overall low level noise of operations is a positive aspect for Cochin harbour. Other minor impacts relate to short term, purpose oriented dredging and/or disposal techniques conducted in an objectionable manner and such operations are to be dispensed off.

Coming back to major negative impacts, turbidity indicates a higher degree of concern in the light of deleterious negative impacts. Closely associated with turbidity are impact assessments on transparency and chlorophyll which are closely linked to the development of turbidity. Inadvertently, negative impacts are also well impressed on bottom fauna while assessing the degree of damage which would lead to feasibility of dredging and on the extent of excavation that is being currently held in this region. The answer to this lies in conduct of dredging exerting stress on the existing ecosystem for the sake of development. On a general note, compromising on bottom fauna would deprive achieving any worthwhile results on dredging a site for achieving highly beneficial proclaimed objectives; alternatively an undisturbed area within an identical geographic setup, in the neighbourhood, may be left part for the continuance and growth of the ecosystem. It shall be ensured that the dredging operations and its ill effects are restricted and would not influence the ambient environment in such a case. Applying such postulation for the Cochin harbour area, the dredging operations definitely have a negative impact at the sites of operation with a limited longitudinal influence but the vast expanse of the backwaters remain untouched permitting biological activity to thrive in the bottom sedimentary layers. Referring back, turbidity and other two assessment parameters which had indicated negative impacts at Cochin harbour, the effects are direct. Though lowering the scale of operations or completely abandoning dredging would appear as a simple solution, which is impractical, the mitigation measures will have to address alternatives in control and prevention of many adverse effects. Such mitigation measures address the problem in many number of ways as discussed hereunder.

Development of unrestricted turbidities are tackled by use of appropriate type of the dredger based on the type of sediments and correct transportation and disposal techniques with the aid of suitable mechanical implements. At Cochin harbour seldom care has been taken in control of turbidity leave alone the questions on environmental care. The role of dredging in removal of toxic substances or unpreceedently militate nutrient cycling are issues to be reckoned with every such operation which involves the trade-off between benefits versus perdition (Kothe, 1997). In this context, two assessment factors (current and salinity) which have been identified as "in equilibrium" may swing unilaterally to result in unfavourably conditions leading to catastrophic results at Cochin harbour in the event of accelerated dredging activities. The detrimental effects would extent upstream of the excavation arena manipulating the tidal flushing and its duration, result in noticeable changes in estuarine circulation, bringing about mixing zone variations and also lead to alterations in sedimentation and distribution of suspended solids; concordantly the status of salinity stratification and pollution dispersion would stand modified. The biological perturbations are beyond comprehension in the event of extensive area dredging. Both long term and short term effects will be more prominently reflected which includes destabilising effects on estuarine land boundaries and altered style in bedload movements. The necessary requirement of dredging at Cochin harbour is evidently limited to maintenance form of operations (mostly) to ensure smooth traffic operations in which case mitigation measures as well as alternate technology and better viable means are cited hereunder to preserve and improve the quality of environment and reduce operational costs.

11. Mitigation measures and alternate approaches

The mechanisms to reduce the negative impacts centre around (1) control on the amount of suspended solids (inclusive as bedload), moving into and silting within the harbour premises and (2) effective, timely and purpose oriented dredging applying the most appropriate mode of excavating technique(s). Individually or a combination of above mentioned factors shall ensure profitability, better upkeep of the environmental conditions and reflect on the degree of scientific excellency in achieving better target results at low impacts.

At many harbours and ports where dredging operations had to be introduced since more than 150 years, past approaches in studies of lowering dredging cost involved model studies. The general outcome of such approaches were recommendations involving construction of breakwaters, groynes or large pit excavation. Some amount of success have been reported (Gower, 1968) but the feasibility and cost effectiveness is a trade off between economy and technical achievements. This is particularly so in light of alternate means to circumvent many of the impact issues (Vandycke, 1996). To state in simpler terms, the use of appropriate type of dredger without operational constraints such as local traffic, proximity to structures, operational timings, locations within intertidal zones, dump locations, seasonal restrictions and more importantly the environmental acceptability would to a large extent alleviate the inherent problems to tropical coastal harbours. At Cochin, trailing suction hopper dredger and grab dredgers are commonly used. At times, cutter suction dredgers have also been used for the conduct of capital dredging along with pipeline discharge. Suitability of other types of dredgers have not gained popularity. For example, installation of sand-clay pumps over conventional dredgers or use of sweep beam dredger (Arts and Kappe, 1996), underwater bulldozers or the newer concept like mud cat dredgers making use of mud shield (considerably lowering turbidity in local waters) may be better alternatives in reducing negative impacts as well as achieving better results (Bray, 1979). The appropriate choice of the type of the dredger(s) and its applicability without operational and environmental constraints is strongly suggested for consideration of decision makers keeping in mind the hydrogeoenvironmental scenario of Cochin. Alternatively, sedimentation controlling systems, appropriate timing of dredging, use of simple and effective semi mechanical devices (as stated above) augmented by hydraulic control, application of concept of nautical depth (Hellema, 1982; Mathew and Chandramohan, 1989) coupled with high tide timings would be advantageous in achieving desirable objectives.

One aspect of concern at Cochin harbour is material movement from the seaward side into the navigational channels, mainly during post and premonsoon months. This period of the year coincides with the timing of maintenance dredging often practiced in this harbour. This study had considered the above aspect in light of low river inputs, extensive churning up of unconsolidated mud of the harbour region, increased marine traffic operations contributing to turbulence, possibility of mud sliding and importantly, the strengthening of tidal currents. The above factors individually or in combination give rise to frequent necessity of material excavation to circumvent silting problems. One approach would be to restrict the movement of material across the tidal inlet thus preventing the shallowing features of the inner channels within the harbour. A suitable cost effective methodology would be to contain the suspended particulate and sediment intrusion during the flood tide by means of using curtains to ventilate the inlet during the high tide period but for depths lesser than 6.0m. The choice of depth could be functionally altered upon actual practice and design features of silt curtains depending on the extent of control to be exercised on inward movement of material for the purpose of maintaining the required draft. Other approaches are fluidization, side casting, silt traps, silt-clay bypassing and to a smaller extent localised agitation dredging in specific cases (Bates, 1978; Bray, 1979; Skelly, 1985 and Hayes et al., 1988). Most of the above alternatives can be applied at locations in the proximity of the harbour or upstream with moderate technical skills. In principle, the objective would be to achieve considerable reduction in material movement and sedimentation within the perimeter of harbour operations. Passive devices like current deflecting wall (CDW) which could be permanently installed in a waterway at locations further away from the harbour could prove effective means of checking silt-clay movement into the harbour sites (Kirby, 1993). Turbidity could also be reduced by use of silt retaining curtains, turbidity screens or diapers which surrounded the dredging sites to contain the agitated mud such that the currents would not transport material to other regions of the channel(s) (Johnston, 1981). The above approach may be of significant importance to operations at Cochin harbour. The concept on nautical depth (specific gravity of clay suspension in water close to 1.2 or less) shall permit the passage of vessels which has of course gained popularity universally.

The DIA studies at Cochin harbour had considered assessment parameters namely current, salinity and textural characteristics apart from a few others (see Flow chart 2) and impacts thereof have been critically discussed in detail (earlier part of this chapter). A novel concept do emerge on reasoning and may be useful towards implementing better control and understanding of the silting processes in channels of Cochin harbour. The basis of the concept coincides with the seasonal stratification features in channels which have been observed from time and time and is now well supplemented by data on current vectors. There exists a hydrostatic inequality comparing the river basin and coastal plains which afford a divergent field which is conducive for sedimentation. It is pointed out that the location of the harbour incidently lies in the divergent plains; the waterway beyond and towards the seaward side is restricted along a tidal inlet of narrow dimensions which would further act as a retardant in the free exchange or unidirectional transport of terrestrially borne material (river inputs to ocean systems). The fluid motion indicates sluggish nature of currents in the proximity of the boundaries of the channels. This condition positively favours sedimentation of finer silt and clay. During post and premonsoon the estuarine circulation hence predominantly brings about sedimentation in and around the harbour region.

Another fact which has received attention is based on the results of this study that turbidity maxima zones often develop in the channels which are again brought about by features of estuarine circulation. Closely probing the causative factors of sedimentation in lower estuarine reaches, the formation of cohesive sediment flocs and accretion of cohesionless coarse sediments are the contributing factors to the addition of material at this harbour. To substantiate this feature, the location of the mixing zone necessarily occurs and passes through the channels of the Cochin harbour. The hydraulic regime is thus currently designed to act as a precursor to aid sediment flocs formation supporting the silting of a portion of such forms of the particulates right within the channels. The stratification phenomena with the event of monsoon and during later seasons (post and premonsoons), the tidal currents, setup a conducive environment favouring sedimentation. The working of hydraulic regime is thus helpful in understanding the equilibrium conditions being maintained (with respect to depth) in vast expanse of backwaters but not in the channels of the Cochin harbour. Under such conditions, effective means of minimising the degree of sedimentation and quantities would be to exercise control over the amounts of terrestrial inputs at upstream locations (techniques already listed above) and to apply additional alternate procedures like that of agitative dredging (say by means of plough- causing unconsolidated mud to eject into the water in a mixture of air and water jet and to carry the same offshore (Gordon, 1982)) during the ebb tide phase alone. The actual location of such operations to be performed in the outer channel is based on the design objectives.

CHAPTER 6

SUMMARY

Dredging is a major human intervention leading to changes on the face of the (aquatic) environment. This is an artificial operational procedure requiring skilled manpower towards successfully achieving multiple objectives. Upto very recent times, developmental issues were projected in conduct of dredging with little care for the environment. Now a days, with increasing awareness on environmental issues, impact studies play an important role in execution of projects which invariably also addresses questions connected with dredging and environment (Hummer, 1997). The dredging impact assessment primarily looks into areas of negative impacts arising out of environmental issues. At Cochin harbour, where DIA has great relevance could serve the operators, managers and policy makers alike with valuable data, priceless information, experimental inputs and analysis of the hydro-system so as to evolve a judicious plan programme for the region. The salient features of DIA are summarized hereunder.

(A) The scientific objectives of conduct of DIA has been defined as identification of process - outcome - assessment -impacts at Cochin harbour.

(B) Identification of impacts and relevant assessment parameters have been made.

(C) Monitoring and assessment based on surveys/field experiments/laboratory analysis has been successfully carried out.

(D) The dredging process, among other outcome(s) at Cochin harbour includes sediment removal, navigation, land reclamation, harbour expansion and a few related developmental schemes.

(E) Assessment has been based upon studies on current and salinity alterations, turbidity development, transparency shift, excavation of bottom materials, nutrient release, chlorophyll content, bottom fauna abundance and noise.

(F) For each parameter listed above both negative and positive impacts have been critically assessed.

(G) Existing issues and recommendations on mitigation measures have been suggested.

(H) The DIA has helped to deduce the following major negative impacts:

1) Excessive turbidity values are of great concern.
2) Increase in extinction coefficient inhibits productivity.
3) Pigment level changes are expected concurrent with alteration in chlorophyll content.
4) Benthic fauna has been greatly affected.
5) Extension of dredging to other areas of the harbour and backwaters would definitely bring about ecosystem disturbances.

6) Dredging brings about local turbulence leading to changes in intensity of mixing.

7) Bathymetry and bed configuration changes may have impacts on inlet stability and estuarine embanks.

(I) Two parameters namely current and salinity have helped to deduce the influence of hydraulic control on estuarine processes vis-a-vis dredging operations. The flood tidal currents are identified as the causative agent to transport material from offshore to boundaries within the harbour area and salinity alterations bring about changes in flocculation and sedimentation features in this tropical estuarine harbour.

(J) Nutrient recycling is quite evident at Cochin harbour due to dredging operations.

(K) Textural characteristics of bottom sediments are relatively less affected by dredging operations in Cochin harbour.

(L) Generation of noise due to operation of dredgers is engulfed in the city cacophony and does not bring about annoyance.

(M) Appeal on aesthetic values are offended at times due to unethical disposal techniques.

(N) The DIA has helped to deduce the following major positive impacts:

1) The excavation activities are conducive to harbour operations.
2) Round the year marine navigational facilities are afforded by maintenance form of dredging at Cochin harbour.
3) Unquantified amounts of toxic substances, if any, is being removed from within the harbour region.
4) The artificial operations regulate the amount of material made available to the nearshore regions.
5) The dredged spoil, at times, is made available as material for land reclamation towards the growth of the metropolitan.
6) Low noise operation is a positive achievement.
7) The dredging operations do not interfere with historical and archaeological packages which are numbered but significant around Cochin.

(O) Salt silt wedge studies have led to the understanding on the development of turbidities in the vertical and on the longitudinal extent towards upstream, during premonsoon.

(P) The siltation study at a capital dredged site has helped to evolve a picture on the sedimentation pattern within the channel. Restoration of the dredged site after a period of intermittent dredging coincides with seasonal availability of sedimenting material.

(Q) To a certain extent ecosystem disturbances are unavoidable in light of (beneficial) development; compromise on bottom fauna warrants careful attention.

(R) Mitigation measures and alternate approaches call upon the implementation of programmes to control the amount of suspended solids reaching the dredging zone and to apply the most appropriate mode of excavating mechanisms.

(S) The feasibility of use of sand clay pumps or mud cat dredgers may be attempted.

(T) Control on material movement into the channels could possibly be minimised by sediment curtains or silt traps or passive devices like current deflecting wall.

(U) Agitative dredging during ebb tide in the approach channel of Cochin harbour is a highly skilled professional operation which would considerably reduce the silt movement through the tidal inlet into the inner channels of Cochin harbour.

(V) The DIA has successfully reviewed the contemporary status of dredging at Cochin harbour to delineate the degree of success/failure and highlights the need towards the development of a policy framework to address and evolve a criteria based evaluation of dredging operations under DIA so as to bring about ecofriendly mode of environmental management.

(W) As concluding remarks, studies have revealed that dredging activities at Cochin harbour evidence environmental degradation. However, there are distinctive positive benefits too. Contemplating that this artificial activity had been implemented since four decades or more, in varying scales of intensity, it remains to be an accepted fact that a "static environmental equilibrium" do exist between natural retrogressive tendencies and stressful conditions arising out of desilting mechanisms. Possibly a time has now come forth to preserve and improve the harbour scenario by means of applying state of art technology. Such an approach would facilitate upgradation of the present environment and also pave the way towards better and healthier developmental enterprises for the region as a whole.

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APPENDIX-I: List of Publications/Presentation of Papers in Seminars/Conferences

Ajith, J.K., Rasheed, K. and Balchand, A.N., 1995a. Impact assessment om tropical estuarine characteristics in relation to river management approaches. IAPSO Symposia, Hawaii, Abstract PS 05, pp 117.

Ajith, J.K., Rasheed, K. and Balchand, A.N., 1995b. The role of natural coastal processes at a tropical tidal inlet in hinterland development. Proc. Int. Conf. Coastal Change'95, Bordomer -IOC, Bordeaux, 373-377.

Ajith, J.K., Rasheed, K. and Balchand, A.N., 1995c. The dynamics of a seasonal barrier beach vis-a-vis coastal ocean processes in tropical fluvial environments. IUGG XXI General Assesmbly, Boulder, Colorado, Abstract OB12A-3, B312.

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Rasheed, K. and Balchand, A.N. 1995. Dredging Impact Assessment (DIA): Sedimentation vs Desilting. Proc. Natn. Sem. Environ. aspects of Water Resour. Develop. Mange.,Thiruvananthapuram, 59-62.

Rasheed, K., Ajith J.K. and Balchand, A.N., 1995a. Studies on salt-silt wedge in Cochin estuary and development of turbidity maxima. Proc. of 7th Kerala Sci. Congress, 82-83.

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Rasheed, K., Ajith, J.K. and Balchand, A.N., 1995c. Sedimentation in tropical estuaries - A case study on marine operations at Cochin in relation to hazard mitigation. IAPSO Symposia, Hawaii, Abstract PS 05, pp 118.

Rasheed, K., Ajith, J.K. and Balchand, A.N., 1995d. Shoreline modifications at a tropical tidal inlet concordant with landscape management and waterways development. IUGG XXI General Assembly, Boulder, Colorado, Abstract OB12A, B312.

Rasheed, K. and Balchand, A.N. 1997. Dredging Impact Assessment (DIA) at Cochin port. Abstract,INCHOE'97, Thiruvanathapuram.

Rasheed, K., Anujee, T.K., Ajith, J.K. and Balchand, A.N., 1997. Transport processes in estuaries - significance of circulation and formation of turbidity maximum. Abstract IAMAS-IAPSO, Melbourne, Australia.