CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

Water quality studies of tidal influenced estuaries should include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics as they require limited data collection and may be utilized to assess a range of management alternatives. Once the hydrodynamics of an estuary system is understood, computations regarding the related coastal processes like dispersion and pollutant transport will become relatively simple extensions to the hydrodynamic modelling. For example, the dispersion of the pollutants may be analyzed from tidal current information developed by the numerical models.

2.2 ESTUARINE WATER QUALITY

Estuaries, a mixing region between river and ocean waters, are the most valuable ecosystem related to human activity (Robert et al., 1997). The most severe pollution problems observed in estuary water quality are nutrient enrichment, organic carbon loading, oil spills, and toxic chemicals (Kennish 2001). The temporal variability and spatial distributions of nutrients in estuaries are controlled by a complex physical–biological–chemical interaction process associated with external loading, tidal advection/dispersion, and wind mixing as well as groundwater inputs.
2.2.1 Nutrients

Excessive nutrient supply in estuaries can result in enhancement of algal productivity and accumulation of biomass, with secondary effects resulting in changes in planktonic community structure (Smetacek et al. 1991). Anthropogenic nutrient enrichment and organic carbon loading are linked to the eutrophication of estuarine waters (Nixon 1995, Valiela et al. 1997; Smith et al. 1999). Degraded water quality due to the availability of nitrogen and phosphorus to algal species is identified as the primary cause of the decline of submerged aquatic vegetation in Chesapeake Bay and its sub estuaries (Staver et al., 1996). Nutrient uptake of highly turbid Humber estuary and adjacent coastal waters was studied by Peter et al. (1998). Tripathy et al. (2001) analyzed chemical and biological parameters at sixteen stations in the mangrove ecosystem, of the Godavari river estuary and Kakinada bay to understand the status of water quality and the impact of external inputs during southwest monsoon.

2.2.2 Dissolved Oxygen

Dissolved oxygen is an important parameter for evaluating water quality in estuaries, because it influences the living conditions of all aquatic organisms that require oxygen. Urban, industrial and agricultural activities and natural occurrences in catchments affect DO levels in streams and other water bodies. The low DO concentration in the water body directly affects the survival of fish, migrations of higher organisms, and thus alters estuarine ecological balance. Frequent occurrences of hypoxia due to sudden shutdown of DO which causes significant reduction in fishery harvests, toxic algal blooms, and loss of biotic diversity (Howarth et al., 2000). The temporal variability and spatial variance of DO in estuaries are controlled by multiple physical and biochemical processes. Physical processes include current advection and turbulent mixing, while key biochemical processes are re-aeration, oxidation due to the carbonaceous biochemical oxygen demand, phytoplankton photosynthesis and
respiration, nitrification, sediment oxygen demand, and bacterial respiration (Ambrose et al., 1993; Chen, 2006). Studies of dissolved oxygen are often conducted for water quality (Lianyuan et al., 2004). Spatial and temporal variations of Dissolved Oxygen and Biochemical Oxygen Demand in the Gulf of Kachchh, was assessed based on data collected since 1976 (Desa et al. 2005).

2.2.3 Heavy Metals

Increase in urbanization and industrialization leads to an increase of waste discharges into estuary may contain heavy metals among other pollutants. Through the natural process of biomagnifications, minute quantities of metals become part of the various food chains and concentrations become elevated to levels which can prove to be toxic to both human and other living organisms (Ackefors 1971; Bryan 1971). Heavy metals entering the aquatic and sedimentary environments can do so in a variety of chemical forms (De Groot et al. 1976). There are five main sources of heavy metals in aquatic and sedimentary systems: erosion of geological sources, industrial processing of ores and metals, the use of metals and metal compounds in industry, the burning of fossil fuels, and leaching from refuse dumps (Wittmann and Forstner 1980). The estuarine environment is the last area for the removal of trace metals in their passage from the terrestrial to the marine environment (Scott et al., 1988). Heavy metals occur naturally as they are components of the lithosphere and are released into the environment through volcanism and weathering of rocks (Fergusson 1990).

Industrial effluent and mining can create a potential source of heavy metal pollution in the aquatic environment (Lee and Stuebing, 1990; Gumgum et al., 1994). An assessment of heavy metal concentrations was performed on two sheltered littoral locations on the north-west coast of Ireland by Gallagher et al., (1996) and an increase in heavy metal concentrations landwards was observed. However, large-scale release of heavy metals to the aquatic environment is often
a result of human intervention (Denton et al., 1997). Heavy metal discharged into the marine environment can damage both marine species diversity and ecosystems, due to their toxicity and accumulative behaviour (Matta et al., 1999). Under certain environmental conditions, heavy metals might accumulate up to toxic concentrations and cause ecological damage (Guven et al., 1999). The surface water is a medium which are commonly used for heavy metal pollution assessment. Heavy metals are stable and persistent environmental contaminants of coastal waters and sediments. Interest in metals like Zn, Cu, Fe and Mn, are required for metabolic activity in organisms, lies in the narrow “window” between their essentiality and toxicity. Fatoki and Mathabatha (2001) investigated the impact of potential pollution sources and distribution of heavy metals (zinc, cadmium, copper, iron, manganese and lead) in seawater and in sediment of East London and Port Elizabeth harbours. Both are ports of major importance to the area in South Africa.

Heavy metals like Cd, Hg, Cr and Pb, may exhibit extreme toxicity even at low levels under certain conditions, thus necessitating regular monitoring of sensitive aquatic environments (Peerzada et al., 1990). Several methods described for the determination of heavy metals in marine environments. These include graphite furnace-AAS (Burguera et al., 1995), flame-AAS (Dapaah et al., 1999; Gomez-Ariza et al., 1999), atomic fluorescence spectrometry (Cheam et al., 1992), anodic stripping voltammetry (Fischer and Van den Berg, 1999; Morales et al., 1999), ICP-AES (Hiraide et al. 1980) and ICP-MS (Ridout et al., 1988; Sakao et al., 1999).

2.3 WATER QUALITY INDEX (WQI)

Assessment of surface water quality can be a complex process undertaking multiple parameters capable of causing various stresses on overall water quality (Bharti and Katyal, 2011). To analyze water quality, different
approaches like statistical analyses of individual parameter, multi-stressors water quality indices, etc. have been considered.

WQI is a mechanism for presenting a cumulatively derived numerical expression defining a certain level of water quality (Bordalo et al. 2006). Simply the WQI summarizes large amounts of water quality data into simple terms (e.g., excellent, good, medium, poor, etc.) for reporting to management and the public in a consistent manner.

In recent decades, various tools have been developed to assist water quality management including mathematical models, optimization approaches and integrated decision support systems (Huang and Xia, 2001). The water quality indices are also being developed and used world-wide due to their simplicity, adaptability and easy-to-use nature (Kannel et al., 2007; Simoes et al., 2008). The popularity of the Water Quality Index (WQI) comes from its pragmatic structure; complex mathematical evaluations of huge quantities of water characterization data are transformed into a simple scale value. This value is easily comprehended by planners, managers and the general public. Some notable implementations of WQI were by the US National Sanitary Foundation (NSF), Oregon Department of Environmental Quality, British Columbia Ministry of Environment, Canada Council of Ministers of Environment (CCME) and Environmental Protection Administration of China (Chen et al., 2006, Lumb et al., 2006).

Methodologically, WQI can be based on objective or subjective criteria. Objective WQI make use of statistical analysis based on pre-defined threshold values set by administrative boards. Subjective WQI are based on a parameter set, relative weights, normalization curves and aggregation algorithms (Abbasi, 2002). The common application areas of WQI are surface waters, coastal areas or aquacultures contaminated by heavy metals and/or organic
matter (Jonnalagadda and Mhere, 2001; Said et al., 2004; Liou et al., 2004; Atazadeh et al., 2007; Kaurish and Younos, 2007).

2.4 ESTUARINE HYDRODYNAMICS

Mixing processes have a major impact on the water quality and ecology of estuarine environments. Knowledge of estuarine circulation pattern is of fundamental importance in determining pollution disposal, dredging methods, nutrient fluxes, resident times and many other estuarine processes (Bjorn 1978). While much observational and theoretical research focused on the identification and quantification of the physical mechanisms driving mixing and dispersion (Fischer et al 1979), little progress has been made on predicting dispersion from first principles (Smith 1977). This is largely due to the extreme complexity of estuarine systems. Estuaries and coastal sea have circulation patterns that are vastly varying in time and space. The hydrodynamic regime in an estuary is governed by the interaction among fresh water inflow, astronomical tides, surface wind stresses, wind-generated surface waves, the Coriolis force, the geometry of the water body, and roughness characteristics of the sedimentary bed material (Dyer 1973). Fresh water flow astronomical tides, surface wind stresses, wind-generated surface waves, the Coriolis force are the driving forces for hydrodynamics. Geometry includes size, shape and bathymetry of the estuary. The geometry and bed roughness interact with the driving forces to control the pattern of water motion (in particular the shear stress and turbulence structure near the bed), frictional resistance, tidal damping, and degree of tidal reflections (Ippen 1966). Ming et.al (1999) studied the numerical simulation of circulation and salinity distribution in the Tanshui estuary. A field experiment and hydrodynamic modelling study of Apalachicola estuary was conducted by Wenrui (2003).
2.4.1 Tide

The word 'tides' is a generic term used to define the alternating rise and fall of sea level with respect to the land, produced by the gravitational attraction of the moon and the sun. Tides depend greatly on the variability in velocity, density, pressure, and sea level rise. Ocean tides dominate the mixing in estuaries (Gross 1972). To predict the actual tidal variations in sea level at any location, the amplitude and phase (known as the Tidal constituents) must be known. These can be determined from a long time series of measured sea level or alternatively from a numerical model.

The tide is a characteristic, sinusoidal oscillation containing either two main cycles per day (semidiurnal tides), one cycle per day (diurnal tides), or a combination of these two (mixed tides). The tidal signal experienced at any location is a composite of multiple partial tides called tidal constituents. Approximately 390 tidal constituents have been defined (Doodson 1922), the most significant 19 of which are formed by the gravitational attraction between the earth and the moon and sun. Sixteen of the 19 significant constituents are diurnal or semidiurnal. Diurnal and semidiurnal constituents are denoted by the subscripts “1” and “2,” respectively, in their symbols (Doodson, 1922., Schureman, 1924., Defant, 1961).

In typical modelling applications, eight constituents are specified: $K_1$, $O_1$, $P_1$, $Q_1$, $M_2$, $N_2$, $S_2$, and $K_2$, because these constituents make up a significant portion of the tidal signal. They are usually sufficient for calculation of tidal water level and current. The principal diurnal and semidiurnal tidal constituents and their significance are given in Tables 2.1 and 2.2.
### Table 2.1 Principal Diurnal Tidal Constituents (Defant 1961)

<table>
<thead>
<tr>
<th>Constituent Name</th>
<th>Symbol</th>
<th>Period (Solar hour)</th>
<th>Frequency (Cycle/Hour)</th>
<th>Amplitude ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luni-solar diurnal</td>
<td>K1</td>
<td>23.93</td>
<td>0.0417807</td>
<td>0.584</td>
</tr>
<tr>
<td>Principal lunar diurnal</td>
<td>O1</td>
<td>25.82</td>
<td>0.0387307</td>
<td>0.415</td>
</tr>
<tr>
<td>Principal solar diurnal</td>
<td>P1</td>
<td>24.07</td>
<td>0.0415526</td>
<td>0.193</td>
</tr>
<tr>
<td>Larger lunar elliptic</td>
<td>Q1</td>
<td>26.87</td>
<td>0.0372185</td>
<td>0.079</td>
</tr>
</tbody>
</table>

### Table 2.2 Principal Semi-Diurnal Tidal Constituents (Defant 1961)

<table>
<thead>
<tr>
<th>Constituent Name</th>
<th>Symbol</th>
<th>Period (Solar hour)</th>
<th>Frequency (Cycle/Hour)</th>
<th>Amplitude ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal lunar</td>
<td>M2</td>
<td>12.42</td>
<td>0.0805114</td>
<td>1.000</td>
</tr>
<tr>
<td>Principal solar</td>
<td>S2</td>
<td>12.00</td>
<td>0.0833333</td>
<td>0.465</td>
</tr>
<tr>
<td>Larger lunar elliptic</td>
<td>N2</td>
<td>12.66</td>
<td>0.0789993</td>
<td>0.192</td>
</tr>
<tr>
<td>Luni-solar semidiurnal</td>
<td>K2</td>
<td>11.97</td>
<td>0.0835615</td>
<td>0.029</td>
</tr>
</tbody>
</table>

#### 2.4.2 Waves

Wind-generated waves are surface waves that occur on the free surface of oceans. They usually result from the wind blowing over a vast enough stretch of fluid surface. Some waves in the oceans can travel thousands of miles before reaching land. Wind waves range in size from small ripples to huge rogue waves. There is little actual forward motion of individual water particles in a wave, despite the large amount of energy it may carry forward.
Wind waves in the ocean are called ocean surface waves. Tsunamis are a specific type of waves not caused by wind but by geological effects. In deep water, tsunamis are not visible because they are small in height and very long in wavelength. They may grow to devastating proportions at the coast due to reduced water depths. The great majority of large breakers one observes on a beach result from distant winds. Four factors influence the formation of wind waves: wind speed, distance of open water that the wind has blown over (called the fetch), time duration the wind has blown over a given area, and water depth. All of these factors work together to determine the size of wind waves. If each variable is greater, waves will be larger. Waves are characterized by:

i) Wave height (from trough to crest),

ii) Wavelength (from crest to crest),

iii) Period (time interval between arrival of consecutive crests at a stationary point),

iv) The direction of wave propagation.

2.4.3 Currents

An ocean current is a continuous, directed movement of ocean water generated by the forces acting upon the water, such as the Earth's rotation, wind, temperature, salinity differences and tides caused by the gravitational pull of the Moon and the Sun. Depth contours, shoreline configurations and interaction with other currents influence a current's direction and strength. Ocean currents can flow for thousands of kilometers, and together they create the great flow of the global conveyor belt which plays a dominant part in determining the climate of many of the Earth’s regions.

Surface ocean currents are generally wind driven and develop their typical clockwise spirals in the northern hemisphere and counter-clockwise
rotation in the southern hemisphere because of the imposed wind stresses. In
wind driven currents, Ekman spiral effect results in the currents flowing with an
angle to the driving winds. The areas of surface ocean currents move somewhat
with the seasons, which is most notable in equatorial currents.

Deep ocean currents are driven by density and temperature gradients.
Thermohaline circulation, also known as the ocean's conveyor belt, refers to the
deep ocean density-driven ocean basin currents. These currents, which flow
under the surface of the ocean and are thus hidden from immediate detection, are
called submarine rivers. These are currently being researched by a fleet of
underwater robots called Argo. Upwelling and downwelling areas in the ocean
are areas where significant vertical movement of ocean water is observed.

Surface currents make up about 10% of all the water in the ocean.
Surface currents are generally restricted to the upper 400 meters of the ocean.
The movement of deep water in the ocean basins is by density driven forces and
gravity. The density difference is a function of different temperatures and
salinity. Deep waters sink into the deep ocean basins at high latitudes where the
temperatures are cold enough to cause the density to increase. The main causes
of currents are solar heating, winds and gravity.

2.5 DISPERSION COEFFICIENT

The dispersion coefficient is highly dependent on many factors that
are unique to individual estuaries. It varies over space and time in response to
changes in channel morphometry, freshwater discharge, tidal currents and wind
stress (Fischer et al., 1979). The estimation of the dispersion coefficient in a
particular estuary is done by one of the following three approaches, (a) Most
commonly, the dispersion required to maintain an observed conservative tracer
(eg. salt) distribution along the length of an estuary are calculated, assuming the
distribution at steady state (Officer, 1978). (b) Dye studies where the release and
subsequent dispersion of the dye are monitored over several tidal cycles are another approach (Hetling and Connell, 1966; Gunn and Yenigun, 1985). (c)The third approach is to measure deviations in velocity and salinity from their spatial means (Dyer, 1974)

Patterson and Gloyna (1965) examined the dispersion of rhodamine B and fluorescein in the Colorado river and the Pierce Canal. Yotsukura et.al (1972) investigated the tracer simulation of waste transport in the muddy creek-rhode river Estuary, Maryland. Ward (1976) measured the dispersion of rhodamine WT in the Frazer estuary, British Columbia by batch and continuous sampling of the dye, and calculated Depth, and Dispersion, from the linear increase of the second moments in time. West and Cotton (1981) measured the dispersion of the Conwy estuary by taking continuous samples at different depths while traversing the dye patch.

Park et al (1986) developed a model for predicting the rate of longitudinal dispersion in non-homogeneous oscillatory flows to study Tyne estuary. Velocity and salinity data collected over 2 years in the Tyne estuary were analyzed for investigating principal factors controlling longitudinal dispersion. West et. al (1990) investigated the intra-tidal variation of vertical and transverse shear-induced dispersion by measured velocity, salinity, and suspended solids concentration. Swarta et.al (1997) computed Longitudinal and lateral dispersion coefficients for the Ems Estuary using a modified version of the tidal random walk model developed by Zimmerman. Salinity distribution, dye release studies, and parameter estimation techniques were used to determine the longitudinal (or tidal) dispersion coefficient in the Plum Island Sound estuary in north-eastern Massachusetts, U.S.A, by Vallino et.al (1998).
2.6 MODELLING OF ESTUARINE DYNAMICS

2.6.1 Numerical Models

Numerical models are computer programs that solve basic fluid mechanics and sediment transport equations (Abbott 1992). Flows in open channels are described by a set of partial differential equations for computer simulation of hydrodynamic and sediment processes (Chaudhry 1993). These equations are solved using numerical methods. Prediction of contaminant distribution and the accurate quantification of their fluxes from estuaries to coastal seas can be achieved by numerical modelling rather than solely by measurement (Lane et al. 1997). There are numerous mathematical models available to simulate sediment transport and depositions in one-dimension, two-dimension, and three-dimension.

2.6.2 One Dimensional Models

One dimensional models, together with their numerical solution methods and applications, were created by Jansen et al. (1979), Cunge et al. (1980), and Vries et al. (1989). One-dimensional models are virtually the only numerical tool available to simulate morphological changes occurring over years in rivers and estuaries (Van Rijn, 1989). Widely used one-dimensional models such as HEC-6 (USACE, 1993) and Mike11 (DHI, 2003) have been used to study sediment transport, scour and deposition in large and small rivers, particularly as affected by engineered channels and structures. They are relatively easy to set up and calibrate quickly on desktop computers. Assumptions of 1D flow may not be valid in many situations. Flow in a channel along with varying cross-section, changing alignment, or complex tidal flows in the estuaries are some of these examples (Hassan, 1995).
2.6.3 Two Dimensional Models

Two dimensional models can be laterally (width) or vertically (depth) integrated. A laterally integrated model solves the laterally integrated momentum and continuity equations for the fluid and the sediment phases (Smith and O’Connor 1977). Two dimensional depth integrated sediment transport models are based on the depth integrated equations of motion and continuity linked to a depth-integrated sediment transport model (Boer et al. 1984; McAnally et al. 1986). Examples of the depth integrated models are Struiksma et al. (1984) and Wang (1989). Struiksma et al. computed bed evolution in a river bend using the sediment transport formula of Engelund and Hansen (1967). Wang studied sediment distribution in a partially closed channel with steady flow. The two sediment transport models most widely employed in engineering practice are MIKE 21 and TABS-MD (Thomas and McAnally, 1990). MIKE 21 was developed by the Danish Hydraulic Institute and is a finite difference sediment transport model that is increasingly gaining acceptance inside the United States. The mechanisms of pollutant transport in the Hudson estuary had been studied by Andrew and Ronald (1990).

A 2-D model is necessary if the problem involves complicated circulation patterns and unsteady flows within the model domain (Hassan 1995). Water flows and cohesive sediment fluxes in the Humber Estuary were modeled by Wu et al. (1998). Ozcan and Gokce (2002) dealt numerical model (MIKE21) application in outfall design. Peri (2004) developed a particle-tracking model to simulate the dispersion of contaminants in the strait of Gibraltar. Li Cai et al. (2007) simulated the transport of a passive pollutant by a flow model using two-dimensional shallow water equations.
### 2.6.4 Three Dimensional Models

Three-dimensional models should be used when flow and sediment transport are stratified. An example might be where freshwater flows over a salt-water wedge or warm water override colder waters. Computations for larger model domains in estuaries or the continental shelf are typically lumped to a single day or one tidal cycle (O’Connor and Nicholson, 1988). The application of a 3D model is very much necessary near or around a hydraulic structure where flow separation and vortex characteristics are truly three-dimensional, and sedimentation processes are complex. Examples of some of the most widely used 3D models are RMA11 (Resource Management Associates, Inc. 2003), ECOMSED (HydroQual Inc, 2003), CH3D-SED (Chapman et al. 1996) and Delft-3D (Delft Hydraulics 2003). Whether the problem is solved in one dimensional, two dimensional or three dimensional, either a finite difference or finite element method will be used for numerical modelling.

Cai et al (2007) simulated the transport of a passive pollutant by a flow modeled through the two-dimensional shallow water equations. Zhang (2006) compared POM (Princeton Ocean Model) and MIKE3 3D flow model. The results indicated that tidal elevations from the two modelling systems were identical. POM provided better simulation for tidal currents, but much more time consuming compared to the MIKE 3 flow model. Suh (2006) utilized a hybrid approach, Eulerian- Lagrangian model in the simulation of coastal dispersion. It is essential to carry out hydrodynamic modelling prior to the dispersion modelling. The governing equations for the hydrodynamic simulations are the depth averaged continuity and momentum equations. Elshorbagy et al., (2006) created a well developed 3D rectilinear grid coastal flow model referred to as the multilevel model to simulate the hydrodynamics of the Arabian Gulf. Solving the continuity, momentum and conservation of salt and temperature equations simulate the hydrodynamics.
The characteristics of water flow and sediment transport in a typical sandy and gravel watercourse of the middle reaches of Yangtze River was investigated using a 2D mathematical model (Yongjun 2005). Ferrarin and Umgiesser (2005) simulated the hydrodynamic circulation of the Cabras lagoon using SHYFEM, a two dimensional shallow water finite element model, taking into account different forces such as tides, winds and rivers. The model was used to investigate the evolution of salinity and water temperature in the lagoon. Based on the observed field data, satellite remote sensing data, a 2-D finite element numerical model was made for yellow river estuary sediment movement in China (Dongfeng 2003). Harari and Camargo (2003) analyzed the characteristics of tides and tidal currents in coastal region of Santos (Brazil) with POM.

A complicated model was used to describe cadmium (Cd) speciation during estuarine transit in the Seine estuary (Jena, 2001). This model was developed from field data. Laboratory experiments based on the use of 109 Cd enabled checking of certain model simplifications and hypotheses and evaluation of parameters which could not be measured directly. Zhang and Gin (2000) devised a three dimensional numerical model with a multi level rectangular coordinate system to simulate the tidal motions in Singapore coastal water. The model results for the velocities and the free surface water elevations coincided with analytical results. Blumberg et al., (1999) reproduced the variations in water level, velocity, salinity and temperature of harbour region using ECOM (estuarine, coastal and ocean model), a three dimensional hydrodynamic model. Two major boundary forcing functions applied at the water surface were the heat flux and the wind stress.
2.6.5 MIKE 21 Modelling

A two-dimensional, depth-averaged kinetic model of copper cycling was developed for the San Francisco Bay estuary, using MIKE 21 by Bessinger et al. (2006). The model was used to predict spatial and seasonal trends in the adsorption and desorption of copper. Babu et al., (2006) simulated tides, currents, Dissolved Oxygen and Biochemical Oxygen Demand in Kochi by MIKE 21 hydrodynamic and water quality modules. They reported this model had been widely used for modelling the hydrodynamics, transport of sediments and water quality parameters in coastal areas. The MIKE21 Spill Analysis model was used to simulate the spill trajectory. The observed spill trajectory and the slick area were in agreement with the model simulations (Vethamony, et al, 2006).

Lumborg and Pejrup (2005) concluded that MIKE 21 model reproduced the hydrodynamics satisfactorily as well as the concentration level and variation of suspended cohesive sediment concentration in the tidal lagoon. Babu et al., (2005) studied the characteristics of tide-driven currents for different seasons in Gulf of Kachch by MIKE 21 hydrodynamic model and concluded that the model results agree very well with the measured currents. In addition to waves and tides, wind forcing also play a significant role in determining the hydrodynamics and net transport. Peri (2004) developed a particle-tracking model to simulate the dispersion of contaminants in the Strait of Gibraltar. The sediment transport along the Mangalore coast using MIKE 21 with inputs wave, wind, currents, tides, bathymetry and sediment type were computed by Sankar babu et al., (2003).

A calibrated and validated numerical model (MIKE21 Hydrodynamics and Near Shore Wave model) was applied to find the water surface topography and its response to different tide, wave and river discharge conditions (Eduardo et al 2002), Merih et al (2002) studied the application of
MIKE21 in marine outfall design. In an outfall design, numerical models can be utilized effectively in a wide spectrum like wave prediction, pipe hydraulics and effluent transport. Warren and Bach (1992) reported that MIKE 21 is a 2-dimensional microcomputer based modelling system for estuaries, coastal waters and seas.

Nicholas et al., (1999) simulated the flow hydrodynamics within a wetland using MIKE 21, a two-dimensional depth averaged model. Tasks completed to form a complete hydrodynamic set up was Bathymetry set up, Boundary conditions and finally creation of verification data. Modelling of Water Flows and Cohesive Sediment Fluxes in the Humber Estuary was done by Wu et al (1998). The mechanisms of pollutant transport in the Hudson estuary has been studied by Andrew and Ronald (1990).

2.7 ESTUARY NUMERICAL MODELS

A number of well established process-based estuarine modelling software are currently available. Brief descriptions of some of the well known and most widely used modelling softwares are given below.

2.7.1 MIKE 11

MIKE 11 – a One dimensional modelling tool from the Danish Hydraulics Institute to examine hydraulic flows in open channel systems (eg. canals, rivers and estuaries). Modules currently supported are hydrodynamics, control structures, advection - dispersion, cohesive sediment, sediment transport and water quality.

2.7.2 MIKE 21

MIKE 21 - a Two dimensional modelling tool from the Danish Hydraulics Institute to examine free surface flow regimes in estuaries and coasts.
Modules supported: hydrodynamics, nested hydrodynamics, advection-dispersion, near shore spectral wind-waves, mud transport, sand transport, boussinesq waves, and particle transport.

2.7.3 DELFT 3D

The DELFT3D suite of modelling tools have been developed by Delft Hydraulics, the Netherlands. The fully integrated computer software suite allows for a multi-disciplinary approach to be made of One, Two and Three dimensional modelling for coast, rivers and estuarine systems. The software has been designed for experts and non-experts alike to carry out predictions of flows, sediment transports, waves, water quality, ecology and morphological developments.

2.7.4 ECOMSED

ECOMSED (Estuary and Coastal Ocean Model with Sediment Transport) is a three-dimensional hydrodynamic and sediment transport model. The hydrodynamic module solves the conservation of mass and momentum equations. Water circulation, salinity, and temperature are obtained from the hydrodynamic module. The sediment transport module computes the sediment settling and re-suspension processes for both cohesive and non-cohesive sediments under the impact of waves and currents.

2.7.5 HSCTM-2D

HSCTM-2D (Hydrodynamic, Sediment, and Contaminant Transport Model) is a single model that incorporates internally linked hydrodynamic, sediment transport and contaminant transport. HSCTM-2D uses a two-dimensional finite element formulation (Hayter et al. 1998) and incorporates the RMA2 hydrodynamic model (King, 1990) and the CSTM-H sediment transport
model (Hayter and Mehta, 1986) extended to include sorptive contaminants. Horizontal water column transport includes advection and shear dispersion. The model can be applied to rivers, lakes, estuaries, and coastal waters.

2.7.6 AQUASEA

AQUASEA is a software package developed to solve the shallow water flow and transport equations using the Galerkin finite element method. AQUASEA was first developed in 1983 to solve two-dimensional problems, and since 1992, it has been continuously upgraded and tested worldwide on the most difficult modelling problems. The AQUASEA flow model can simulate water level variations and flows in response to various forcing functions in lakes, estuaries, bays and coastal areas. The water levels and flows are approximated in a numerical finite element grid and calculated on the basis of information on the bathymetry, bed resistance coefficients, wind field and boundary conditions.

2.7.7 FASTER

The FASTER model, which can be used to simulate hydrodynamic, solute and sediment transport processes in well-mixed rivers and narrow estuaries, had been developed based on the solution of the St Venant equations through an implicit finite difference scheme, with a varying grid size over a space-staggered grid. The water quality module of this model was developed based on a finite volume solution of the advective diffusion equation proposed by Kashefipour and Falconer (1999).

2.7.8 DIVAST

DIVAST was developed for simulating hydrodynamic, solute and sediment transport in estuarine and coastal waters. The hydrodynamic module was developed based on the solution of the depth integrated Navier Stokes
equations. For the water quality and sediment transport module, the two-dimensional advection-diffusion equation was solved for a range of water quality indicators using the highly accurate ultimate quickest scheme (Lin and Falconer 1997).

2.8 EARLIER WORKS ON UPPANAR ESTUARY

Distribution and seasonal variation of dissolved nutrients in Uppanar estuary was studied by Murugan and Ayyakkannu (1991). In general, negative correlation was found between salinity and nutrients. Bioaccumulation of heavy metals like Iron, Manganese, Zinc and Copper in the Scad fishes from Cuddalore water was done by Srinivasan (1992). Fluoride distribution and its quantitative load in the Uppanar estuary and waste disposal from a nearby industrial complex were studied by Karunagaran and Subramanian (1992), while studies on hydrobiology of Uppanar backwater and hydro biological investigation on the intertidal diatoms in Uppanar estuary were made by Mathavan Pillai (1994).

At Cuddalore backwaters, 6 species of Phyta and 2 species of Rhodophyta were recorded. Compressa and Valentiæ were the dominant algae. Studies on the biochemical contents of some macro algae from Cuddalore and Thirumullaivasal estuaries were made to find out the interrelationship between these two estuaries. Compared to Cuddalore backwater, there was more number of species at Thirumullaivasal. This might be due to the fact that Cuddalore backwater receives various kinds of effluents from different industries (Palanisamy and Selvaraj 1998).

Spatial and temporal variation in concentration of essential elements as Cu and Zn and non-essential elements like Cd and Pb in the whole body and organs namely gill, mantle and adductor muscle of oyster Crassostrea madrasensis were studied in the Uppanar, Vellar and Kaduviar estuaries. Seasonal variation in tissue metal concentration was observed, with higher levels
during the monsoon and lower levels in the summer. Metal levels in the oyster were in the order of Zn > Cu > Pb > Cd. This order reflects the metal levels in the ambient medium (Senthilnathan and Balasubramanian 1998).

Scattered patches of oyster populations were found throughout the Uppanar estuary but in small clusters constituted by a population of Madrasensis (68.2%) and S. Cucullata (31.8%). Occasionally oysters are fished along with other mollusks such as clams for lime making (Rao et al., 1996). With the onset of cold weather during the monsoon season, many plants and animals attached to the oyster shells die, but the oysters survive irrespective of the seasons (Balasubramanyan and Srinivasan, 1987).

2.9 SUMMARY OF LITERATURE REVIEW

The literature reviewed under this chapter is very useful to understand the water quality problems in estuary. It also helped to understand the estuarine dynamics and the factors affecting the estuarine hydrodynamics in an elaborate manner. The different modelling system i.e one dimensional, two dimensional, three dimensional and their merits and demerits are studied. The various software used for hydrodynamics modeling were analysed in this chapter, this will assist to select the suitable modeling software for the present study. The literature study of earlier works on Uppanar estuary was helped to identify the gaps in water quality monitoring and assist to frame the present methodology.