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 comprehension 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
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 Herbitsch (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
1. Sediment removal
2. Navigation
3. Mining
4. Beach nourishment
5. Reclamation
6. Construction

DREDGING
(PROCESS)

OUTCOME

ASSESSMENT

IMPACTS

CURRENTS

CURRENTS

- Changes in estuarine circulation
- Tidal flushing and its duration
- Mixing zone variations
- Bedload movement
- Distribution of suspended solids

SALINITY ALTERNATION

SALINITY ALTERNATION

- Stratification
- Positional change of mixing zone
- Pollution dispersion
- Sedimentation and flocculation
- Biological perturbation

TURBIDITY DEVELOPMENT

TURBIDITY DEVELOPMENT

- Clogging of fish gills
- Changes in water quality
- Development of turbidity maxima
- Decrease in light penetration

TRANSPARENCY SHIFT

TRANSPARENCY SHIFT

- Alteration of extinction coefficient
- Reduced photosynthesis
- 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., 1978; 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
chlorophyll have helped to deduce the waterway surrounding the Cochin harbour where dredging was held (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. Ratios 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, 1981; 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 salt 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 unprecedently militate nutrient cycling are issues to be reckoned with every such operation which involves the trade-off between benefits versus perdiction (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 floes 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 floes 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.