<u>**Final Report**</u>

Waste Load Allocation &

Waste Assimilative Capacity Studies for

Ennore Creek

&

North Chennai Coastal Waters

for

Department of Ocean Development

Under the

Integrated Coastal and Marine Area Management Program

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EXECUTIVE SUMMARY

This report details the first attempt to conduct a comprehensive WasteLoad Allocation (WLA) and Waste Assimilative Capacity (WAC) study in coastal and estuarine waters of India. The study was designed and executed by the National Institute of Ocean Technology (NIOT) with administrative and financial support from the Department of Ocean Development, Govt. of India. Three sites were identified for the WLA and WAC project – Ennore creek and North Chennai coastal waters; Tapi River/estuary; and Hooghly estuary. NIOT is responsible for implementing the waste assimilative capacity studies at Ennore and Hooghly, while an international group of consultancy firms is responsible for conducting the WLA at Tapi

The objective of the study is to develop a conceptual design for treatment and management of wastewater inputs into the Ennore Creek and North Chennai water, such that water quality standards in these receiving waters are met. The approach adopted was to conduct comprehensive, synoptic field studies for hydrographic measurements, water quality and biological characteristics such that deterministic models capable of predicting the fate and transport of pollutants could be simulated. Three field surveys representing different seasons were completed in 1999 – 2000.

The field studies revealed that the Ennore Creek is a typical metropolitan water body. The creek receives wastewater from numerous sources including untreated wastewater from sewered and unsewered areas, treated effluents from industrial sources and clandestine unauthorized discharges from a company with ISO 14000 certification. The study reveals that permitted discharges account for less than 40% of the total BOD load measured in the creek.

Ennore Creek

The field study also suggests that life cycle assessment concepts need to be adopted by industrial units. Nutrient rich solid wastes from industries are used as landfill, dumped into the creek in the vicinity of the waste generating industry itself, without scientific assessment of the impacts on surface water and ground water quality. Oil tankers are found to regularly discharge their washings into the creek or any low lying area.

The water quality and sediment studies highlighted the low DO and excessive BOD, pathogenic and nutrient loads into the Ennore Creek, suggesting the need for treatment / relocation of the wastewater discharges and the need for solidwaste management. The data was used to calibrate the model for BOD and fecal coliforms, the two parameters indicating significant violation of water quality standards. Field studies were also conducted to estimate kinetic coefficients for various parameters such as sediment oxygen demand bacterial decay rates, photosynthetic and respiration rates of primary productivity. Peer researchers have also suggested that some of these experiments like SOD are the first of its kind in the country.

The calibrated model was applied to determine the improvement of receiving water quality if treatment / management is undertaken. It was determined that the creek is unlikely to meet the water quality standard even with treatment. Another issue is that, even if all wastewaters are collected, secondary treatment with disinfection will not remove the nutrients and the current levels of entrophication will remain (or possibly increase due to the partial removal of toxics). Thus it is suggested that the wastewater entering the creek, directly or through the Buckingham Canal, be collected and discharged, after primary treatment and disinfection, into the open ocean through a marine outfall located at 15m water depth.

North Chennai Coastal Waters

The major discharge into the North Chennai is the Royapuram sewage outfall. The field study revealed that the littoral drift transports the effluent plume alongshore, thus violating water quality criteria for pathogens along the beach. With the coastal protection works currently being executed along this stretch of the coast, the water quality concerns are likely to increase if the beach that is safe for swimming develops. Thus it is recommended by the municipal wastewater outfall Royapuram be at minimum, disinfected and discharged through a marine outfall at 15m water depths. This can also improve the water quality in the fisheries harbor when the littoral currents move southerly during Dec-Feb.

General Recommendations

The results of the waste assimilative capacity study can be applied to a larger context, although site-specific studies need to confirm these conclusions

- Inland creeks like the Ennore Creek, Adyar River & Cooum River have limited waste assimilative capacities, especially since they are prone to sand bars forming across the creek mouths. Even if treated effluents are discharged into the creeks, the creeks will not be capable of assimilating the excessive nutrients resulting in serious eutrophication. Thus, ocean outfalls must be considered. The excessive productivity with its associated aesthetic and odor problems may not provide significant benefits in comparison to the costs of treatment.
- Life cycle assessment for raw materials / goods, finished products/wastes and services must be carried throughout the supply chain by the industries such that the suppliers and

contractors are also influenced to carry out their services with a responsibility towards management of wastes.

- The responsibility of the industry / waste generator cannot cease merely by outsourcing disposal of waste products to an external agency

Site Specific Summary

- Over 60% of the wastewater enters into the receiving waters (Creek and coastal) are from untreated municipal wastewaters. Unfortunately no discharge permits exists for these sources. Discharge permits are applicable only to industrial wastes as enforcement is easy.
- Monitoring of industrial discharges should not be limited to maintenance of records of routine sampling surveys of industrial discharges. There needs to be an additional effort to monitor/inspect the environment in the vicinity of the industrial wastes to ensure that the performance is consistent. It is therefore essential that receiving water quality monitoring be carried out routinely to support the routine industrial monitoring.
- Although industries may outsource its supplies and services for environmental management and waste disposal to external agencies, it is wholly responsible for the externalities generated by such contractors and therefore are required to conduct a life-cycle assessment of its goods and services. For e.g., oil tanker washings and treatment of the wastewaters may be carried out inside the refinery premises
- Scientific assessment of water quality kinetics, although initiated in this project, needs to continue to improve the reliability of water quality modeling. Experiments on growth rates of plankton, nutrient consumption, BOD decay rates, sediment uptake will greatly enhance the quality of modeling. At the same time, ecological modeling of the food chain needs to be initiated to establish the linkages between water pollution and ecosystem health.
- Long-term monitoring of the coastal environment needs to maintain focus on the use classification of the area such that the quality objective is met. For instance, if bathing and swimming are the uses of the area, then that is the highest quality the monitoring program must achieve and therefore focus on the beach and not at 5m or 10m water depths..

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1 INTRODUCTION

1.0 CONCEPT OF WASTE LOAD ALLOCATION AND WASTE ASSIMILATIVE CAPACITY

Water Quality Management aims to maintain the quality of water resources within acceptable limits. For receiving waters, i.e. waters accepting disposal of wastewater, there have been two primary approaches. One is the technology-based approach that sets wastewater concentration limits for a discharge based on the technology or type of industry and the best available technology for treatment of industrial wastes. For example, effluents from municipal treatment plants in a region will be required to discharge the same minimum wastewater quality. This approach has the advantage of easy implementation by a regulatory agency, as time spent on scientifically assessing the capacity of the receiving water, prior to issuance of the discharge permit is minimized. The technology-based approach assumes that receiving water bodies are subject to limited pollutant mass loadings and/or have adequate dilution capacity.

However, if the discharge quantity rises due to increasing development or if the receiving water is limited in size, the capacity of the natural water body may be impaired beyond acceptable levels. In the water quality based approach, the discharge permits are designed to ensure that the resultant receiving water quality is acceptable.

In order to achieve water quality based controls, the water quality engineer assesses the wastewater inputs, transformation and movement of the pollutants and the resulting concentration at selected times and at key locations. With this understanding, control measures are evaluated for meeting the water quality standards. Both analytical methods and mathematical models using computers may be used to model the fate and transport of pollutants. A cost benefit analysis will focus on the best available options.

In the last three decades, there has been a tremendous increase in the use of mathematical models in environmental engineering for designing and executing water quality based controls in the developed countries. This project envisages the evaluation of a variety of readily available models and their suitability for modeling different water environments and problems.

1.1 WASTELOAD ALLOCATIONS

In India, water quality management needs and objectives have been summarized by the Central Pollution Control Board in a document - "Scheme for Zoning and Classification of Indian Rivers, Estuaries and Coastal Waters" (CPCB 1979). The objectives addresses the Board's need:

- to lay down water quality standards for surface and ground waters;
- to designate best use of the water, develop a "water use map";
- to determine a rational basis for evolving effluent standards and allocation of load to achieve the water quality and set discharge standards for effluents;
- to sustain the zoned class of the receiving water; and
- to set minimum treatment requirements for pollutant sources.

Current implementation of the 1978-79 CPCB objective centers around the issuance of discharge permits based on the nature of the point source, i.e., technology based control. Additional efforts in the coastal areas are required to expand the list of water quality parameters, designated best use classification and allocation of waste loads for the estuarine or coastal waters based on the assimilative capacity of the receiving waters.

The terminology Waste Load Allocation is derived from the US Environmental Protection Agency (USEPA). According to USEPA, waste load allocation is termed as:

1. The maximum load of pollutants each discharger of waste is allowed to release into a particular waterway. Discharge limits are usually required for each specific water quality criterion being, or expected to be, violated;
2. The portion of a stream's total assimilative capacity assigned to an individual discharge.

WLA has been one of the most effective methods for achieving desirable water quality for an area based on its assimilation capacity. The WLA is ideally performed when the environment and its kinetics for a particular site are understood through environmental monitoring. These processes are then input to a mathematical model for calibration and validation. The application of the calibrated model will assess the advantages and disadvantages of various design options. Using a cost-benefit analysis, the best option that results in the desired water quality can then be recommended for implementation. Thomann and Mueller (1987) best describe this process for a dissolved oxygen problem in a river through Figure 1.1. Waste load allocations have been performed in several locations in US over the last three decades and are an integral part of the USEPA's Total Maximum Discharge Limits (TMDL) requirement.

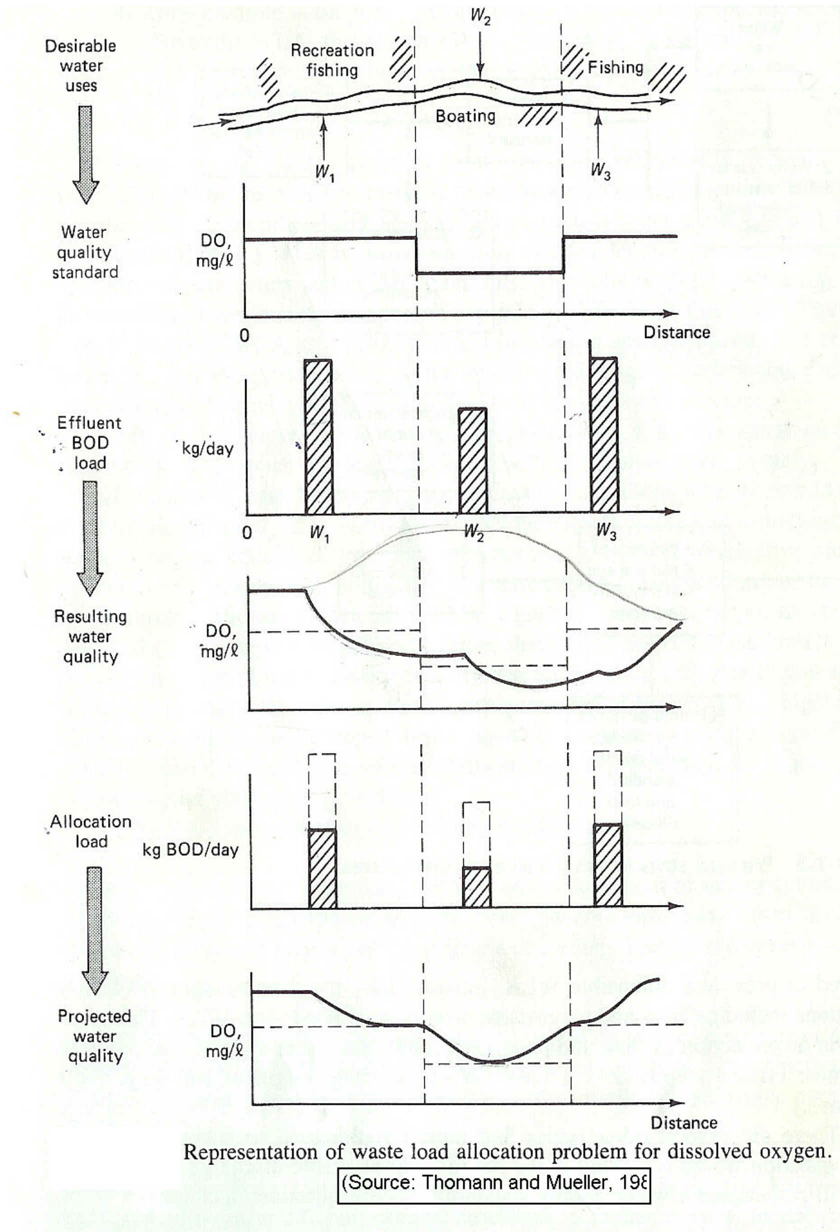


Fig 1.1 The Waste Load Allocation (Thomann and Mueller 1987)

One important aspect is the choice of design condition for model application under which the WLA is to be conducted. This choice requires experience, especially since the model cannot be a complete representation of reality. The WLA may be performed for a critical summer period that allows violation of the criteria for no more than seven days once in 10 years. On the other hand, the choice may be to apply the model under storm conditions that result in inputs from overflowing drains, and increased runoff from the upstream watershed. Both these projections may be made relatively quickly and with confidence if the calibrated and validated model is in place.

1.2 METHODOLOGY AND APPROACH FOR WASTE LOAD ALLOCATION STUDY AT ENNORE

The steps in the WLA study for Ennore were as follows:

1) Evaluate existing water quality data and pollutant sources information to define the problems at Ennore Creek;
2) Evaluate the designated use classification of the study area and suggest improvements, if required;
3) Design a water quality sampling program specific to the identified problems, the goals of the designated use classification and tools (mathematical models) to be used for WLA;
4) Interpret the results and define the basic kinetics controlling water quality;
5) Calibrate and validate a water quality model for the study area; and
6) Apply the model for waste load allocation scenarios and recommend options for achieving the water quality standards, relative to the designated use classification.

1.3 AGENCIES INVOLVED

Numerous agencies were involved in executing the project as shown below. While the overall responsibility of the project implementation was assigned to NIOT, the roles and responsibilities of other institutions involved in the study are given in Table 1.1.

Table 1.1 Roles & Responsibilities of other institutions

Task	Institution(s)	Role(s)
Project Co-ordination	Department of Ocean Development	Review and monitoring of project activities, contracts, logistical support and coordination with World Bank, Technical Advisory Committee and project institutions.
Hydrographic measurements	NIOT	Design, specification of requirement and review.
	Indomer	Deployment and data retrieval
Water & sediment quality measurements	NIOT	Sample collection, field laboratory processing, analysis, sediment analysis
	CECRI	Analysis of nutrients, laboratory infrastructure
	Annamalai University	Sample collection, Secondary data collection
	TNPCB	Sample collection, Secondary data collection
Modeling	NIOT	Overall responsibility in addition to training of TNPCB personnel
	TNPCB	Assistance in modeling

2 ENNORE CREEK AND ITS ENVIRONS

2.0 DESCRIPTION OF STUDY AREA

The study area covers the North Chennai region consisting of the coastal waters and the Ennore creek (Fig 2.1). The Ennore creek drains the Kortalliyar River watershed and discharges into the Bay of Bengal off North Chennai coast. Treated and untreated municipal and industrial wastewaters are discharged to the Ennore Creek and coastal waters. The industrial wastewater input generated in the study area is provided in Table 2.1. The study area was divided into two areas (i) the coastal waters off North Chennai and (ii) the Ennore creek, for a detailed study of a localized hot-spot area where the pollutant signal is very prominent, which has been discussed in greater detail in this chapter

Table 2.1 Details of discharge from industries

NAME OF THE INDUSTRY	Volume of trade effluent (KLD)	Volume of effluent (KLD)	Total discharge (KLD)
Amullavoyal Canal Inputs			
Madras Fertilizer Ltd (MFL)	2385	1050	3435
Tamilnadu Petro Products Ltd (TPL)	1164	90	1254
Madras Refineries Ltd (MRL)	7200	480	7680
Buckingham Canal Inputs			
India Additive Ltd	315	27	342
Ashok Leyland	200	650	850
Discharges on Land			
Sriram Fibers Ltd	475	203.5	678.5
CETEX Petro Chemicals	70	5	75
Spic Heavy Chemicals Division (SPIC-HCD)	200	100	300
Madras Petrochemicals Limited (MPL)	200	10	210
Indian Organic Chemicals Ltd	1400	200	1600
Balmer Lawrie & Company Ltd (Leather division)	0.83	12	12.83
Tamilnadu Minerals Ltd	130	3	133
Corborundum Universal Ltd	17.5	114	131.5
Discharges into Bay of Bengal			
Manali Petro Chemicals Ltd	3400	15	3415
Spic Organic Chemicals Ltd	4500	50	4550
Kothari Sugars & Chemicals Ltd	305.5	15	320.5
ICI India Ltd (Pharmaceutical division)	22	20	42
Madras Rubber Factory	1000	1000	2000
Eveready Industries (India) Ltd	66	66.7	132.7
EID Parry Ltd (Fertilizer division)	4	0.83	4.83
Royal Enfield Motors	90	40	130
Ennore Power Station (ETPS)	68020	0.2	68020.2
North Chennai Thermal Power Plant (TNPCB)	1860	42	1902
Source: Tamil Nadu Pollution Control Board			

2.1 COASTAL WATERS

2.1.1 Harbors

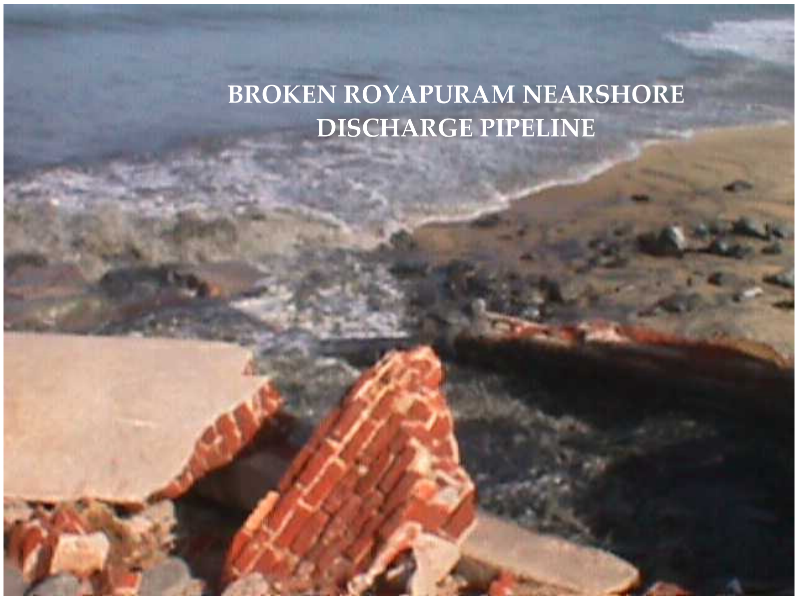
The study area falls within the coastal stretch of North Chennai coastal waters i.e., Bay of Bengal, extending from the Chennai Port in the South and to the Ennore Port in the North. The Royapuram (Kasimedu) fishing harbor is located alongside the Chennai Port. All the ports are manmade and are characterized by the presence of breakwaters. The area has high traffic of seagoing vessels, boats and trawlers from the nearby Chennai Port and Royapuram fishing harbor.

Chennai Port handles all types of cargo including bulk materials, petroleum and oil liquids (POL), gas, containers, etc. The maximum draft is 17.0m, permitting carriers upto 1,50,000DWT. The draught in the navigational channel is maintained by dredging approximately 1 million m^3 annually. Shoreline changes due to the Chennai Port are well documented in literature, where the areas south of the Chennai Port (Marina Beach) have accreted significantly, while the coast to the North (i.e the WLA study area) has undergone severe erosion.

Ennore Port began operations in 2001. Ennore Port currently handles bulk cargo (coal) for the North Chennai Thermal Power Station (NCTPS) and intends to handle iron ore and POL in the future. The maintenance dredging is currently negligible. Shoreline changes due to the Ennore Port are thought to be the primary causes for the closure of the Ennore creek mouth by a sand bar. Ennore Port disputes this claim as scientific studies to clearly prove / disprove the hypothesis have not been published.

2.1.2 Inputs

Raw municipal sewage, industrial trade effluents, industrial cooling waters, oil from boat repairs, fish cleaning wastes etc., are some of the wastewater discharges into the coastal waters of North Chennai between the Royapuram fishing harbor and the Ennore Port.



One of the major carriers of industrial and municipal effluents and runoff from watersheds is the Ennore Creek, which discharges into the coastal waters through the creek mouth as well through the cooling water discharge of the ETPS. However, since the first WLA survey (February 1999), the Ennore creek mouth mostly remains closed and thus, discharge occurs primarily through the ETPS discharge. It needs to be emphasized here that the EPTS cooling water discharge quality is directly related to the quality of water in the Ennore creek, since the ETPS intake is from the Ennore Creek.

Major wastewater inputs into the coastal area are:

- 12.84 MLD of Municipal sewage enters the coastal waters north of the Royapuram Fishing harbor at the Royapuram outfall. The current discharge (1998) from Royapuram sewage outfall is 2.25 times more than the 1978 value.
- Some of the petrochemical industries discharge their effluents into the sea through submerged pipelines south off Ennore Creek mouth. E.g., MPL-SPIC-HCD submerged outfall
- Patches of oil were observed at the Royapuram fishing harbor (within the breakwaters), which may possibly be due to oil spillage from fishing boats or from boat repairs.
- The Ennore thermal power station discharges approximately 68020 KLD (1999) of coolant water with high flyash concentrations into the sea through a pipeline, south of the Ennore creek mouth. The ETPS water intake is located in Ennore Creek and thus the ETPS discharge represents chlorinated and heated Ennore Creek water mixed with flyash. ETPS ceased discharging flyash only recently in 2002.
- Washings and wastes from fish processing are inputs from the fishing harbor as many of the operators process the catch in the harbor. Fish processing wastes have high BOD.
-

FRACTURED EID PARRY OUTFALL

ETPS OUTFALL DISCHARGING COOLANT WATERS

THE PIPELINE ABOVE THE OUTFALL CONVEYS FLYASH SLURRY FOR DISPOSAL FURTHER OFFSHORE

2.2 ENNORE CREEK

The Ennore creek is a backwater that drains the Koratalliyar River. It is located in the northeastern part of Chennai City, Tamilnadu, India and is spread over an area of 4 km^2 along the coast of Bay of Bengal (Fig.2.1).

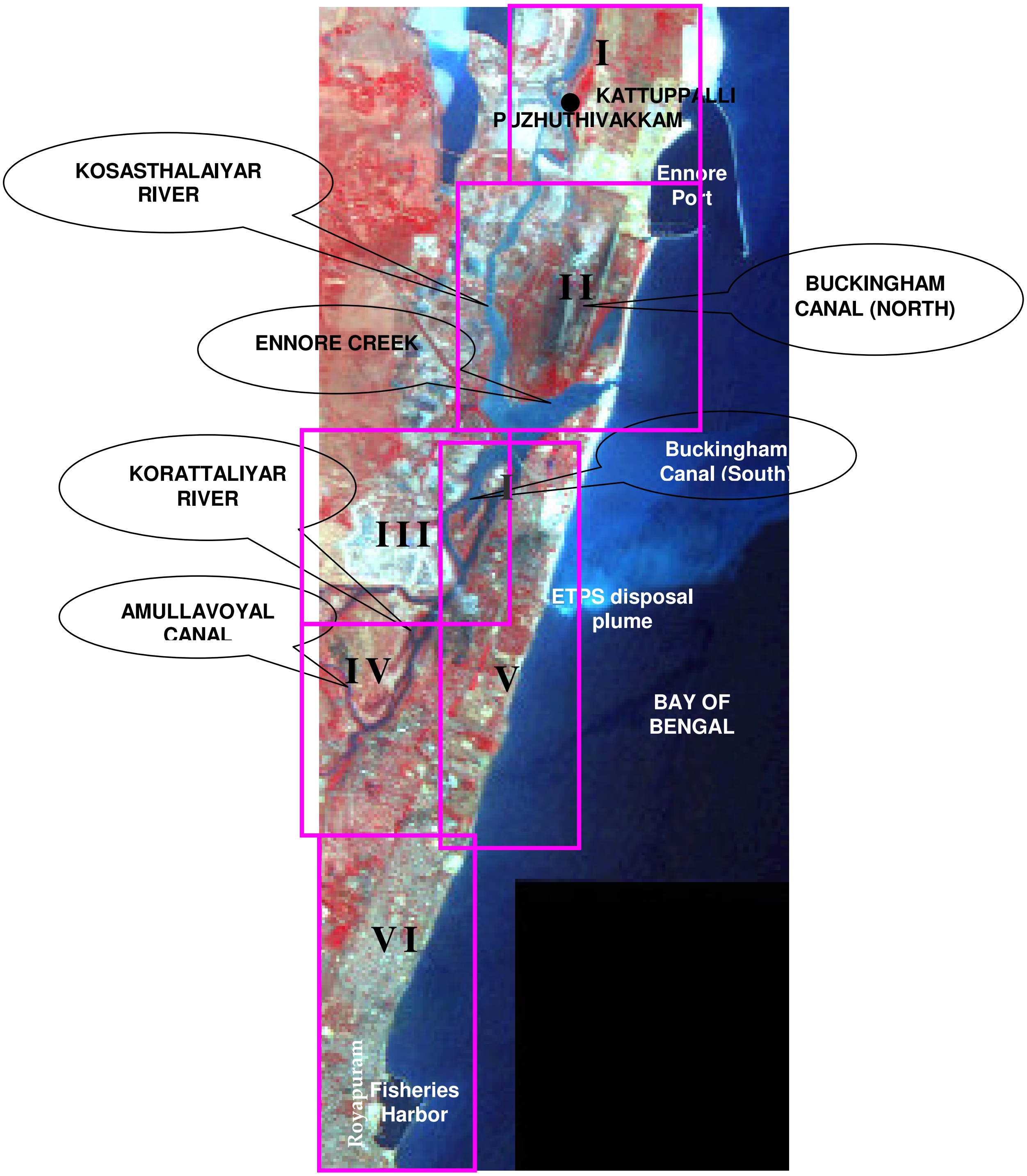


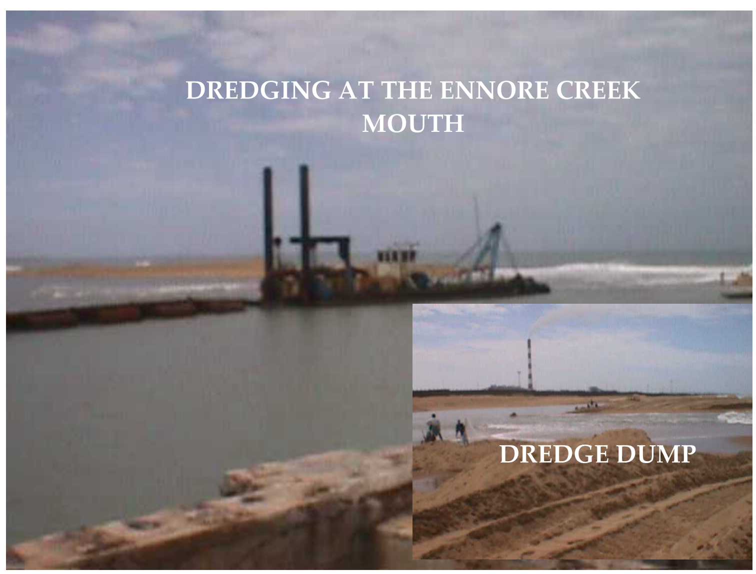
Fig 2.1 Ennore Creek and its environs

The creek lies between the city of Chennai, a large metropolitan and the Pulicat Lake, the second largest brackish water lake in India. The southern arm of the creek, fringing the northern areas of the City of Chennai, is well developed with industries, utilities, suburban residential areas and fishing hamlets. The northern section of the creek or Kosastalaiyar backwater is connected to the Pulicat Lake and has two major developments – the North Chennai Thermal Power Plant and the recently built Ennore Port. Development in the northern area is likely to intensify with a major industrial park being proposed, having power utilities, petrochemical industries and chemical storage units.

Wastewater enters the creek through the Buckingham canal, a waterway that was built for navigation. The canal section that traverses between Chennai and Ennore currently serves as an open sewer, receiving municipal and industrial wastewaters. The creek also receives wastewater from industries in the Manali Industrial area.

The Koratalliyar River originates from the Tamaraipakkam, a ‘barrage’ that diverts most of the freshwater to the Chembarampakkm / Red Hills Lake, which supplies drinking water to Chennai. On rare occasions, the Red Hills has surplus inflows, and the excess water is sent to the sea through the Amullavoyal Canal.

Two power utility companies withdraw cooling waters from the creek, while traditional fishermen use the areas near the mouth for fishing. The greatest pressure, however, that this stressed waterway faces is the closure of the creek mouth due to sand accretion. This prevents inflow of waters from the Bay of Bengal, resulting in starving the power utilities of their cooling water needs and reduction in dilution of the wastewater inputs. The sand accretion has been a natural phenomenon over the past several years, requiring regular dredging at the creek mouth. However, according to the two electric utilities, the rate of accretion has increased since the construction of Ennore Port. The dredging companies are unable to keep up with the rate of accretion, while the utility companies continue to evolve long-term methods to meet their cooling water needs.



A schematic flow diagram of the various discharges and intakes of the Ennore creek is shown in Fig.2.2.

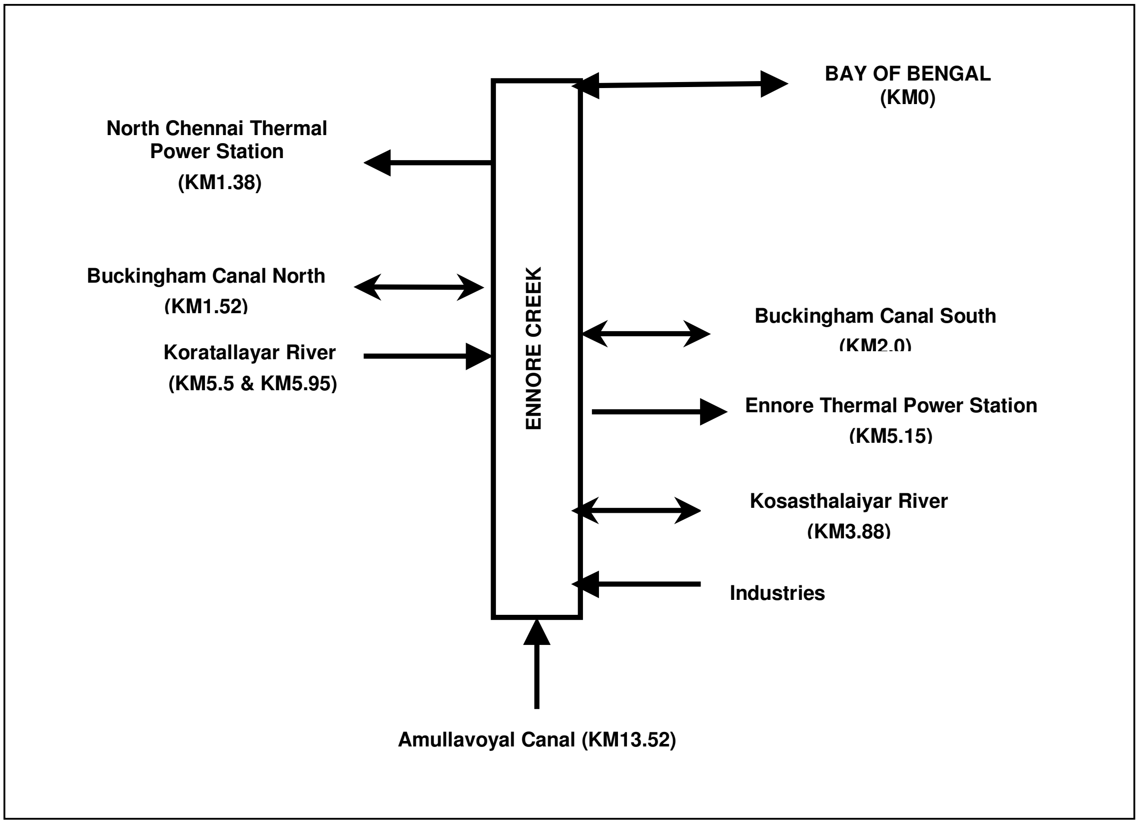


Fig 2.2 Schematic flow diagram for Ennore creek

2.2.1 Existing Landuse

The area to the West of Ennore Port on the landward side is barren salt marsh with little or no vegetation. Agriculture is the major occupation of the people to the north and west off Ennore Creek. Cultivation is generally dependent upon monsoon and the major crops grown are millets, groundnuts and paddy. During non-monsoon, cultivation is carried out in reduced area using groundwater. No recreational swimming (contact) or water sports (non-contact) activity is prevalent in the area. The primary resource utilization from the creek area is shell fishing, industrial cooling water intake and discharge and saltpans.

The landuse distribution (transcribed satellite map 1:5000 scale - Fig. 2.3) consists of built-up settlements (22.5%), agricultural lands (47.5%), wasteland (2.5%), creeks/canals (2%), sandy beaches (12.5%), saltpans (8.5%) and industrial (4.5%).

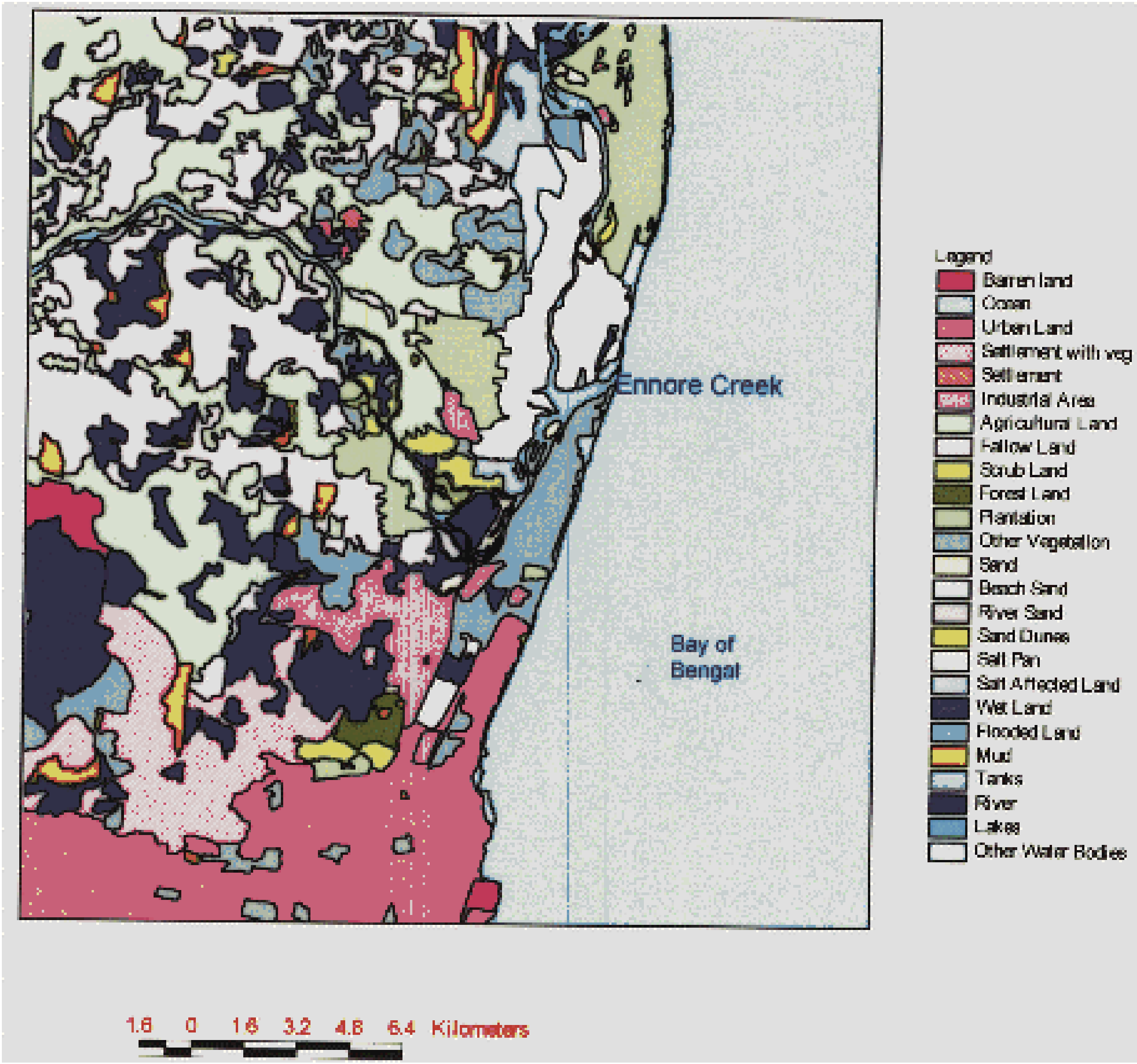


Fig 2.3 Landuse interpretation of a Satellite Imagery in the Ennore creek region

Fishing used to be one of the major activities in the Ennore creek up to the area of Ennore Railway Bridge. The local fisher folk use catamaran and canoes for fishing. Previously, fishermen used this area for fishing craft parking. However with the closure of the creek mouth, there is a considerable drop in all these activities. Near the Railway Bridge oyster (*Crossostrea madrasinensis*) are abundant and hence shell fishing is one of the main sources of income to the local fishermen. Fishermen previously used Ennore creek as a passage to sea with their mechanized country boat and catamaran. At present, only catamaran is used with the shallow depths available due to mouth closure.

Stunted mangroves are found in the Ennore Creek arm leading towards Pulicat (called Kosasthalaiyar in this study). A number of saltpans also exist in this area along the Kosasthalaiyar.

Locals residing on the banks of Korataliyar River near the causeway in Ponneri road use the river for laundry and bathing. The upstream stretch of the Amullavoyal canal beyond the Manali Industrial area is used for bathing. Local people have built an earthen bund across the Amullavoyal canal immediately upstream of the Manali industrial area to prevent saline water intrusion and to retain freshwater.

The heavy land based activities at Manali industrial belt and sewage from North Chennai leads to considerable effluent discharge into the upper reaches of Ennore creek, Amullavoyal and Buckingham Canals (south), in turn discharging into the Ennore Creek.

REMANANTS OF SHELL FISHING IN THE CREEK

- The Amullavoyal Canal receives wastewater from industries. In addition, solid wastes from the industry are dumped along the canal. Productivity blooms are visible in the Amullavoyal Canal throughout the year.
- Oil discharges are visible and appear to be related to tanker washings. A common facility for tanker washing with appropriate treatment could be a good housekeeping alternative.

OIL TANKERS QUEUE FOR REFILLING NEAR MADRAS REFINERIES RETAIL TERMINAL (BANKS OF BUCS)

2.2.2 Description of Ennore creek environs

The uses of the land and the various water systems in the Ennore region vary along the length and breadth of the creek. The following sections aim to summarize these under different zones as indicated in Fig. 2.1

Zone-I Area north of Ennore Creek from Kattupalli to Pulicat Lake

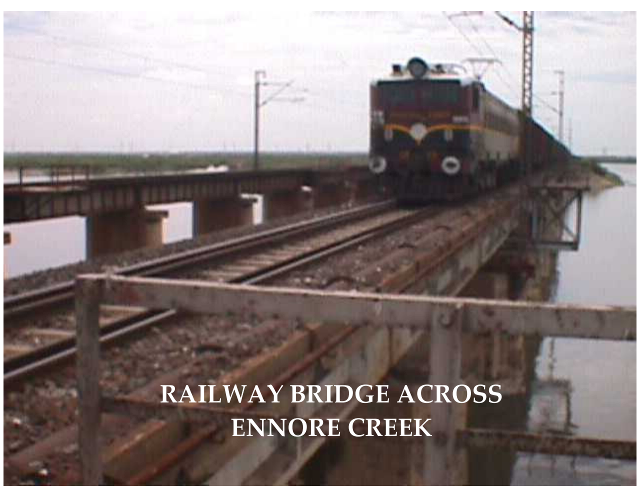
The Kattupalli "Island" is bordered by the Ennore Creek in the south, Bay of Bengal in the east, and Buckingham Canal in the west and the Pulicat Lake in the north. The Island is 15km long from North to South with an average width of 1.25 km with 2.25 km being the broadest point. Patches of mangroves are sighted on the banks of the Buckingham Canal. There are several sand dunes found on this Island.

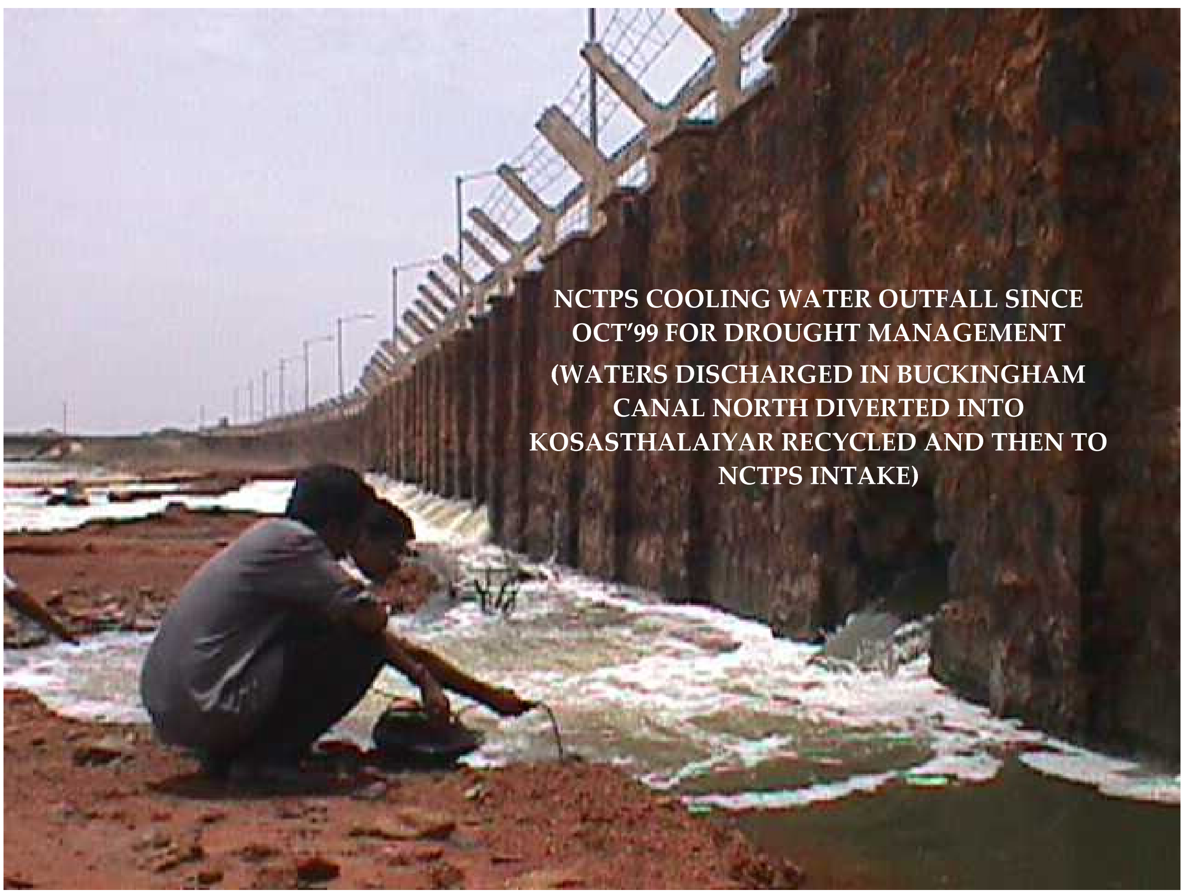
The Tamilnadu Industrial Development Corporation (TIDCO) has selected the southern most part of the island for setting up of a petrochemical park. The North Chennai Thermal Power Station (NCTPS) is situated at the southern tip of the Island.

Pulicat is the second largest brackish water lake in the country spreading across Tamilnadu and Andhra Pradesh with 13000 hectares of water spread in Tamilnadu. The lake is a nursery ground for planktons, fish and prawns.

Zone-II Ennore Port, TIDCO, NCTPS, Kosasthalaiyar River, Buckingham Canal North

The Ennore Port accesses the vast Manali Industrial area, two thermal power plants and has about 3500 acres of its own land. Along with the Tamilnadu Industrial development Corporation (TIDCO) it has an access to another 4000 acres of land around the port area. The location is fairly uninhabited with barren salt marshes all around and therefore strategically situated to handle hazardous cargo to cater to the Manali Industrial area and TIDCO Petrochem Park proposed adjoining the port. The port has excellent connectivity with the hinterland through the National Highway and well connected by railway network. Initially the port had been developed for receiving coal from Talcher in Orissa for the North Chennai Thermal Power Plant.


RAILWAY BRIDGE ACROSS ENNORE CREEK



The Buckingham canal traverses through the Ennore creek enters Ennore near the Railway Bridge and receives significant volumes of domestic and industrial effluents. Some of the nonpoint and point discharges photographed during the survey period are shown below.

OIL RELEASED FROM TANKER ON THE BANKS OF BUCS BEFORE REFILLING

OIL REFINERY EFFLUENT DISCHARGE FROM MADRAS REFINERIES INTO BUCS

MRL OIL EFFLUENT OUTFLOW FROM FACTORY INTO BUCS

SMALL SHACKS AND SHOPS IN MANALI PROVIDING REFRESHMENTS FOR TRANSPORTERS, SMALL WASTEWATER LOADS FROM WASHINGS, SOLID WASTES

MRL OILWASTEWATER DISCHARGE (WITH OIL)

ONE OF THE NON POINT WASTEWATER DISCHARGE FROM INDUSTRIAL SOURCES

ONE OF THE NON POINT WASTEWATER DISCHARGE FROM INDUSTRIAL SOURCES

SPREAD OF ASHOK LEYLAND EFFLUENT ACROSS COMPOUND WALL INTO BUCS BANKS

DISCHARGE FROM ETPS ACROSS COMPOUND WALL

UNKNOWN PIPELINE DISCHARGES INTO BUCKINGHAM CANAL

The frequent closure of the Ennore mouth has resulted in insufficient tidal inflow and thus reduced cooling waters for the thermal power plants. The North Chennai Thermal Power Plant, that withdraws water from the creek, used to discharge the warm water into the coastal waters. NCTPS has now opted to discharge the warm water back into the creek through the Buckingham Canal, in an attempt to maintain the water quantity in the creek. However, it was found that the warm water would flow directly back to the intake structure with minimum retention time, resulting in the power plant withdrawing warmer water for their operations (Fig.2.4).

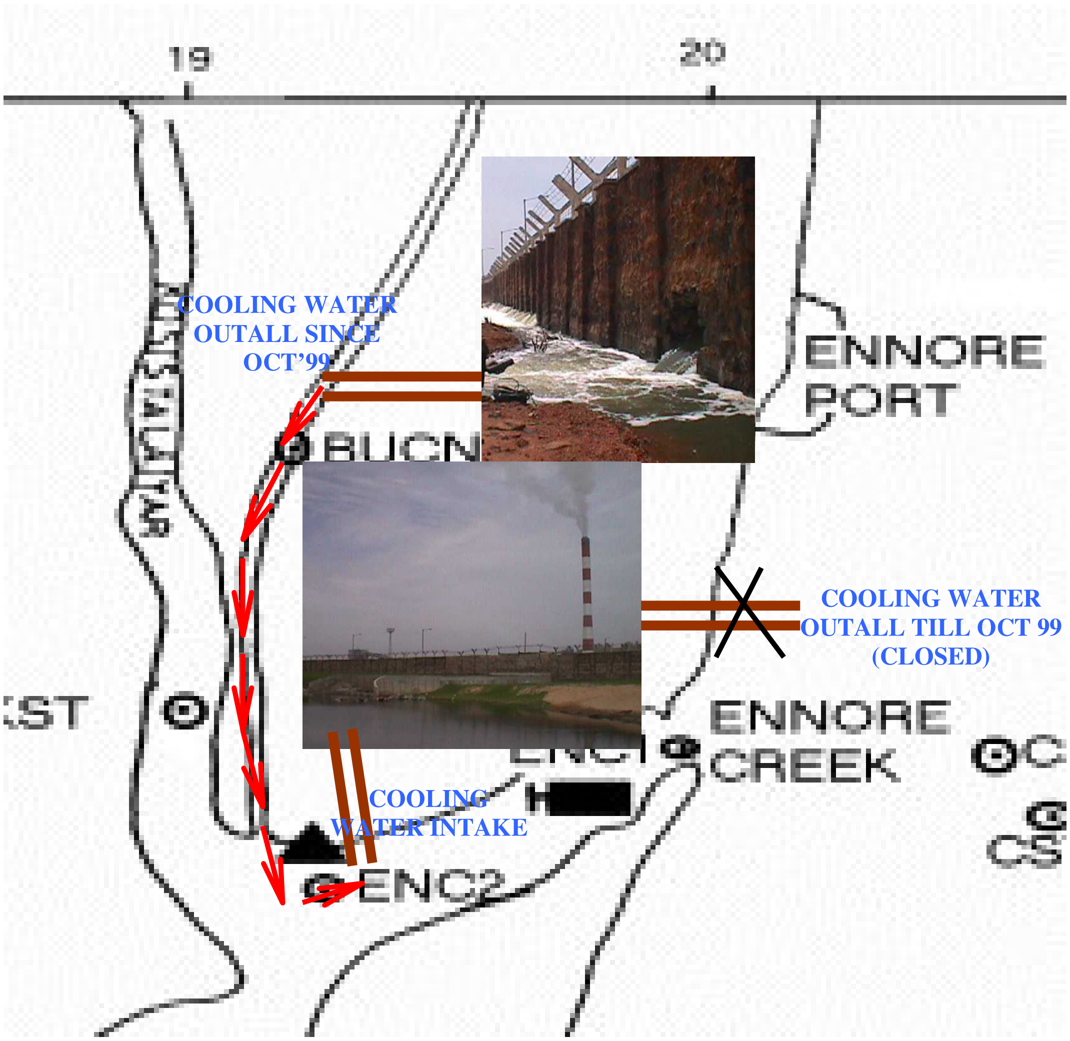


Fig 2.4 NCTPS operations in Ennore Creek

Since Buckingham connects to the Kosastalliyar at two points, north and south of the discharge point, the utility company has placed a bund across the Buckingham canal, immediately south of the discharge point, thereby ensuring that the waters travel northwards to the Kosasthalaiyar backwaters and return to the Ennore creek (Fig 2.5). The result is longer contact with the atmosphere and thus greater cooling of the warm water.

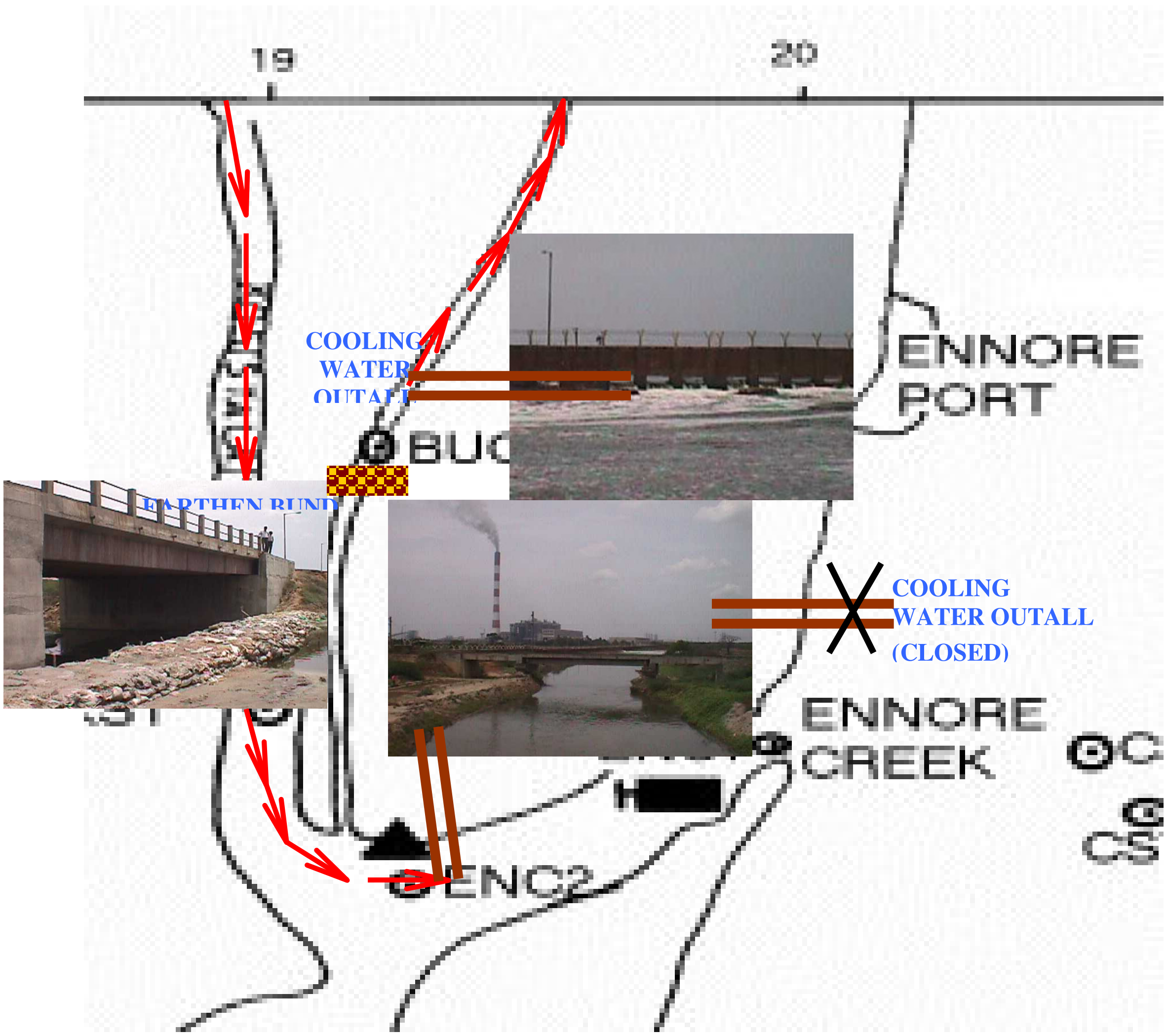


Fig 2.5 Modified NCTPS cooling water discharge

One of the issues that have been raised by this arrangement is the discharge of the heated water to the Pulicat Lake. It can be proved with a simple mass balance that the demand/withdrawal of water is greater in the Ennore creek than the supply. With the closure of the Ennore creek mouth, this difference has to be supplied by Pulicat Lake and thus water tends to flow into the Ennore creek from Pulicat and not vice versa.

This can also be shown with simple mass balance:

- Inflows to the creek are: Mouth (Inflows into the creek) + Amullavoyal canal + Korataliyar River + NCTPS effluent + Kosasthalaiyar inflow.
- Outflows are: Mouth (Outflows from the creek) + outflow from Ennore to Pulicat through Kosasthalaiyar backwaters + NCTPS intake + ETPS intake.

Amullavoyal Canal and Korataliyar River have zero freshwater flows for most of the year. Similarly, the mouth is closed and thus there is negligible inflow and outflow through the mouth. The NCTPS intake and effluent are equal and thus there is zero net inflow/outflow due to NCTPS. Therefore Kosasthalaiyar inflow must equal the Kosasthalaiyar outflow and the ETPS intake. With ETPS intake remaining constant, the Kosasthalaiyar inflow must be greater than the outflow, indicating that inflow from Pulicat Lake is required for ETPS requirement.

Zone III Ennore Creek and West of Ennore Creek upto Korataliyar

The primary source of fresh water is the Korataliyar River. At the headwaters, the Poondi reservoir is constructed across the Korataliyar River, approximately 65 km upstream of Ennore creek. A diversion structure, viz., Kesavaram anicut, is used to divert flows either to Cooum River or to the Korataliyar River. Further downstream, another diversion, the Thamaripakkam anicut is located approximately 15 km from the Ennore creek diverts low flow to the Chollavaram Tank and then to Pulal Lake (Red Hills Lake). Excess flows from Red Hills flow into the Ennore creek through the Red Hills surplus canal (Amullavoyal canal). Fresh water inflow volumes to the Ennore creek can be estimated from the excess flows from the Thamaripakkam anicut and the Red Hills Surplus. Flow data for both the sources are available from the Public Work Department (PWD) and have been collected from 1994 to 1999.

Zone IV South West off Ennore Creek - Manali Industrial estate and townships

The Manali Industrial Estate has several fertilizer and petrochemical industries like the Madras Fertilizers Limited (MFL), Chennai Petroleum Corporation Limited (CPCL), Spic Heavy Chemicals, Madras Refineries Limited (MRL), and Indian Additives Limited (IAL) etc., (Table 2.1)

EUTROPHICATED AMMULAVOYAL CANAL WATERS NEAR MADRAS FERTILISER LIMITED

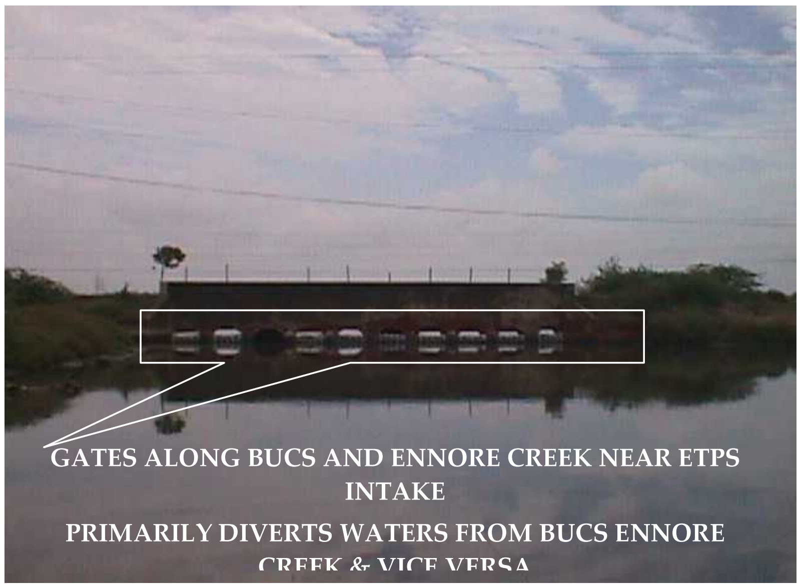
ONE OF THE EFFLUENT DISCHARGES IN THE AMULLAVOYAL CANAL

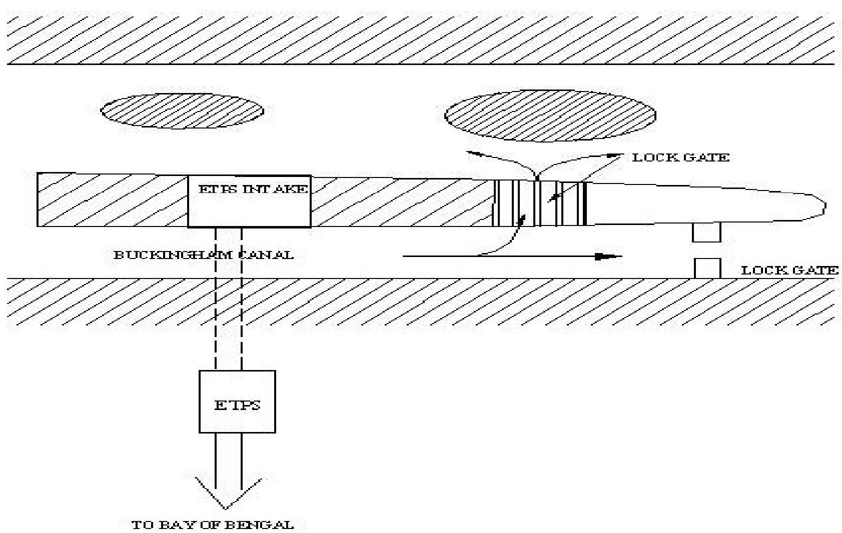
The boundaries are the causeway at Amullavoyal village and an earthen bund along the Amullavoyal canal. At the Amullavoyal canal, the local inhabitants build an earthen bund every year in an attempt to stem salt-water ingress. The bund is removed if excess water is released by the Red hills reservoir into the surplus canal. Agriculture is carried out in these areas for most part of the year. The Amullavoyal canal receives high volumes of industrial and domestic effluents downstream of the earthen bund.

Zone V Coast south off Ennore Creek, ETPS, Buckingham Canal South upto Kasimode

Agriculture is the main occupation in the area to the west of the Ennore Creek. The Ennore Thermal Power Station is located along this stretch. The Buckingham Canal South runs from the Ennore Creek in the North to the Cooum River in the South and further southwards from there on. Several discharges enter this stretch of the Buckingham canal from industrial sites such as Madras Refineries Ltd., (MRL), Indian Oil Corporation (IOC) etc. Municipal discharges also enter from a number of drains from the North Chennai area. The Otteri Nullah is also a major carrier of mixed effluents to the Buckingham Canal.

Gates are constructed between the Buckingham Canal South and Ennore Creek off ETPS intake to enable ETPS withdraw cooling water from the Ennore Creek during low flows in the Buckingham Canal South.

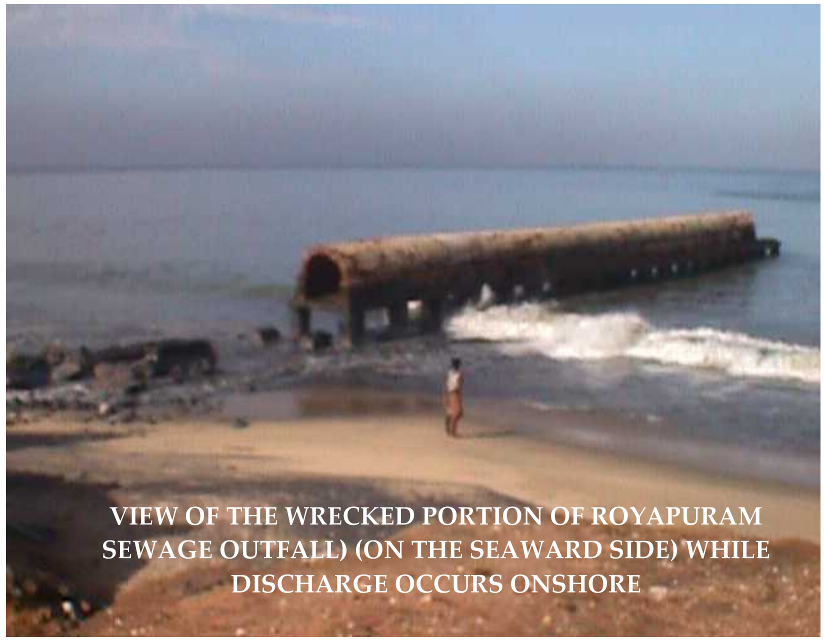




PLAN VIEW OF THE SLUICE GATES AND FLOW PATTERN

Zone VI North Chennai Coast, north off Royapuram fishing harbor

While heavy deposition occurs in the area south of the Chennai Port resulting in the widening of the Marine beach, the area to the north of the Royapuram fisheries harbor is heavily eroded resulting in loss of several hectares of valuable land. The Royapuram sewage outfall discharging 12.84 MLD (Year 1998 CMWSSB value) of mostly raw untreated municipal sewage is located along this coastline.


VIEW OF THE WRECKED PORTION OF ROYAPURAM SEWAGE OUTFALL) (ON THE SEAWARD SIDE) WHILE DISCHARGE OCCURS ONSHORE

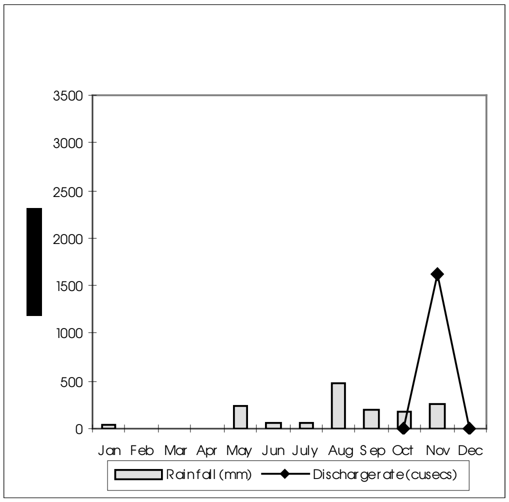
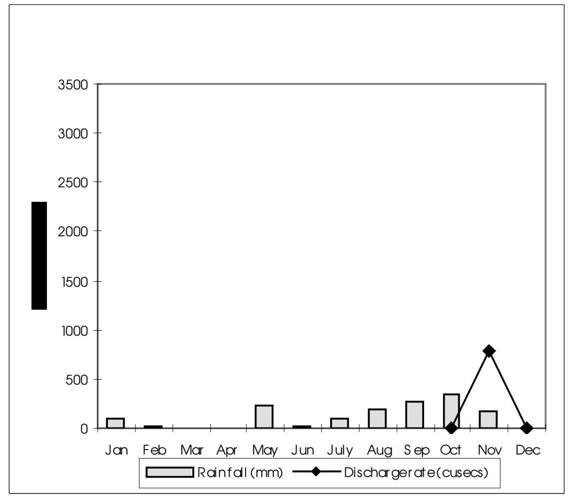
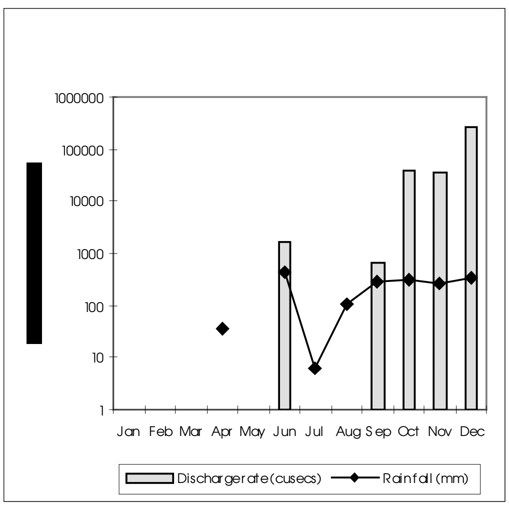
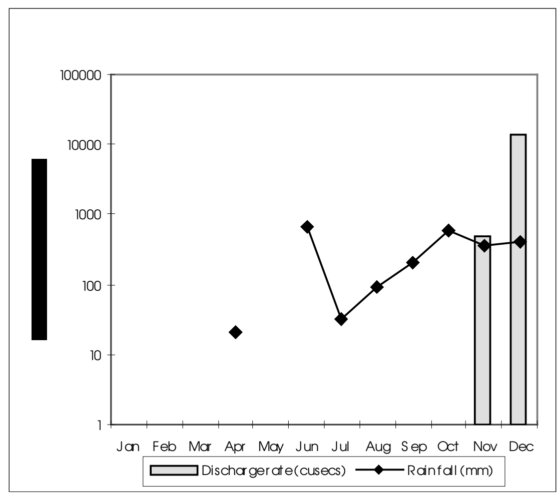
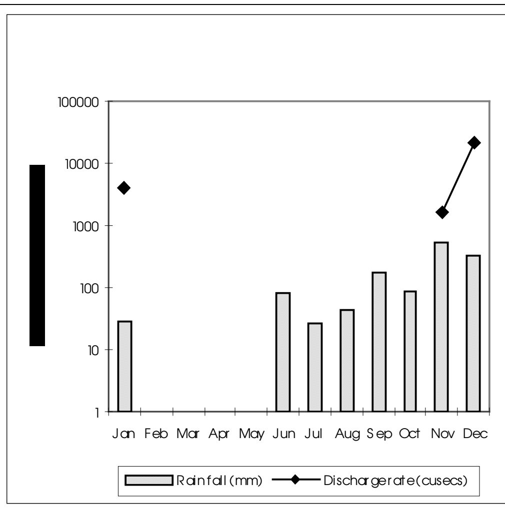
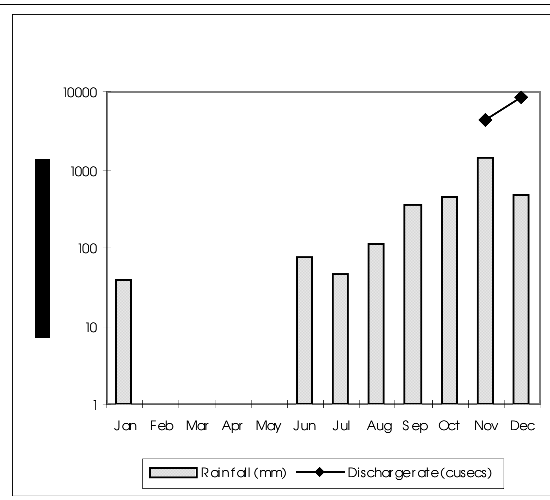
2.3 SEASONS

Meteorological data for Ennore shows average minimum air temperatures varying between 20°C and 28°C and maximum temperatures ranging from 28°C to 37°C. The seasons of Ennore influences its oceanographic characteristics, i.e., strong winds during the SW and NE monsoons and cyclonic winds producing larger waves. The coast of Ennore is characterized by the following seasons.

1. South West Monsoon : June to August
2. North East Monsoon : September to November
3. Winter : December to February
4. Summer : March to May

2.3.1 Rainfall

The region mostly receives rainfall from the Northwest monsoon during the months of October and November. The normal rainfall for Chennai is 753mm. The total rainfall recorded in the Red Hills station representing the study area was 1859mm in the year 1999.

Discharge (cusecs) and Rainfall (mm) recorded between 1995 and 1999 in the study area	
Thamaraipakkam	**Red Hills**
 1995	 1995
 1996	 1996
 1997	 1997

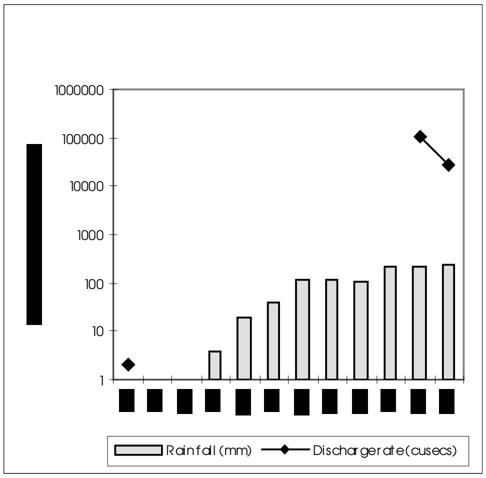
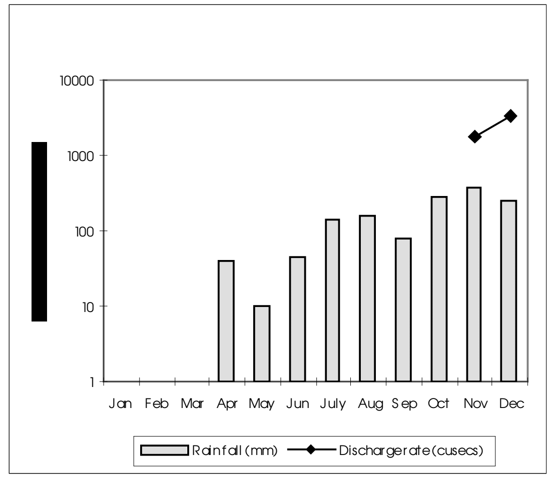
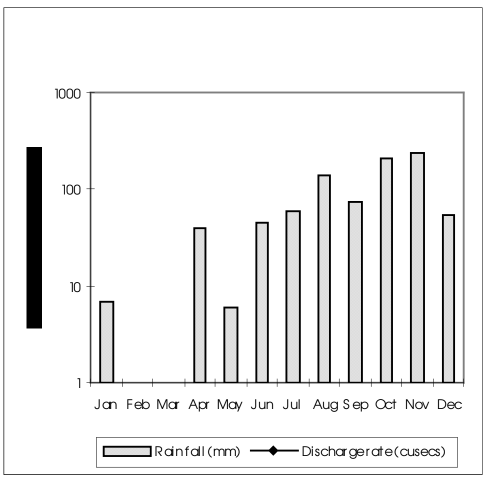
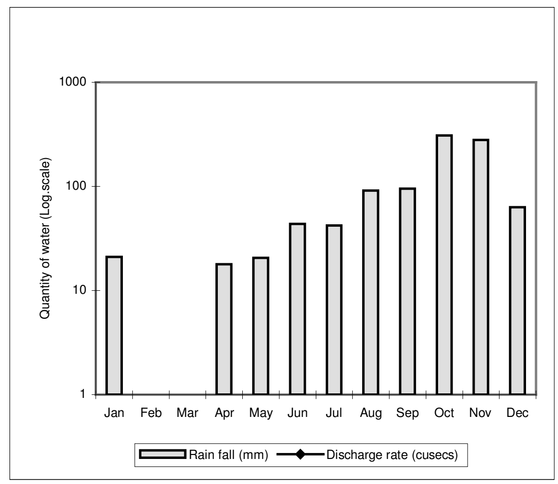
Discharge (cusecs) and Rainfall (mm) recorded between 1995 and 1999 in the study area	
Thamaraipakkam	**Red Hills**
 1998	 1998
 1999	 1999

Fig 2.6 Freshwater inflow

Fig 2.6 and Table 2.2 show the rainfall recorded and the discharges at Thamaraipakkam and Red Hills, which feed the Kortalaiyar River and the Amullavoyal Canal respectively.

Table 2.2 Rate of Fresh water discharge

Year	Thamaraipakkam		Red Hills	
	Rainfall (mm)	Discharge (Cusecs)	Rainfall (mm)	Discharge (Cusecs)
1994	1146	2414	1729	3965
1995	474 (Aug) [Total: 1484]	1628 (Nov) [Total: 1628]	351 (Oct) [Total: 1428]	791 (Nov) [Total: 791]
1996	453 (June) [Total: 1809]	1664 (Jun), 684 (Sep), 38509 (Oct), 36602 (Nov), 253472 (Dec) [Total: 330931]	646 (June) [Total: 2344]	500 (Nov), 13904 (Dec) [Total: 14404]
1997	535 (Nov) [Total: 1301]	4112 (Jan), 1585 (Nov), 20844 (Dec)	1442 (Nov) [Total: 2990]	4384 (Nov), 8345 (Dec) [Total: 12729]

		[Total: 26541]		
1998	234 (Oct)	2 (Jan), 110537 (Nov), 27540 (Dec)	374.4 (Nov)	1792 (Nov), 3315 (Dec) [Total: 31889]
1999	241 (Nov)	-	307.6 (Oct)	-

2.4 HYDROGRAPHY – COASTAL/CREEK

The status of the Ennore creek mouth influences the tide and current pattern inside the Ennore creek. The mouth remains partially closed during the pre-monsoon and monsoon seasons and fully open during post-monsoon. The Ennore Port now influences the dynamics of the creek mouth.

Tidal waters also enter through the Kosasthalaiyar backwaters and thus the sand bar formation across Pulicat Lake mouth also can influence the entire system. The currents are generally tidally influenced depending on the mouth condition. The withdrawals for cooling waters have the potential to impact flow pattern in the creek significantly.

2.4.1 Tides

Tides at Ennore are semi-diurnal having two peaks and two lows every day and in the duration between new and full moon days (Spring and neap)

The different levels of tides at Ennore are as follows:

Mean Lower Low Water Springs(MLLWS) :+0.09m
Mean Low Water Springs (MLWS) :+0.14m
Mean Low Water Neaps (MLWN) :+0.43m
Mean Sea Level (MSL) :+0.65m
Mean High Water Neaps (MHWN) :+0.84m
Mean High Water Springs (MHWS) :+1.15m

- The maximum, mean and minimum possible tidal ranges are estimated as 1.06m, 0.70m and 0.22m respectively.
- Considerable reduction in tidal range is possible inside the creek when compared to the tidal range in the open sea due to partial closure of the creek mouth during monsoon sampling.
- When the mouth is open, tidal range for spring and neap tides inside the creek and in the open sea may be similar.

2.4.2 Waves

In general significant wave heights were found to vary between 0.9m and 1.6m, with maximum of 1.6m and 1.5m observed in May and June respectively during SW monsoon. The average wave heights were found to vary between 0.57 m and 1.0m in the year 1998. Predicted wave height was 8.0m during cyclones.

Higher wave periods were observed during SW monsoon with overall ranges varying from 8.1 to 11.1 seconds. Waves are found to approach Ennore predominantly from two directions. From March to September it is 135^{o}N and 90^{o}N from November to January

2.4.3 Currents

Tidal currents in the Creek are expected. Freshwater flows are seasonal and limited to 2-3 months. Due to the low tidal range, the tidal currents are expected to be low, in the order of 10-20 cm/s.

2.5 LITTORAL DRIFT AND ITS IMPACT ON ENNORE CREEK MOUTH

The seasonal circulation in the Bay of Bengal influences currents in the coastal waters. Currents move along the coast towards the North from March to October and move southwards from November to February. This phenomenon is also responsible for the sediment transport/littoral drift, which results in net sedimentation on the southern side of any structure built on the coast. Tidal currents influence the Ennore Creek. The flood and ebb tide is a significant component of the flushing characteristics of the tide.

Littoral drift occurs in the Northerly direction along the Chennai/Ennore coast for 8 to 9 in months in a year, with the waves approaching the coast from Southeast direction. There is a southerly littoral drift for 3 to 4 months when waves approach the coast from east. The littoral drift is intercepted by Ennore Creek inlet flows.

2.6 SECONDARY DATA

2.6.1 Water resources

The major surface freshwater sources in the study area are the Kosasthalaiyar River and the rare excess freshwater flows from the Red Hills reservoir. The freshwater sources are highly intermittent and may occur for only 2-3 months a year. Groundwater is the other freshwater source and is extracted, consequently leading to increasing saltwater ingress. The Chennai Metropolitan Water Supply and Sewerage Board has prepared a master plan to supply about 127 lpcd of water in the area by 2011.

2.6.2 Fisheries Potential

Fisheries data along the study area (47 Km length) was collected from the Directorate of Fisheries, Tamilnadu Fisheries Dept. The catch composition indicated dwindling percentage of crabs, cephalopods and prawns between 1994-95 and 2000-2001. Analysis of the data revealed that fisheries catch is increasing in Tamilnadu while it is decreasing in the study area. Possible reasons for downward catch in the study area may be attributed to

- Overexploitation from bottom trawling, gill nets etc.
- People preferring employment on land to fishing, especially if there is diminishing trend in fish catch and alternative employment opportunities are available
- Increasing catch/unit effort
- Increase in operations cost
- Fishing activity moving away from the study area towards coastal Andhra Pradesh
- Decreasing breeding and spawning grounds e.g., Pulicat, Ennore Creek, Cooum, Adayar estuaries
- Increased pollution

However, there is no information to test a hypothesis that pollution is a significant cause for localized decrease in fish catch. The notable feature is that fishing activity is increasingly moving offshore; suggesting that land based activity may have an impact. Figs. 2.7 shows trends in fall of fisheries in the study area while it is found to be increasing in Tamilnadu as a whole.

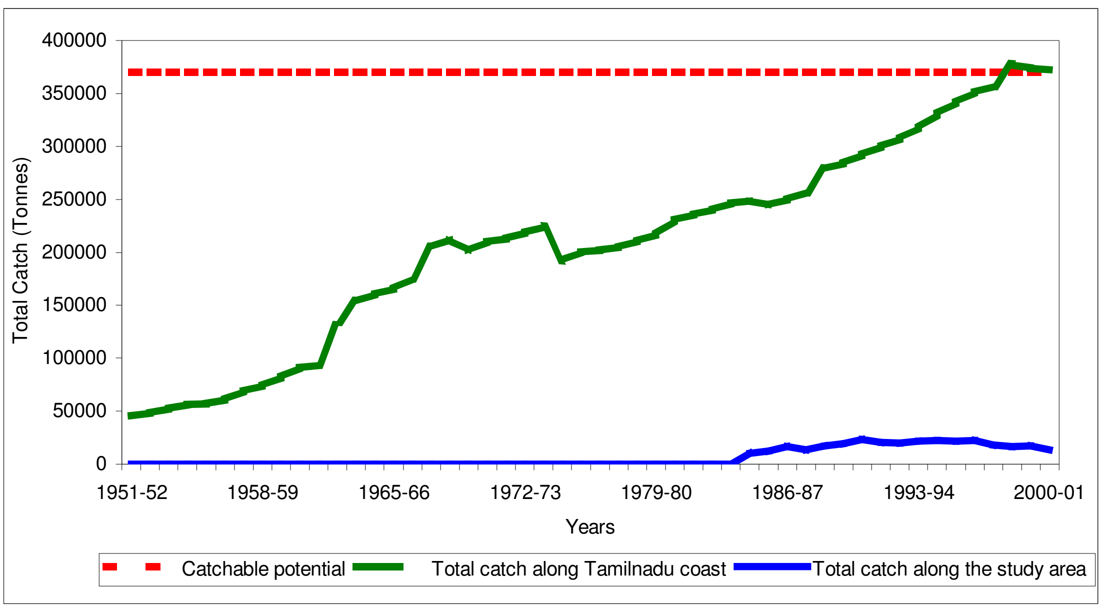


Fig 2.7 Fishery data for Tamilnadu and Ennore

2.6.3 Socio-economics

The area comprises 54 villages and 11 urban areas with over 70% of the villages having population of less than 2000 persons. About 25% of the urban centers have population between three and five thousand.

- Groundwater is the only source of water in the villages of the study area. However the availability of groundwater varies with the seasons

- While there is limited communication facilities like post-offices and telephones, 93% of the villages have a pucca approach road. However, public transport facilities to these villages are infrequent.
- Very few health and limited educational facilities are locally available in most of the villages. Most of the villages depend on the towns for these facilities. Towns are located between 3 to 10 km distances from the villages.
- Twenty-six percent of the villages in the study area have less than 50% literacy.
- Agriculture related workforce is predominant in the villages. However this occupation is seasonal.
- While 64% of the villages have power supply for all purpose use, 26% have power supply for domestic and agriculture and 10% for only domestic use.

2.6.4 Population growth

The rural and urban centers in the region of interest in spread in Ponneri, Saidapet taluks of the Chengalpet MGR district and partly in Chennai city. The total rural population in the 54 villages is 102503 (1991 census) and in the 11 urban areas it is 331294 (1991 census).

- Seventy percent of the villages have a population of less than 2000 persons
- About 25% of the towns have population varying from three to five thousand
- The density of population is less than 700 persons per square km in about 61% of the villages
- The average density of population is 862 with a minimum of 64 and maximum of 4813 persons per square km
- Population growth in Tiruvottiyur (urban area, south west of Ennore Creek) has a high rate owing to rapid industrial growth of the Manali area. Similarly Kathiwakkam also shows high growth. Villages like Pulicat, Puzhuthivakkam, Ennore, Karunguli and Kattuppalli show increase in population figures over the years.

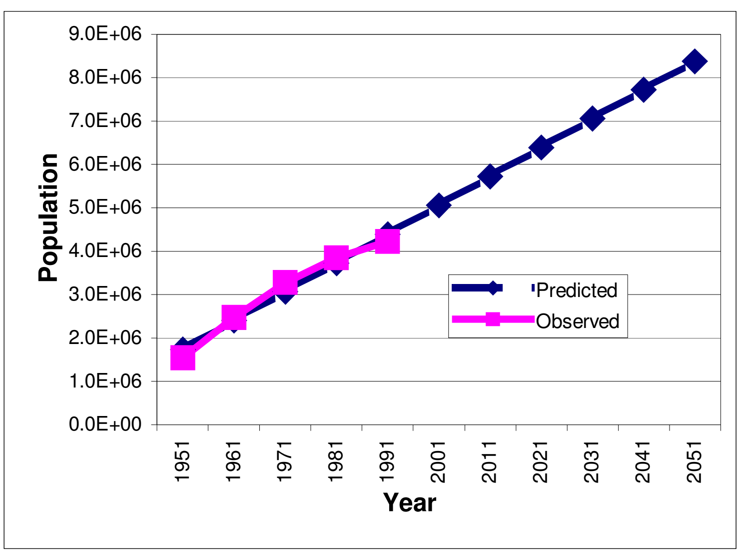


Fig 2.8 POPULATION GROWTH TREND FOR CHENNAI

(SAME TREND ASSUMED FOR ENNORE)

3 WATER QUALITY STANDARDS

3.0 DESIGNATED BEST USE CLASSIFICATION

The first requirement for water quality management through WLAs is to set the objective that is to be achieved. This is done by

- Determination of traditional use of the water body from present and historical data. If there are several uses, determine the use that requires the highest quality.
- Classification of each stretch of the water body into one of the five MoEF seawater criteria (SWI to V) based on the traditional uses and activity that demand highest quality

Through monitoring, water quality is determined in each of these stretches and compared with standards prescribed for the designated best use. When water quality of the stretches are found to conform to the relevant standards, then the WLA would strive to

- Maintain pollution loads into the system at the existing levels and aim for continual improvement of the system
- Determine the limits of assimilative capacity of the system and estimate the maximum loading that the system could assimilate while conforming to the required best-use classification
- Estimate additional future loads into the system and appropriately determine the daily loads and treatment processes based on the assimilative capacity

If the water quality of the stretches does not conform to the relevant standards, then parameters that violate the standards are evaluated, and the WLAs would determine the pollution loads, the levels of treatment required and methods of disposal for achieving the required standard.

3.1 NEED FOR CLASSIFICATION

Coastal waters are used for several other purposes such as bathing, fishing, water sports, salt and chemical recovery, industrial cooling, shipping, navigation etc. The quality required for each use varies with uses like fishing and bathing demanding higher quality, while other uses including navigation and wastewater disposal requiring lower quality. The quality can be specified using numerical standards for water quality indicators such as Dissolved Oxygen and Fecal coliforms.

For coastal stretches in India, the Central Pollution Control Board (CPCB) has classified all coastal stretches into five categories of uses, ranging from SW-I to SW-V. These uses are based on the traditional and organized uses of the water. Among the various types of uses in a category, there is one use that demands highest level of water quality/purity and that is termed a "designated best use" in that stretch of the coastal segment, based on which the classification is made.

The need for classification is to:

1. provide guidance for existing water quality as well goals for maintaining or improving that quality;
2. indicate the general type of discharges allowed;
3. show areas of conflict between uses and areas where waters are degraded;
4. establish standards for toxicity to protect aquatic life;
5. establish priorities for pollution mitigation and remediation.

Based on this, primary water quality standards have been specified for the following designated best uses:

Class/ Standards	Designated best use
SW-I	Salt pans, Shell fishing, Mariculture and Ecologically sensitive zone
SW-II	Bathing, Contact Water Sports and Commercial fishing
SW-III	Industrial cooling, Recreation (non-contact & aesthetics)
SW-IV	Harbor
SW-V	Navigation and Controlled Waste Disposal

The designated best use classification has been done by the Ministry of Environment & Forests (MoEF) after review of the several international standards for water quality.

3.1.1 Goals of use classification

Objective of use classification is to ensure that the water quality criteria meet the minimum standard requirement. This is achieved by

- determining the deficiency in the ambient water quality from the assigned class category in any zone
- enforcement of necessary pollution control measures by the concerned State Pollution Control Board on the basis of observations

The purpose is to control pollution caused by human activities based on the designated uses. Any deficiency in the ambient water quality would then require appropriate pollution control on the discharges. The designated best use classification has associated water quality criteria for coastal and marine waters (BIS: 7976:1976). The Ministry of Environment and Forests later notified the criteria as standards in 1999.

The parameters (for which standards are specified) are limited to physical and chemical parameters such as pH, DO, colour and odour, floating matters, BOD, turbidity etc. and does not include toxics (metals and organics). For SW-I, metals such as Mercury, Lead and Cadmium have been included. Though SW-I is desirable to be safe and relatively free from hazardous chemicals like pesticides, heavy metals and radionuclide concentrations, such standards have not been specified. For SW-III, dissolved Iron and dissolved Manganese are included exclusively for industrial cooling purpose.

Standards for bacteria indicators are limited to fecal coliform to indicate potential human health risk from acute gastrointestinal disease, whereas other pathogens, which may cause throat, skin, eye, ear and respiratory tract infections, are not specified.

3.2 RATIONALE FOR PRIMARY WATER QUALITY CRITERIA

- Primary water quality criteria are scientifically established limits of physical, chemical and biological constituents/pollutants of water.
- While water quality criteria for a specific use can cover several constituents of coastal parameters, it is logistically difficult to consider all and therefore constituents are limited to a set of environmental indicators.
- Parameters defined for water quality criteria signify only those, which are of *primary* concern for the five designated use classes. These are evolved after surveys of present traditional water uses and water quality along the Indian coastlines and also a review of the criteria as specified in BIS: 7967-1976 and those developed in countries such as USA, UK, West Germany, Canada and Japan.

3.3 REVIEW OF INTERNATIONAL STANDARDS

Some of the international standards corresponding most closely to the specific use designation for the Indian use classification system reviewed are:

- Environmental Protection Agency Standards (USEPA)
- European Community (EC) Directives
- Natural function of the water body and human activities (Thailand)

Review of the International standards for water quality suggest that the standards:

- Cover metals and organics in addition to conventional parameters;
- Treat total coliforms and fecal coliforms as pollution indicators for contact water recreation uses. In addition to these, EC standards use streptococci fecalis indicator for bathing waters. While the presence of fecal coliforms (E.Coli) in an aquatic system can be taken as evidence of recent fecal pollution, the survival rate usually is much shorter in seawater than in freshwater. However, pathogens found to cause diseases such as infection of wounds, urinary and respiratory tracts, cystic fibrosis, dermatitis, folliculitis, otitis and conjunctivitis, are not considered.

Site-specific toxicity is preferred for marine waters, rather than a uniform standard. Site-specific toxicity was beyond the scope of the study the not planned. Utilization of results from other studies was not considered appropriate as most of them apply to temperate countries. Thus, this review of various International standards concludes that the first approach to WLA must address conventional issues such as DO and fecal coliforms, for which Indian standards are available.

Subsequent research for site-specific toxicity for trace metals and organics is recommended as, the combined (synergistic or antagonistic) effects on health and aquatic lives are not yet clearly known. These chemicals undergo bioaccumulation, magnification and transfer to human and other animals through food chain. In areas where fisheries, saltpans are the governing considerations, and presence of such chemicals apprehended/reported, bioassay test should be performed following appropriate methods for the purpose of setting case specific limits.

3.4 REVIEW OF CURRENT CLASSIFICATION

For Indian waters, the Central Board for the Prevention and Control of Water Pollution in 1982 assigned a classification on the basis of a reconnaissance survey. They were classified into five classes viz. SW I to SW V. The coastal waters of India were zoned on the basis of this classification (COPOCS/6/1993). Any deficiency in the ambient water quality needs appropriate pollution control on the discharges reaching the zone from the land sources. Any stretch of coastal water identified with multiple use situations were assigned with the use, which demanded the highest degree of water quality.

For Tamilnadu, the designated best use classifications had been published in coastal pollution control series COPOCS/1/1982. The Ennore coastal area is designated as water suitable for harbor purpose. Yet, surveys indicate that the current use pattern along the stretch demands higher degree of water quality than the statutory levels. Fig 3.1 shows the designated use for the study area and the related information is given in Table 3.1.

Since the designated use classification of 1982 resulted in fairly coarse resolution maps on macro scale with long stretches (10-30 km stretches) of the coast being classified to a single use. This study suggests modifications to the designated use classification on the basis of the higher resolution and the existence of higher quality users.

Table 3.1 Use map information for TN Sector : Ennore-Madras

1	MAJOR COASTAL ACTIVITIES	Harbour. Industrial, Oil Exploration/Refining, Mining/Excavation, Industrial Wastes Disposal, Municipal Wastes Disposal, Industrial Cooling, Recreational Tourism, Residential Tourism, Fishing, Aquaculture, Salt Production, Protected Areas
2	MAJOR POLLUTION SOURCES	Thermal Power Plant, Fertilizer, Chemical and Engineering Industries, Municipal Discharges from Ennore and Madras
3	TYPES OF POLLUTANTS	Sewage, Flyash, Chemicals, Heavy Metals, Oil and Grease, Thermal Discharges

4	IMPACT OF POLLUTION ON ACTIVITY, IF ANY	Cooum River discharge impacts negatively on Marine Beach in Madras and also the Elliot Beach
5	PRESENT WATER QUALITY CLASSIFICATION	Not Available
6	PRESENT USES OF THE COASTAL WATER	Harbour, Waste Discharges, Industrial Cooling, Recreation
7	CLASSIFICATION BASED ON DESIGNATED BEST USE	SW I (Marina & Elliot Beach) SW IV (Other areas)
8	ECOLOGICALLY SENSITIVE AREAS	Nil
9	AREAS OF SPECIAL INTEREST	Madras Port, Marine Beach, Elliot Beach
10	ACTION RECOMMENDED	Improvement of water quality of the Cooum River Treatment of wastewater discharges from the following Industrial units: Kothari Chemicals E.I.D. Parry Ashok Leyland Easun Limited Carborundum Universal Ltd. National Carbon Company Immediate action is required on the above.

Source: CPCB

3.5 PROPOSED USE CLASSIFICATION AND JUSTIFICATION

The present work intends to generate higher resolution spatial definitions to justify the need for micro level zoning. The Ennore coastal area situated at the east coast of India warrants refinement of statutory designated use classification, as it is on coarse scale.

Designated use classification implies that the classification will be based on the highest quality uses. This area has been designated as SW-IV, possibly due to the proximity of the Chennai Port and fishing harbour. The new Ennore Port could be used to further support this classification.

However, intensive shell fishing of blue-green mussels carried out in Ennore creek from May to September and is generally sold in Kerala. In addition, fishing is also done in the creek waters by the non-mechanized crafts. The water quality in the creek becomes critical especially since shellfish are filter feeders. Other higher quality users are the Ennore Thermal Power Station (ETPS) and the NCTPS, where poor quality waters result in excessive maintenance costs of the cooling water system. Offshore, the fishing activities demand that the water bodies as SW-II.

3.5.1 Suggested use classification

The attempt to refine the current classification is justified especially where other uses are prevalent as presented below. Considering the land use pattern, pollutant discharges and surface and ground water withdrawals in this area, the following reclassification is suggested for Ennore creek and adjoining coastal waters (Fig. 3.2).

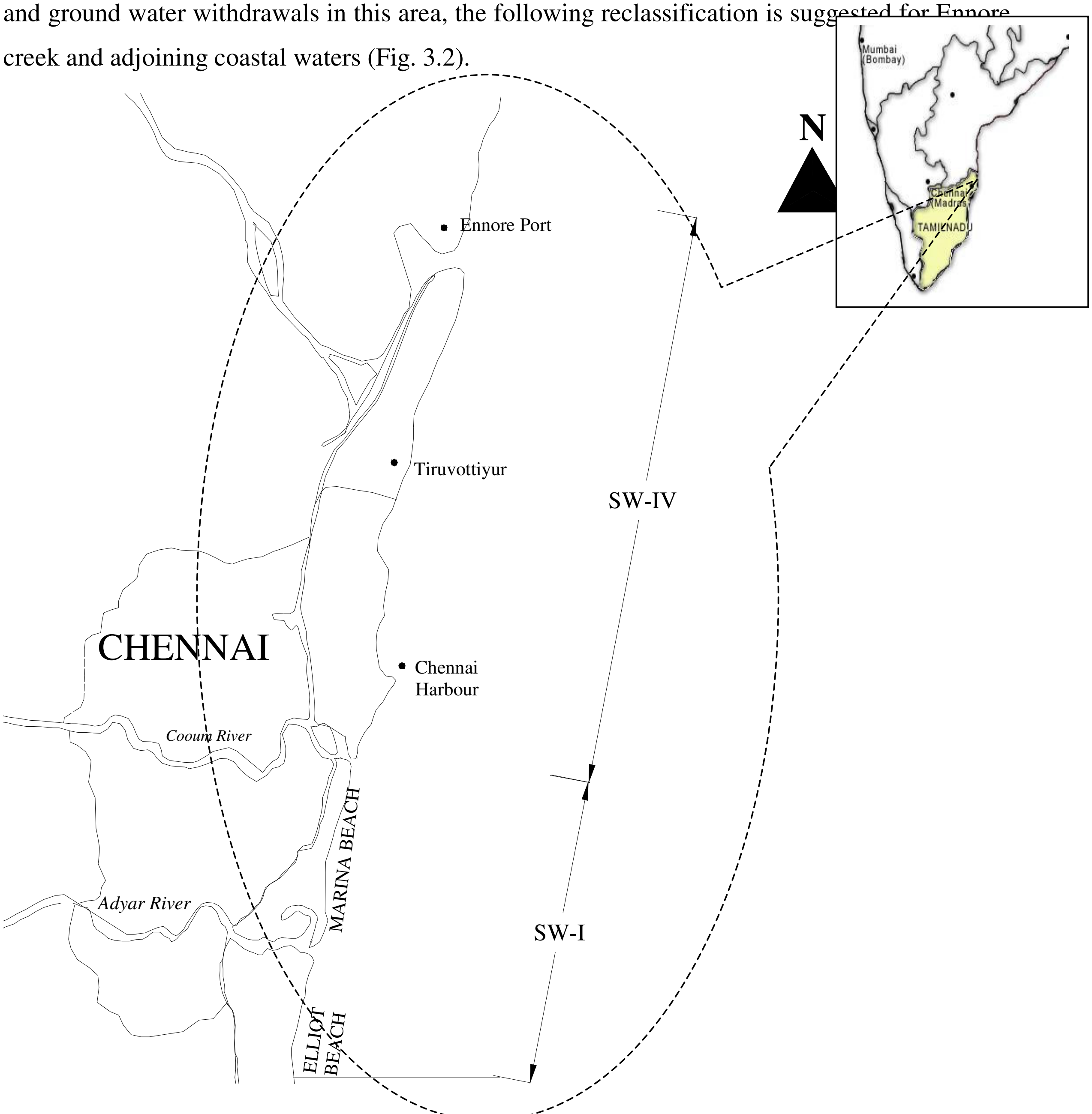


Fig 3.1 Existing Designated use classification for the study area

(Prepared based on CPCB classification)

- From the creek month to the Railway Bridge – SW–II waters to accommodate commercial fishing. While extensive shell fishing is prevalent in this stretch, the water quality criteria required for SW-I standards may be unattainable and thus is not recommended.
- From the Railway Bridge to the Ennore Thermal power plant Intake – SW–III for the cooling water requirements of the power plant.
- Retention of SW-V for remaining section of the creek.
- Classification of the coastal waters from the south of Ennore Port to north Royapuram fisheries harbor as SW-III to meet requirements of ETPS if necessary

- Retention of SW-IV for coastal waters up to 10m water depths since minimal fishing occurs in this area
- Beyond 10m water depths, SW-I criteria may be applied

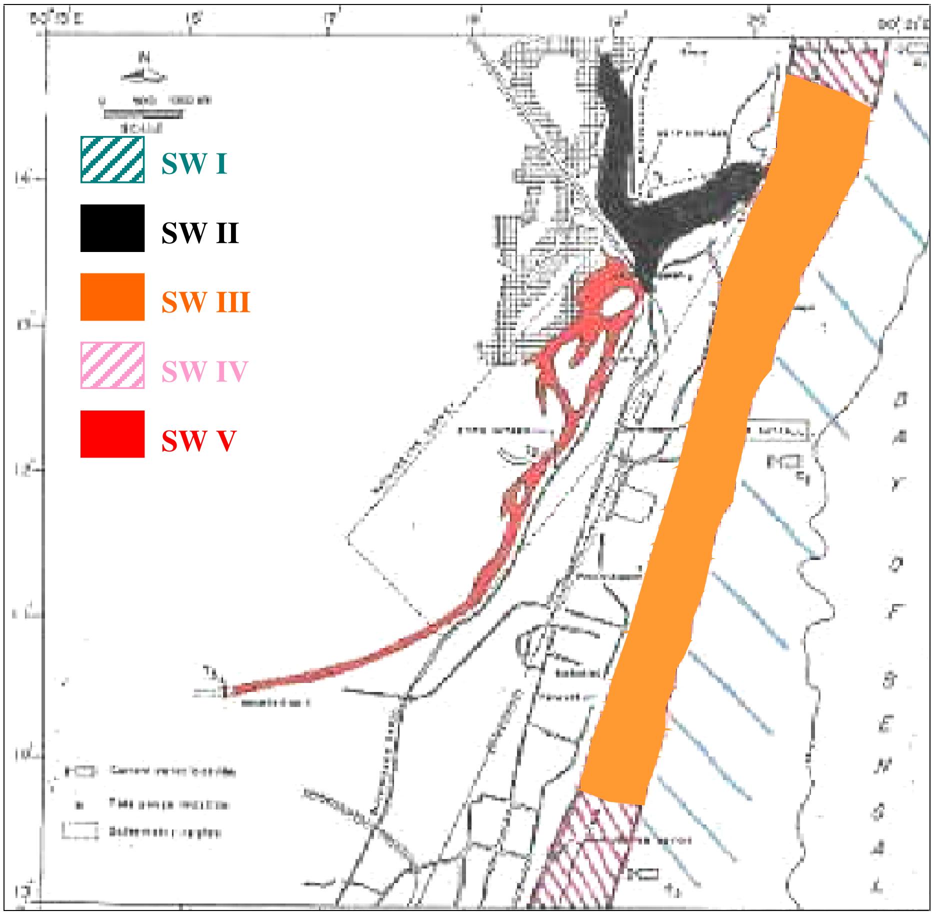


Fig 3.2 Suggested reclassification for Ennore creek and adjoining waters

3.6 GOALS OF SUGGESTED RECLASSIFICATION AND WLA

The objectives of the suggested reclassification are:

- To continue shell fishing in the Ennore Creek only after sufficient analysis of shell fish for health criteria as the waters do not meet the criteria required for SW-I uses (shell fishing); recommend that the minimum standard to be attained as SW-II
- To ensure commercial fishing in the stretch between creek mouth and Railway Bridge by prescribing limits on the BOD and fecal coliform loading in this stretch in order to conform to SW-II standards;
- To maintain SW-III standards in the coastal stretch between the railway bridge and ETPS intake
- To maintain SW-V standards between ETPS intake and southwards, as the current uses do not warrant higher quality than required for controlled waste discharge;

Since the secondary data shows problems with DO and fecal coliform, for which standards exist in Indian environmental legislation, the study focused on DO-BOD kinetics and pathogens.

4 SAMPLING PROGRAM DESIGN

4.0 INTRODUCTION

The objective of this sampling program was to define the Dissolved Oxygen and pathogenic pollutant water quality kinetics of Ennore creek and North Chennai coastal waters. A calibrated model would enable modeling of the system for WLA. Therefore the study was designed to sample at the point sources and receiving waters simultaneously to verify and calibrate models capable of defining water body responses to a specific set of loadings. Monitoring of hydrodynamics, water quality in receiving waters and discharge of point sources needed to be done simultaneously, primarily due to the dynamic nature of tidal flows, point source discharge/intake conditions and in particular for Ennore, the characteristics of the bar at Ennore mouth. This section briefly describes the considerations in the sampling program design.

4.1 SAMPLING DESIGN CONSIDERATIONS

Following considerations were made while designing of field sample collection program.

i) *Study objectives*
ii) *System characteristics*
iii) *Data presently available*
iv) *Modeling approach selected*
v) *Quality requirements*
vi) *Project resources (equipment, boats, funds, personnel)*

4.1.1 Study objectives

The objective of the study was

- To estimate and monitor the pollutant loadings and receiving water responses to the pollutant loading
- To model this behavior of water quality and hydrodynamics in the Ennore estuary and the coastal waters off the North Chennai coast so as to calibrate a water quality model
- To apply the calibrated model to determine a waste load allocation that would meet the water quality criteria

4.1.2 System characteristics

The characteristics of Ennore Creek that were taken into consideration while designing the location, frequency and parameters were:

- Frequent closure of mouth and flows into the creek from the Kosasthalaiyar, Kortalaiyar, Amullavoyal Canal etc.,
- Dominant processes in the creek such as cooling water withdrawal & release

- Inputs from municipal and industrial wastewaters
- Location of cooling water discharge and intake points
- Semi-diurnal tides at Ennore having two peaks and two lows every day and in the duration between new and full moon days (Spring and neap)
- Entry of tidal waters into Ennore Creek through Kosasthalaiyar river
- Seasons of Ennore influencing its oceanographic characteristics, i.e., strong winds during the SW and NE monsoons and cyclonic winds that produce larger waves.

4.1.3 Past data

Initial judgments as to the location and frequency of sampling and the parameters of concern were made from data available from previous studies in the Ennore Creek. Past data for the Ennore creek area was obtained from the Coastal Ocean Monitoring and Predictive System (COMAPS) program of the Department of Ocean Development (DOD). Data was collected by the nodal agency - Central Electro Chemical Research Institute (CECRI), Chennai, DOD from 1993 to 1997. Table 4.1 gives the list of parameters analyzed under this program.

Table 4.1 Past COMAPS parameter list

Physical characteristics	Chemical	Biological
Temperature, salinity, TSS, pH, DO	IP, TP, NH_3N, NO_2N, NO_3N, TN, BOD, PHC, Cd, Pb, Hg, sediment organic carbon, organic matter	Primary productivity, Chlorophyll a, Phaeophytin, Zooplankton biomass, population, total groups, major groups & bacterial population
• Parameters were analyzed once a year and hot spot monitoring was carried out at specific sites twice (Pre & Post monsoon seasons) a year		

Evaluation of the COMAPS study for the Ennore Creek indicated

- Some violations of (DO & Total coliform) in Ennore creek and sewage point (ENC & ENS). The Ennore creek points (ENC 1, 2, 3 & ENS 1, 2) recorded lower DO values and higher coliform values in comparison to the CPCB standard for SW-IV during 1994, 1995.
- DO violations in terms of SW standards, in general, in samples collected during 1100, 1200, 1300, 1600 hours and total coliform violations in samples collected during 800, 1200, 1300 hours. The DO & total coliform violation may be attributed to the discharge of organic waste into these sites.

Based on the review of the past COMAPS data, the design focused on the following criteria

A. Ennore creek	Water quality tidal and current data, water quality to focus on DO and faecal coliform concentrations
	Eutrophication problems to be incorporated in sampling design. Toxics to also be considered, depending on analytical and financial resources.
B. Coastal waters	Currents, Tides, Fecal coliform, temperature, suspended solids.

4.1.4 Model Selection

The option of providing one 2-D model, which included both, the coastal waters and the creek together, was initially considered. However, the secondary data did not suggest that the water quality of Ennore creek influenced the coastal waters significantly, while the coastal waters were relatively stable near the Ennore creek mouth suggesting that a constant water quality boundary condition could be used. The option of two separate models, one for the creek and one for the coastal waters was therefore kept open as smaller localized problems will have limited cumulative errors near the area of interest, for instance, near an outfall.

In addition, the WLA requirements of the two waters are different and therefore it was decided to delink the two waters and use separate models for the two domains. For modeling of the Ennore Creek, it was proposed to evaluate the adequacy of a one-dimensional model or a longitudinally vertical, two dimensional model, while the coastal waters required a two dimensional model. These model input data requirements and sensitivity of the models to processes and parameters were considered while developing the sampling plan, frequency of data measurements, parameters and experiments.

Three surveys were planned to allow calibration of a model with two survey data and validation with the third.

4.1.5 Quality

The quality and quantity of data determine to a large degree the confidence that can be placed on the modeling results

- The quantity of data requirement was taken into consideration before selecting the number of sampling locations and the justification if selecting a particular sampling location. For point sources, a total number of 23 industrial discharges were evaluated and ranked according to their pollution loads. Based on the ranks, parameters and logistics, 5 industrial discharges were collected for the point sources.
- The degree of quality control that could be provided in the laboratory analysis and sample collection was evaluated before selecting a particular parameter for analysis.

In general, operating logistics like manpower, budget, equipments, sample storage and preservation, scheduling of sampling crews are some of the major factors that need proper planning for successful organization of a well-conceived WLA.

Location of the laboratory and deep freezer was in Chennai, about 25 Km away from the sampling location and therefore it was considered essential to have a field laboratory at Ennore where the land, coastal and estuarine samples were collected and preserved before being transferred to the laboratory in Chennai.

For the Ennore WLA, resource allocation, sampling schedules and organization were as follows.

a) One sampling crew each for the three domains of interest, i.e., coastal, estuary and industrial sources

b) Sampling for a total 48-hour period in 6-hour intervals. Therefore two teams with twelve-hour shifts were assigned to each area, making a total of six teams for the three areas.
c) Samples were collected for high tide and low tide periods
d) Samples were stored in ice till they were brought ashore to the field laboratory and transported to the deep-freezer in the laboratory within 24 hours
e) In-situ tests conducted were DO, temperature and salinity measurements using insitu probes
f) Sample logs were maintained in the field laboratory where numbers and types of samples after each sampling run were sorted

4.2 SAMPLING PLAN

Table 4.2 provides a summary of sampling stations and Fig. 4.1 gives the details. The sampling focused on tide and diurnal variations resulting from algal productivity.

Table 4.2 Details of sampling locations

Location ID	Description	Location	
		Latitude	**Longitude**
	Coastal sampling locations		
CST1	South reference boundary – near fishing harbor	13^{0}07'20"	80^{0}18'50"
CST2	Royapuram sewage out fall – 5m water depth	13^{0}08'20"	80^{0}18'40"
CST3	Royapuram sewage out fall – 10m water depth	13^{0}07'17"	80^{0}19'08"
CST4	MPL-SPIC-HCD submerged out fall – 5m water	13^{0}10'52"	80^{0}19'20"
CST5	MPL-SPIC-HCD submerged out fall – Transact No.2	13^{0}10'46"	80^{0}19'50"
CST6	ETPS Fly ash out fall – 5m water	13^{0}12'07"	80^{0}19'42"
CST7	ETPS Fly ash out fall – Transact No.2	13^{0}11'59"	80^{0}20'06"
CST8	Ennore river mouth – 5m water	13^{0}14'04"	80^{0}20'28"
CST9	Ennore river mouth – Transact No.2	13^{0}14'00"	80^{0}20'46"
CST10	North reference boundary – near satellite port	13^{0}15'07"	80^{0}21'00"
	Ennore creek sampling locations		
ENC 1	Ennore creek – mouth (100m inside)	80^{0}19'48.3"	13^{0}13'55.2"
ENC 2	Ennore creek – south of railway bridge	80^{0}19'08.3"	13^{0}13'24.6"
ENC 3	Ennore creek – D/S of Korataliyar river junction (ETPS Intake)	80^{0}19'31.5"	13^{0}12'12.8"
ENC 4	Ennore creek – D/S of Amullavoyal junction (wooden Bridge)	80^{0}17'42.5"	13^{0}11'02.4"
KST 1	Kosasthalaiyar river – D/S of Kosasthalaiyar river junction	80^{0}18'54.1"	13^{0}14'59.7"
KRR 1	Korataliyar river – Cause way in Ponneri road	80^{0}16'21.1"	13^{0}13'00.5"
AMC1	Amullavoyal canal – Bridge in Ponneri road near Madhavaram inner Ring road	80^{0}15'20.7"	13^{0}10'46.1"
	Industrial effluents discharge locations		
ETAS	Ennore thermal power station Ash Slurry out fall	80^{0}18'38.8"	13^{0}12'07.7"
ETCW	Ennore thermal power station coolant out fall near coast	80^{0}19'20.7"	13^{0}12'10.7"
NCTPS	North Chennai thermal power station coolant outfall	80^{0}19'10.8"	13^{0}15'24.6"
MRL	Madras refineries limited, combined trade effluent outlet	80^{0}17'00.5"	13^{0}09'05.1"
MPL	Manali Petrochemical limited, combined trade effluent outlet	80^{0}16'40.4"	13^{0}10'21.7"
TPL	Tamilnadu Petro products limited combined trade effluent outlet	80^{0}16'50.4"	13^{0}10'34.1"
NCTPS	NCTPS coolant water discharge at B. canal	80^{0}19'38.1"	13^{0}15'40.2"

Location ID	Description	Location	
		Latitude	Longitude
Municipal effluents discharge locations			
BUCN	Buckingham canal – Near NCTPS intake	$80^0$19'10.4"	$13^0$14'56.9"
BUCS	Buckingham canal – Korataliyar and Buckingham canal junction	$80^0$19'02.1"	$13^0$14'56.9"
RYSO	Royapuram sewage pipe line	$80^0$17'58.7"	$13^0$08'24.4"

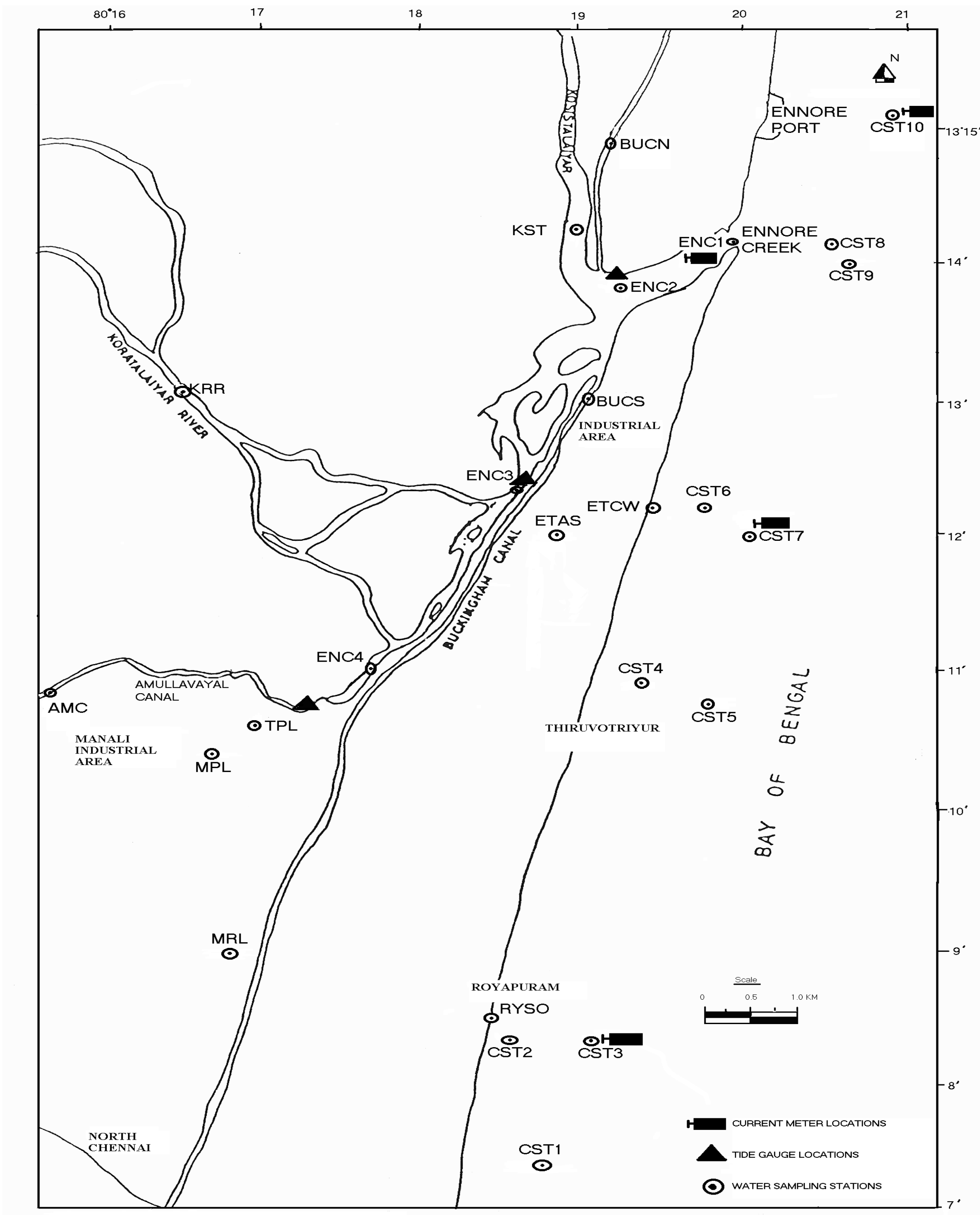


Fig 4.1 Location map of water quality sampling stations

The salient features of the sampling study is given in Table 4.3

Table 4.3 Salient features of sampling study

Parameter	Period	Location	Standard Method
Hydrodynamics – Tides and Currents	Three seasons, 15 days per season; Minimum one tidal cycle from spring to Spring/neap to neap tides. (15 days)	Tides – Ennore Creek Currents – Coastal waters	Deployment of calibrated current meters RCM7 & 9 and tide gauges
Water quality	Three seasons during high and low tides	Coastal & Ennore Creek locations, municipal sewage outfalls, industrial sources	"Standard methods for examination of water and wastewater" APHA 19th edition 1995

4.3 SELECTION OF SAMPLING SITES

4.3.1 Point sources

There are over 30 discharges into the receiving waters. The design flows for each of these discharges were collected from the TNPCB, together with the monthly effluent monitoring data. The average concentration of each water quality parameter was multiplied by the discharge to provide the mass loading in kgs/day. These mass loadings were ranked. The top five discharges were selected for sampling. These discharges account for more than 90% of the discharge – on paper. The industrial point sources to Ennore creek are TPL and MRL, both of which drain to the Buckingham canal. The Amullavoyal canal receives effluents from MFL, which needs to be represented as the increase of loads between Amullavoyal canal and the most upstream sampling location of Ennore creek.

Table 4.4 gives the ranks of the industries based on the loadings and Fig 4.2 shows the inputs (loadings) from the various industries.

Table 4.4 Ranking table

S.Nos	ID	Industry	Rank based on loadings of						
			TSS	TDS	CL	SO_4	O&G	BOD	COD
1	ETPS	Ennore Thermal Power Station	1	1	1	1	2	1	1
2	NCTPS	North Chennai Thermal Power Station	2	3	2	2	10	4	4
3	MPCL	Manali Petrochemicals Ltd	3	2		9	6	5	5
4	MRL	Madras Petro Chemicals Ltd.	4	5	3	4	4	2	2
5	SPICO	Spic Organics Ltd.	5	6		6	5	6	6
6	MRF	Madras Rubber Factory	6	4	4	3	3	3	3
7	MFL	Madras Fertilisers Ltd	7	8	8	8	7	8	8
8	IOCL	Indian Organic Chemicals Ltd.	7	7	6	5	8	11	7
9	SRF	Sri Ram Fibers Ltd.	9	11	10	13	13	7	10
10	TNPL	Tamil Nadu Petro Products Ltd.	10	9	9	7	9	12	9
11	INAL	Indian Additives Ltd.	11	10	7	15	12	10	12

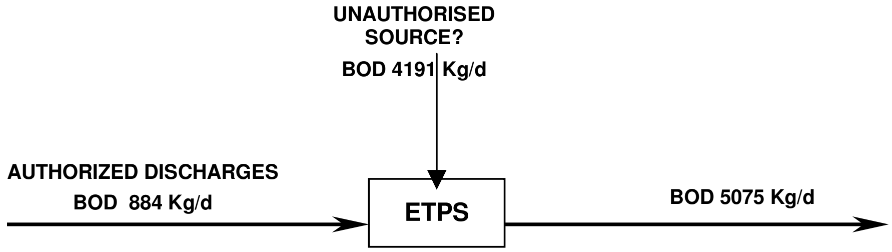
S.Nos	ID	Industry	Rank based on loadings of						
			TSS	TDS	CL	SO_4	O&G	BOD	COD
12	TML	Tamil Nadu Minerals Ltd.	12	17	14	19	16	15	17
13	MSPC	Madras Petro Chemicals Ltd	12	18	14	16	1	17	13
14	ASL	Ashok Leyland Ltd.	13	12	11	11	11	9	11
15	SPICH	Spic Heavy Chemicals Ltd.	14	9	5	10	15	16	15
16	REM	Royal Enfield Motors Ltd.	15	14	11	14	16	13	16
17	KSCL	Kothari Sugars and Chemicals Ltd.	15	15	13	18	14	18	18
18	ICI	ICI Ltd. (Pharmaceuticals Division)	15	17	14	17	19	20	19
19	BLCL	Balmer Laurie & Company Ltd. (Leather Division)	16			21		21	21
20	CETEX	CETEX Petrochemicals Ltd		13	14	12	18	14	14
21	EVIL	Eveready India Ltd.		18	14	21	17	19	20
22	CUL	Carborundum Universal Ltd.		11		20	19	22	22
23	EIDP	EID Parry Ltd. (Fertilizer Division)		17	12	20		23	23

Selection of sampling locations were based on the following criteria:

- ETPS ranks first in the discharge of TSS and BOD. ETPS accounts for over 98% of TSS and 82% of BOD of the total mass of the 23 industries considered. Therefore the ash slurry discharge point (in the Creek) was considered;
- NCTPS ranks next to ETPS in terms of TSS loading making this point source also significant and therefore considered;
- Other point sources into the Buckingham Canal such as MRL, MPL, MFL, TPL etc., were considered in the order of their ranking and discharge of combined trade effluent into the Buckingham canal and logistics involved in sample collection from the discharge points; and
- The Royapuram sewage outfall discharges mostly untreated municipal sewage directly into the coastal waters and thus a significant contributor to the coastal water quality.

Thus the ETPS is expected to reflect the combined loading from the permitted point sources discharging into the Ennore creek/Buckingham canal as well as the unsewered and discharges not monitored by the pollution control authorities.

Fig. 4.3 shows the loadings for TSS and BOD from authorized discharges. ETPS is the highest contributor with 98.6% and 82.6% loadings for TSS and BOD respectively. The key point to note is that ETPS is essentially the Ennore creek water discharged into the coastal water with the mere addition of heat. Since the approximately 18% BOD loading or 884 kgs /day from various industries also finally reaches the Ennore Creek through the Buckingham Canal or Amullavoyal Canal, ideally, the ETPS loading should not exceed the combined loading of the other point sources (Fig. 4.3). This anomaly explains that the unauthorized / unsewered / untreated wastewaters far exceed the permitted treated point sources. A better representation of the input/output at ETPS would be



This implies that the WLA will need to apportion a significant amount of the waste reduction to the unmanaged/unknown/unsewered discharges. Therefore the WLA will be capable of identifying the extent of treatment required, but cannot define the location of treatment facilities. This will need to be done through a complete survey of the sources of pollution starting from North Chennai to the Manali Industrial area.

4.3.2 Receiving waters-Ennore creek

The backwaters of Ennore creek have a number of manmade, natural and industrial effluent point sources entering the system (Fig. 2.2 Section 2.3). The sampling of water quality included the following boundaries.

- Korataliyar freshwater boundary
- Kosasthalaiyar backwaters from Pulicat
- Buckingham canal from North Chennai
- Buckingham canal from Pulicat
- Amullavoyal canal

The sampling points on Ennore creek represent water quality at the mouth region, i.e., the quality of flood flows from coastal water or ebb flows from the Ennore creek after receiving wastewater and other inputs. The coastal sampling near the Ennore mouth represented the boundary condition water quality at the mouth.

A second station (ENC2) represents the confluence of Kosasthalaiyar and Ennore. ENC3 represents intake water quality to ETPS as well as a calibration point between Buckingham canal and Korataliyar. ENC4 represents a calibration point between the headwaters and Korataliyar.

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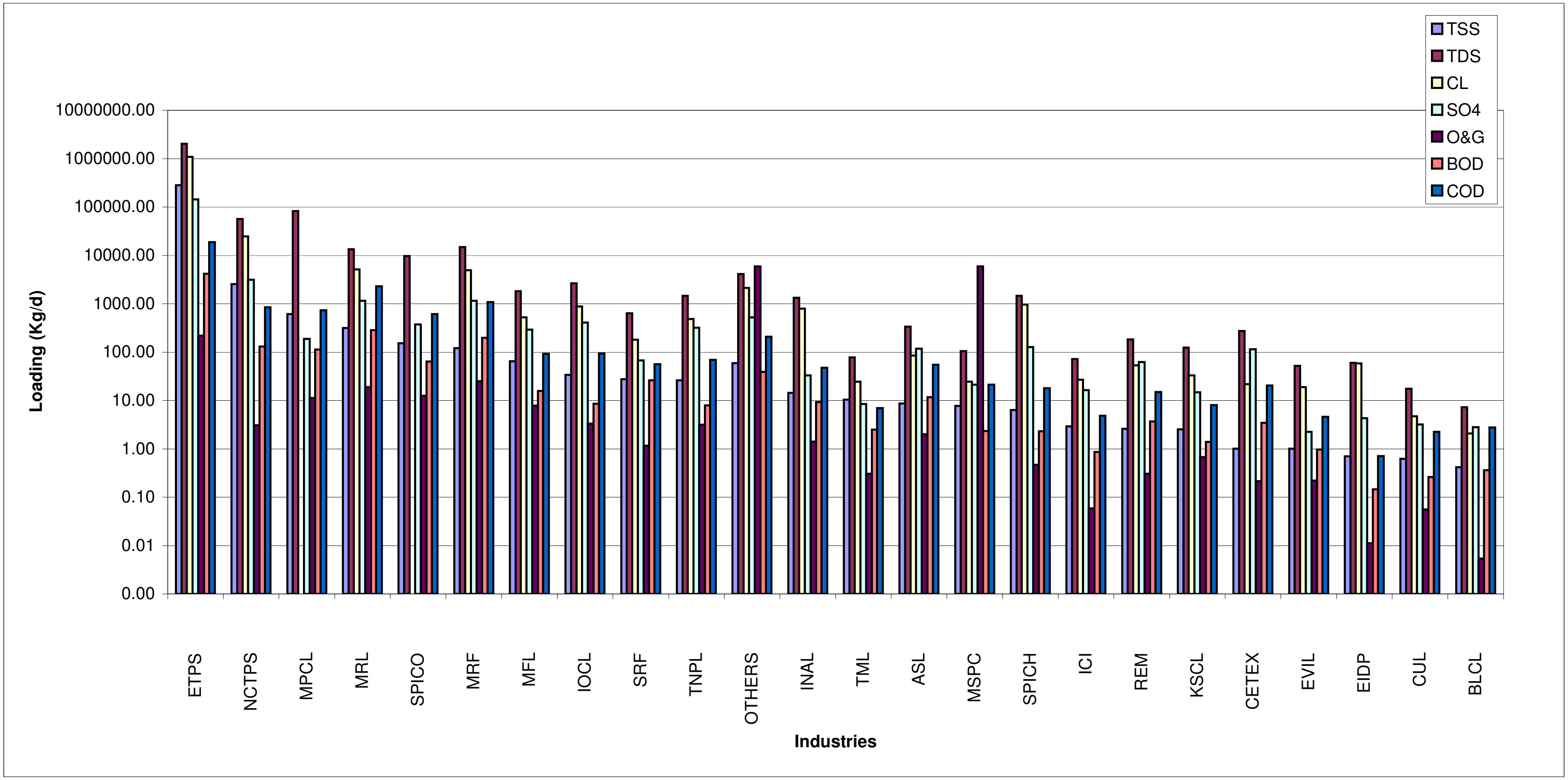
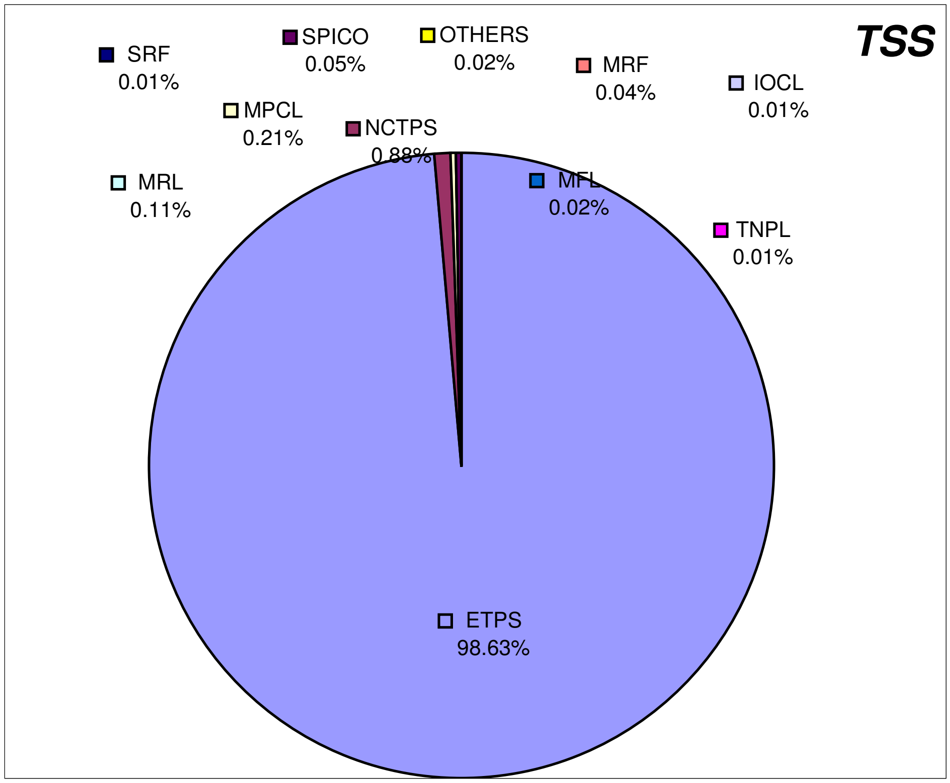


Fig 4.2 Loadings from various industries discharging in the study area



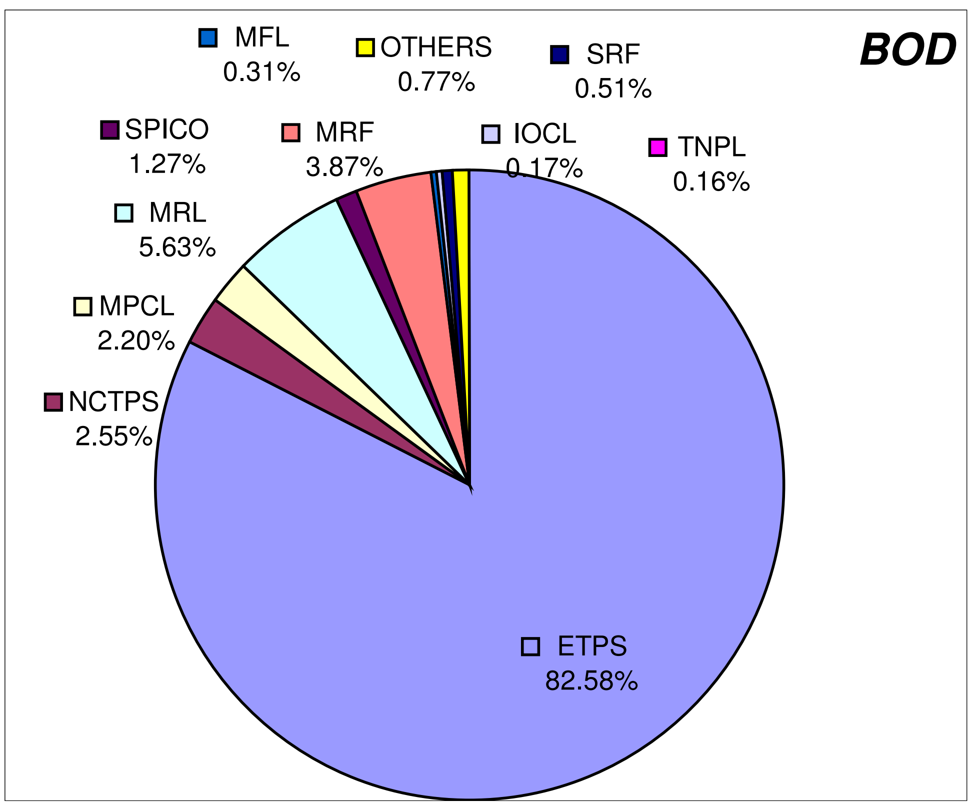


Fig 4.3 TSS and BOD loadings from point sources

The distances of the various sampling sites from the Ennore Creek mouth is located by the distance in kilometers measured from the Ennore creek mouth entering the Bay of Bengal as given in Table 4.5. For example, KM0 is the Ennore mouth, while KM5.15 is the location along the creek where the ETPS withdraws water for cooling purposes. This notation will be used throughout this report and will aid in identifying the Ennore Creek water sampling locations. Locations on the northern branch or Kosasthalaiyar River have been defined as Branch km or BKM, measured from the point (BKM0) where the Kosasthalaiyar River joins the Ennore creek

Table 4.5 Distance between Ennore creek sampling stations

S.No.	Station code	Distance in Km	Remarks
1	Creek mouth	0	
2	ENC 1	0.18	
3	Current meter	0.18	
4	ENC 2 (NCTPS)	1.38	
5	KST	3.88	2.34 BKM
6	Railway bridge	1.95	
7	ETPS	5.15	
8	ENC 3	5.15	ETPS withdrawal
9	Tide gauge	5.15	
10	KRR	16.50	15.25 BKM
11	ENC 4	6.30	
12	Tide gauge	6.30	
13	AMC	13.52	

4.3.3 Coastal Waters

The coastal sampling stations were selected to represent the dispersion of the effluent in nearshore and offshore locations. CST1 and CST10 represent the southern and northern boundaries respectively for the coastal sampling. Table 4.6 gives the summary of coastal locations considered.

Table 4.6 Summary of coastal locations

S.No	Location	Closest outfall	Frequency / Period	Period
1	CST2 (nearshore) and CST3 (offshore)	Royapuram sewage outfall	48 hour sampling during high and low tides during each sampling season in February 99, May 99 and December 99	5/02/99 – 6/02/99 28/05/99 – 29/05/99 18/12/99 – 19/12/99
2	CST 4 and CST5	MRL submerged outfall		
3	CST6 and CST7	ETPS cooling water and ash discharge outfall		

4	CST8 and CST9	Ennore Creek mouth	99	

4.3.4 Hydrodynamics measurement sites

Creek

Tidal data of open sea was obtained from Chennai Port and Indian Tide Tables, while tide gauges were located in the Ennore Creek to measure tidal excursion along the creek (amplitude and phase lag). Details of measurements are given in Table 4.7

Table 4.7 Summary of tide measurement design

ID	Location	Instrument	Frequency / Period	Dates
T1	NCTPS intake	NIOT Acoustic Tide Gauge	Data recorded at 30 minute intervals for 30 days during the first season; 15 days during the second and third season	17/02/1999 to 20/03/1999 26/05/1999 to 7/06/1999 10/12/1999 to 21/12/1999
T2	ETPS intake	NIOT Acoustic Tide Gauge		
T3	Manali Bridge	Tide pole		

Coastal waters

Current meters were located at Ennore Port, ETPS and Fishing Harbor. Ennore Port and Fishing Harbor represented boundary conditions for the expected domain area, while ETPS is a calibration location. Details of measurements are given in Table 4.8. Current meter measurements in the Ennore creek were constrained by the lack of water depth and thus only one current meter was located.

Table 4.8 Summary of current measurement design

ID	Location	Location		Frequency / Period	Dates
		Lat	Long		
C1	Ennore Port			Data recorded at 20 minute intervals for 30 days during the first season; 15 days during the second and third season	18/02/1999 to 19/03/1999 28/05/1999 to 5/06/1999 14/12/1999 to 21/12/1999
C2	ETPS outfall				
C3	Off Royapuram outfall				
C4	Ennore Creek- between ENC1 and ENC2				

4.4 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

A rigorous quality assurance plan was developed prior to carrying out field sampling and laboratory analysis. The procedures were communicated to all personnel involved in the WLA program. The main goal of the Quality Assurance program for the project was

a) To maintain consistency in field and laboratory operations

b) To ensure accuracy and precision of all sample collected and analysis
c) To ensure data comparability

NIOT was responsible for sampling, processing of the samples and analysis of various physico-chemical and biological parameters. A series of pre-survey of the sampling locations were conducted by NIOT to ensure compliance with prescribed sampling protocols. A field QA checklist was developed to provide comparability and consistency in the sampling program. Quality control during the sampling period was accomplished using a variety of QC sample types and procedures.. The sampling program and further analysis conformed to the "Standard methods for examination of water and wastewater" APHA 19th edition 1995. The various aspects of the project for which QA/QC procedures were adopted are listed below.

- Field Sampling
  - Field operation for sample collection and documentation
  - Calibration of instruments used for in-situ measurements of water quality parameters
  - Collection of multiple samples for select stations
  - Sample custody
  - Preservation
  - Labels and custody transfer
  - Storage
- Laboratory Analysis
  - Standard operating procedures
  - Calibration
  - Precision, accuracy and repeatability
- Data Evaluation
  - Analytical detection limits
  - Data management
- Data presentation and reporting

4.4.1 Data Analysis

Details of statistical analysis carried out on data sets for all surveys and the precision of measurements are shown in Table 4.9 to Table 4.17.

Table 4.9 Analytical completeness of individual water quality parameter analysis (Feb.1999)

Parameters	Number of samples collected	Number of accepted data	% Completeness
Atmospheric temperature	176	172	97.7
Water temperature	176	172	97.7

Parameters	Number of samples collected	Number of accepted data	% Completeness
PH	140	129	92.1
Salinity	176	172	97.7
Dissolved Oxygen	76	73	96.1
Biological Oxygen Demand	84	83	98.8
Total Suspended Solids	84	82	97.6
Nitrite-Nitrogen	104	98	94.2
Nitrate-Nitrogen	104	85	81.7
Ammonia-Nitrogen	104	101	97.1
Total Nitrogen	104	96	92.3
Inorganic Reactive Phosphorus	104	100	96.2
Total Phosphorus	104	101	97.1
Chlorophyll a	76	76	100.0
Pheophytin a	76	73	96.1

Table 4.10 Analytical completeness of individual water quality parameter analysis (May.1999).

Parameters	Number of samples collected	Number of accepted data	% Completeness
Atmospheric temperature	178	167	93.8
Water temperature	178	176	98.9
PH	178	176	98.9
Salinity	178	176	98.9
Dissolved Oxygen	178	176	98.9
Biological Oxygen Demand	102	100	98.0
Total Suspended Solids	102	100	98.0
Nitrite-Nitrogen	102	102	100.0
Nitrate-Nitrogen	102	98	96.1
Ammonia-Nitrogen	102	98	96.1
Total Nitrogen	102	102	100.0
Inorganic Reactive Phosphorus	102	102	100.0
Total Phosphorus	102	100	98.0
Chlorophyll a	102	94	92.2
Pheophytin a	102	86	84.3

Table 4.11 Analytical completeness of individual water quality parameter analysis (Dec.1999).

Parameters	Number of samples collected	Number of accepted data	% Completeness
Atmospheric temperature	184	184	100.0
Water temperature	184	184	100.0
PH	184	165	89.7
Salinity	184	175	95.1
Dissolved Oxygen	184	184	100.0
Biological Oxygen Demand	108	102	94.4
Total Suspended Solids	108	107	99.1

Parameters	Number of samples collected	Number of accepted data	% Completeness
Nitrite-Nitrogen	108	101	93.5
Nitrate-Nitrogen	108	103	95.4
Ammonia-Nitrogen	108	100	92.6
Total Nitrogen	108	104	96.3
Inorganic Reactive Phosphorus	108	103	95.4
Total Phosphorus	108	102	94.4
Chlorophyll a	108	107	99.1
Pheophytin a	108	105	97.2

Table 4.12 Precision measures of the water quality analysis (Feb-1999)

Parameters	Target % of RPD	Achieved	
		Concentration range µMole/L	RPD % Range
Biological Oxygen Demand	±20	1.1-328.5	-18.2-18.4
Total Suspended Solids	±20	10.4-9249	-15.4-11.8
Nitrite-Nitrogen	±20	0.26-14.75	-11.8-16.8
Nitrate-Nitrogen	±20	3.3-31.5	-14.7-4.9
Ammonia-Nitrogen	±20	7.1-59.5	2.6-14.1
Total Nitrogen	±20	56.8-294	-14.6-4.2
Inorganic Reactive Phosphorus	±20	0.59-9.4	-15.6-5.1
Total Phosphorus	±20	2.4-10.3	-10.7-16.7

Note: * mg/L, RPD-Relative Percentage Deviation

Table 4.13 Accuracy measures of the water quality analysis (Feb-1999)

Parameters	Target % of RPD	Achieved	
		Concentration range µMole/L	RPD % Range
Nitrite-Nitrogen	90-110	0.26-14.75	91.9-101.3
Nitrate-Nitrogen	90-110	3.3-31.5	92.3-104.4
Ammonia-Nitrogen	90-110	7.1-59.5	91.5-101.5
Total Nitrogen	90-110	56.8-294	91.9-93.9
Inorganic Reactive Phosphorus	90-110	0.59-9.4	90.5-114
Total Phosphorus	90-110	2.4-10.3	91.7-107.3

Table 4.14 Precision measures of the water quality analysis (May-1999)

Parameters	Target % of RPD	Achieved	
		Concentration range µMole/L	RPD % Range
Biological Oxygen Demand	±20	1.55-228.5	-17.1-19.4
Total Suspended Solids	±20	11.9-3867	-9.2-12.1
Nitrite-Nitrogen	±20	0.35-7.56	-11.4-10.5
Nitrate-Nitrogen	±20	2.6-16.9	-14.8-2.3
Ammonia-Nitrogen	±20	2.9-290.9	-2.2-18.4

Parameters	Target % of RPD	Achieved	
		Concentration range µMole/L	RPD % Range
Total Nitrogen	±20	23.6-83.1	-13.4-14.6
Inorganic Reactive Phosphorus	±20	0.45-38.2	-1.9-17.1
Total Phosphorus	±20	1.9-42.3	-10.5-5.7

Note: * mg/L, RPD-Relative Percentage Deviation

Table 4.15 Accuracy measures of the water quality analysis (May-1999)

Parameters	Target % of RPD	Achieved	
		Concentration range µMole/L	RPD % Range
Nitrite-Nitrogen	90-110	0.35-7.56	92.4-98.2
Nitrate-Nitrogen	90-110	2.6-16.9	90.2-101.9
Ammonia-Nitrogen	90-110	2.9-290.9	92.1-106.4
Total Nitrogen	90-110	23.6-83.1	91.7-113.3
Inorganic Reactive Phosphorus	90-110	0.45-38.2	95.1-112.6
Total Phosphorus	90-110	1.9-42.3	90.2-117.6

Table 4.16 Precision measures of the water quality analysis (Dec-1999)

Parameters	Target % of RPD	Achieved	
		Concentration range µMole/L	RPD % Range
Biological Oxygen Demand	±20	1.5-405 *	15.4-16.7
Total Suspended Solids	±20	51.3-1032 *	-15.5-16.4
Nitrite-Nitrogen	±20	0.67-51.05	-5.97-17.98
Nitrate-Nitrogen	±20	1.22-26.26	-8.28-4.92
Ammonia-Nitrogen	±20	3.55-281.1	-6.76-9.54
Total Nitrogen	±20	174.8-360.2	-6.83-8.63
Inorganic Reactive Phosphorus	±20	0.61-22.75	-4.96-5.51
Total Phosphorus	±20	2.92-36	-7.64-6.52

Note: * mg/L, RPD-Relative Percentage Deviation

Table 4.17 Accuracy measures of the water quality analysis (Dec-1999)

Parameters	Target % of RPD	Achieved	
		Concentration range µMole/L	RPD % Range
Nitrite-Nitrogen	90-110	0.67-51.05	90.7-97.4
Nitrate-Nitrogen	90-110	1.22-26.26	93.8-101
Ammonia-Nitrogen	90-110	3.55-281.1	91.1-95.8
Total Nitrogen	90-110	174.8-360.2	92.5-104.7
Inorganic Reactive Phosphorus	90-110	0.61-22.75	95.9-99.1
Total Phosphorus	90-110	2.92-36	90.2-96.5

4.5 SUMMARY OF SAMPLING DESIGN

Based on the various sampling design considerations and modeling input data requirements, it was considered essential to conduct a three season i.e., post-monsoon, monsoon and pre-monsoon survey to obtain synoptic measurements of the various water quality parameters. Hydrographic measurements of currents and tides would be done to estimate transport while water quality sampling would be done at coastal, creek and point sources. All samples would be collected simultaneously. Coastal water quality would be collected from floating craft, while creek and point sources would be sampled using land transport. The surveys would be conducted for 48 hours with 6-hour intervals.

5 RESULTS OF DATA COLLECTION

5.0 DISCUSSION OF RESULTS

Four surveys were completed for the WLA study as shown in Table 5.1. Three surveys were conducted as per the design of the study, i.e. 48 surveys with the complete list of parameters in coastal, creek and point sources. A fourth sampling program was added to the survey to confirm an observation made during the first two surveys, where distinct pollution plumes could be not be identified in the coastal stations. It was hypothesized that the signal was limited to the mixing zones and/or transported by the littoral currents. Thus, a close grid sampling was also carried out along the coastal stations for a limited number of parameters.

The close grid survey was conducted with 96 stations (Figure 5.1) with 3 hourly intervals and included beach samples. The survey was limited insitu measurements, fecal coliform, BOD and TSS measurements. However, this type of survey could not continued for the other seasons due to the high cost involved in handling/analyzing large number of samples.

Table 5.1 gives details of the four surveys carried out during different seasons

Table 5.1 Details of survey

Dates	Hydrographic parameters	Parameters	Remarks
5/02/1999 & 6/02/1999	Currents & tides	Temperature, pH, Salinity, DO, TSS, BOD, Nutrients, PHC, Microbiology, Plankton Nekton & Benthos	Post-monsoon season sampling in Ennore Creek & coastal waters
28/05/1999 & 29/05/1999	Currents & tides	Temperature, pH, Salinity, DO, TSS, BOD, Nutrients, PHC, Microbiology, Plankton Nekton & Benthos	Pre-monsoon season sampling in Ennore Creek & coastal waters
19/07/1999 & 20/07/1999	-	Temperature, pH, Salinity, DO, TSS, BOD, Microbiology	Intensive close-grid pre-monsoon season sampling in coastal waters only
18/12/1999 & 19/12/1999	Currents & tides	Temperature, pH, Salinity, DO, TSS, BOD, Nutrients, PHC, Microbiology, Plankton Nekton & Benthos	Monsoon season sampling in Ennore Creek & coastal waters

The post-monsoon, pre-monsoon and monsoon season sampling were supported by hydrographic measurements of tides and currents.

The data collected for hydrodynamics, water quality and ecological parameters is summarized and interpreted here to establish trends and make preliminary estimates of the importance of the various processes and wastewater inputs. Results of water quality analysis are provided in Volume I-Annexure II. The data is summarized by the average, maximum, minimum, and standard deviations of 95% confidence limits. Spatial and temporal plots for all parameters are provided in Volume III. Key plots are provided in the main text to illustrate the inferences from the data analysis.

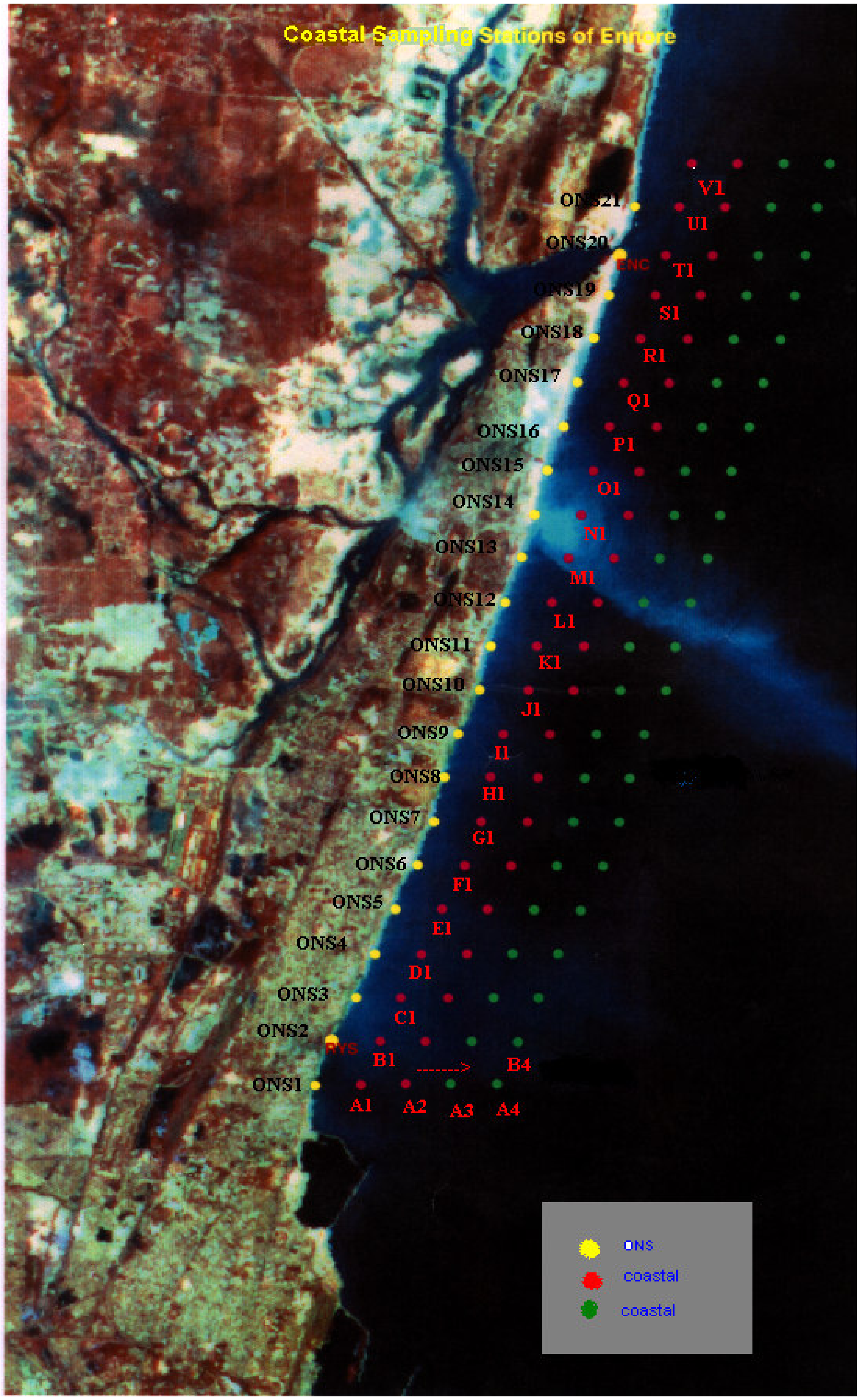


Fig 5.1 Location of sampling sites for detailed survey

A brief discussion of the results of the analysis of these samples is provided in the following paragraphs. The water quality data has been analyzed for the behavior of individual parameters during the various season as well as assessed for the relationship between all parameters one season at a time.

5.1 BATHYMETRY

5.1.1 Creek

Bathymetry survey was conducted by surveying 35 sections along the Ennore creek from the Ennore creek mouth to Amullavoyal Canal and along the Kosasthalaiyar River from NCTPS to the NCTPS Bridge on Kosasthalaiyar River and Kosasthalaiyar river entry to Ennore. Bathymetry measurements were carried out only for one season i.e., February 1999 using single beam echosounder and GPS.

In general water depths were greater near the NCTPS intake, with maximum depths of 6+ meters. Depth along the northern arm of the backwaters, i.e. Kosasthalaiyar was about 1.2m, while along the Korataliyar stretch, maximum depth was about 1.5m. Bathymetry around the islands of the southern arm of the Ennore creek near the ETPS intake were difficult due to the shallow depths, making echo sounding difficult. At the same time, the soft sediments did not permit leveling. Thus, bathymetry was covered in the main channel only.

The Ennore creek mouth is subjected to closure due to the littoral drift. In addition, dredging occurs daily and the area of dredging occurs from the mouth upto NCTPS. Localized dredging also takes place at the ETPS intake structure. All these factors result in the mouth condition being changed during the different seasons of a year. Conditions of the mouth during the three surveys were as follows:

February 1999:	Partially open, 200m wide, 3m deep
May 1999:	Shallow & almost closed, 110m wide, 0.6m deep
Monsoon:	Partially open, 50-75m wide, 1.1m deep

5.2 HYDRODYNAMICS

5.2.1 Tides

All tidal measurements were carried out only inside the creek. For the coastal waters, the Indian Tide Table data was used. The tidal amplitude at the Ennore creek mouth was similar to the Indian Tide Table for Chennai in February 1999, when the creek mouth was open. For the pre-monsoon, the closed mouth resulted in low tidal amplitudes of 0.2 to 0.4m only. The phase lag between the mouth and the Amullavoyal Canal was approximately 15 minutes. Table 5.2 gives the summary of tide data measured during the various surveys.

Table 5.2 Summary of Tide Levels (m) with respect to CD

ID	LOCATION	I SEASON		II SEASON		III SEASON	
		MIN	MAX	MIN	MAX	MIN	MAX
T1	NCTPS intake	-0.11	1.11	0.13	0.78	0.74	1.16
T2	ETPS intake	0.08	1.1	0.14	0.67	0.86	1.16
T3	Manali Bridge	-0.62	1.2	0.21	0.64	0.77	1.05

- During the first Season survey, tidal range for spring and neap tides inside the creek and in the open sea were almost the same, as the creek mouth remained open during this season
- In the second Season survey, tidal measurement indicated considerable reduction in tidal range inside the creek compared to the tidal range at the open sea, which can be attributed to the partial closure of the creek mouth and reduction in tidal flow.
- During the third Season survey, considerable reduction in tidal range was observed inside the creek when compared to the tidal range in the open sea due to partial closure of the creek mouth.

5.2.2 Currents

Table 5.3 gives summary of current data measured in the coastal and creek locations during the various surveys

Table 5.3 Summary of Current speeds (m/s)

ID	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
C1	Ennore Port	0.005	0.592	0.119	0.0049	0.377	0.139	0.011	0.764	0.242
C2	ETPS outfall	0	1.07	0.159	0	0.249	0.109	0.011	0.639	0.158
C3	Off Royapuram outfall	0.01	0.19	0.0676	0.011	0.177	0.038	0.011	0.438	0.070
C34	Ennore Creek- ENC2	0.011	0.392	0.170	0.01	0.25	0.0688	0	0.098	0.042

Creek

Currents varied from a high of 0.2m/s for post-monsoon February 1999 survey to 0.02-0.1m/s for May and December 1999 near the NCTPS intake. The bar mouth closure resulted in the virtually stagnant conditions during the second and third survey. The current directions are driven by tides with distinct flood and ebb tides. The maximum currents were found to occur at mid tide. The flood and ebb flow was found to be approximately 225^o and 45^o with respect to North.

Coastal

- During the February 99 survey, currents along the coast were unidirectional towards South (190° with respect to North). A total reversal was observed at the end of the sampling period (10° with respect to North). The pattern of flow speed and direction was similar for all coastal current meters. Variations of current speed occur with tide with current speeds ranging from 0.05 to 0.25 m/s.
- Currents along the coast during the May 99 survey were found to be unidirectional towards the North (20 ° N), while nearshore currents were found to be weak currents (0.05 to 0.25 m/s) showing variations with respect to tides.
- The currents along the coast during the December 99 survey were unidirectional towards South (180 ° and 225° with respect to North). Current Speeds varied from 0.05 to 0.2 m/s

5.3 WATER QUALITY

5.3.1 Temperature

The water temperature ranges in each of the systems are given in Table 5.4 and the variations in the individual sites are given in Table 5.5.

Table 5.4 Water temperature (°C) ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	23.0 – 33.0	27.5 – 39.0	23.0 – 29.0
Municipal discharges	25.9 – 33.0	25.0 – 34.0	23.0 – 38.0
Point sources (industrial discharges)	25.0 – 37.0	29.0 – 40.0	21.0 – 40.0
Offshore waters	26.5 – 29.0	27.8 – 31.5	25.5 – 26.5
Nearshore waters	26.0 – 28.5	27.1 – 29.1	25.6 – 26.4

Table 5.5 Seasonal Variation of water temperature (°C) – stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	23	28.5	26.9	29.0	31.0	30.2	24	27	25.8
ENC2		26.0	30.0	28.0	29.3	31.5	30.0	25	28	26.9
ENC3		26.0	30.0	27.9	27.5	32.0	29.7	23	26.5	25.0
ENC4		25.8	32.0	28.9	27.5	32.5	30.2	24	27.8	25.3
AMC		27.0	30.0	28.6	29.0	32.0	30.5	23.0	26.5	25.3
KST		26.0	33.0	28.9	28.6	32.0	30.1	26.0	29.0	27.4
KRR		27.0	31.0	29.1	29.3	32.0	30.8	24.0	27.0	25.7
BUCN	Municipal sewage discharge	25.9	32.0	28.9	25.0	34.0	29.8	33.0	38.0	36.0
BUCS		27.8	33.0	29.7	29.2	32.5	30.6	23.0	28.0	25.6
RYSO		28.0	29.3	28.8	30.1	33.0	31.4	25.0	28.0	26.5
CST1	Offshore	27.5	29.0	28.1	27.8	28.9	28.2	25.7	26.5	26.1
CST3		27.5	29.0	28.0	28.1	29.1	28.3	25.5	26.3	26.0
CST5		26.5	28.2	27.6	28.0	28.8	28.3	25.6	26.3	26.0

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
CST7		27.0	28.0	27.6	28.0	28.6	28.3	25.7	26.3	26.0
CST9		27.0	28.0	27.6	28.1	28.8	28.4	25.5	26.1	25.9
CST10		27.0	28.0	27.5	28.5	31.5	29.9	25.5	26.2	26.0
CST2	Nearshore	26.0	28.0	27.5	27.1	28.1	27.3	25.7	26.3	26.0
CST4		27.2	28.5	27.8	27.9	29.1	28.3	25.7	26.4	26.0
CST6		27.0	28.0	27.6	28.0	28.7	28.3	25.6	26.2	25.9
CST8		27.0	28.5	27.7	28.1	28.5	28.3	25.6	26.2	25.9
ETCW	Industrial sources	-	-	-	35.2	38.0	36.3	31.2	35.0	33.1
ETAS		30.3	33.5	32.3	30.1	32.5	31.0	28.0	28.5	28.1
NCTPS		33.0	37.0	35.3	37.0	40.0	38.6	36.0	40.0	37.8
MRL		25.0	30.0	27.4	29.0	34.0	31.5	21.0	27.0	25.0
MPL		28.2	32.0	30.3	31.0	34.0	32.0	26.0	34.0	28.5
TPL		26.0	30.0	28.0	31.0	33.0	32.0	27.0	28.0	27.5
NCTPS1		-	-	-	-	-	-	34.0	38.0	36.8

The data for coastal waters show higher water temperatures in May of approximately 28.5°C while the December temperatures average approximately 26.5°C, while current speeds are almost the same, irrespective of season. For the WLA, this implies that the scenarios must be run for the higher temperatures as the increased rate coefficients for growth and decay generally have an adverse impact. For instance, a higher temperature will increase the BOD decay rate, resulting in increased DO uptake and thus will have an adverse impact on the DO levels close to the point of discharge.

The temperatures in the creek are generally higher than the coastal water temperatures due to the semi-enclosed water body. The NCTPS discharge temperatures are significantly higher than the ETPS discharge temperatures. In February, the difference (ΔT) between intake water temperatures (ENC1) for NCTPS and the effluent was approximately 7°C and rose to 11°C in December. For ETPS, the ΔT was ranged between +6 to +8°C. The NCTPS, ΔT far exceeds the MoEF standards of +7°C.

As indicated earlier, NTCPS discharges the warm water into the Ennore creek, in order to ensure sufficient water in the creek for their cooling water requirements. The KST and ENC2 samples indicate that impact of this discharge is minimal as the temperature increase is approximately +1°C.

A distinct signal of temperature increase due to the cooling water discharge was not recorded as observed by the temperatures at CST7 (off the cooling water discharge point) and at CST6 (offshore off CST7) with the larger grid sampling. The sampling stations required being closer to the point of discharge. With the closer grid sampling, the temperature increase in the receiving water is in the order of +1°C within 500 m of the point of discharge. The temperature impacts appear to be similar to the Royapuram sewage disposal. The finding is significant as it shows that the temperature increase of the ETPS is limited to local waters and thus the impact is very localized. This finding of the impact of a warm water discharge is similar to observations of other thermal dispersion modelers (Kolluru, Pers. Comm. 2001), yet unlike the observation made at Kalpakkam, where the temperature plume is measured for 1 km. The key difference between Kalpakkam and Ennore discharges is the presence of large sand pit in front of the Kalpakkam discharge that prevents mixing of the warm water with the cooler ocean water.

5.3.2 pH

The pH ranges in each of the systems are given in Table 5.6 and the variations in the individual sites are given in Table 5.7.

Table 5.6 pH ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	7.3 - 8.7	7.1 – 8.1	5.9 – 8.4
Municipal discharges	7.1 – 8.4	7.0 – 8.4	6.0 – 8.2
Point sources (industrial discharges)	7.0 – 10.9	7.0 – 8.1	6.0 – 11.3
Offshore waters	8.0 – 8.4	7.5 – 8.5	7.9 – 8.5
Nearshore waters	8.1 – 8.4	7.0 – 8.4	7.4 – 8.5

Table 5.7 Seasonal Variation of pH – stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	8.0	8.3	8.1	7.5	8.1	7.8	7.2	8.4	8.1
ENC2		7.3	8.3	7.9	7.2	8.0	7.5	7.0	8.4	8.0
ENC3		7.6	8.3	8.0	7.3	7.9	7.7	6.0	7.6	7.1
ENC4		7.6	8.5	8.0	7.2	8.0	7.7	6.3	7.8	7.3
AMC		8.2	8.7	8.4	7.5	7.8	7.7	5.9	7.2	6.6
KST		8.0	8.4	8.2	7.6	7.9	7.8	7.2	8.3	8.0
KRR		7.3	7.8	7.5	7.1	7.4	7.2	6.2	7.3	7.0
BUCN	Municipal sewage discharge	7.9	8.4	8.2	7.9	8.4	8.2	7.0	8.2	7.8
BUCS		7.2	8.3	7.6	7.1	7.5	7.2	6.0	7.5	7.0
RYSO		7.1	7.4	7.3	7.0	7.6	7.2	6.0	6.8	6.4

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
CST1	Offshore	8.2	8.4	8.3	7.8	8.2	8.0	7.9	8.4	8.2
CST3		8.1	8.4	8.3	8.0	8.5	8.0	8.0	8.5	8.2
CST5		8.2	8.3	8.2	7.5	8.5	8.0	8.0	8.5	8.2
CST7		8.0	8.3	8.2	7.8	8.2	8.0	8.0	8.5	8.2
CST9		8.1	8.3	8.2	7.9	8.1	8.0	8.0	8.5	8.2
CST10		8.0	8.3	8.2	7.7	8.3	7.9	8.0	8.4	8.2
CST2	Nearshore	8.2	8.3	8.3	7.0	7.5	7.0	8.0	8.4	8.2
CST4		8.2	8.4	8.3	7.8	8.4	8.0	8.0	8.5	8.2
CST6		8.1	8.3	8.2	7.8	8.2	8.0	7.4	8.4	8.1
CST8		8.1	8.2	8.2	7.8	8.4	8.0	8.0	8.5	8.2
ETCW	Industrial sources	7.7	8.1	7.8	7.4	7.9	7.7	7.3	7.7	7.5
ETAS		7.0	8.2	7.4	7.1	7.3	7.2	7.1	7.7	7.3
NCTPC		8.1	8.2	8.1	7.4	7.6	7.6	7.8	8.2	8.0
MRL		7.4	7.8	7.6	7.4	7.5	7.4	7.0	7.4	7.1
MPL		10.5	10.9	10.7	7.0	8.1	7.5	6.0	11.3	7.8
TPL		7.6	8.9	8.1	7.3	7.7	7.5	6.4	7.2	6.8
NCTPS1		-	-	-	-	-	-	-	-	-

The pH variations in the creek were found to range between 7.0 and 8.7 during the first two surveys, with the December 1999 survey recording a range of 6.4 – 8.4. The inner creek samples (ENC3, ENC4, AMC, KRR) show lower minimum values, indicating the influence of freshwater. The high variation may therefore, be an indication of eutrophication and/or freshwater in the inner creek. Respiration produces Carbon dioxide, which in turn reduces pH values. pH ranges for Ennore coastal waters are typical of seawater.

The variations of pH in coastal waters were negligible and relatively constant both spatially and temporally. This suggests that eutrophication may not be a significant issue. Also there is no evidence of significant chemical or freshwater inputs into the coastal waters that alter pH values. The highest pH variations are recorded at the MRL outfall ranging from 6.0 to 11.3.

5.3.3 Salinity

The salinity ranges in each of the systems are given in Table 5.8 and the variations in the individual sites are given in Table 5.9.

Table 5.8 Salinity (ppt) ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	BDL – 32.5	BDL – 41.0	BDL – 36.0

Municipal discharges	1.3 – 29.4	BDL – 31.0	BDL – 36.0
Point sources (industrial discharges)	BDL – 35.0	BDL – 38.0	2.0 – 36.0
Offshore waters	30.1 – 35.0	31.7 – 34.9	28.0 – 30.4
Nearshore waters	30.5 – 34.0	31.2 – 34.8	28.1 – 29.5

Table 5.9 Seasonal variation of salinity - stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	25.0	32.5	30.3	33.0	39.0	35.4	24.0	34.0	29.9
ENC2		16.0	32.0	25.0	28.0	39.0	31.6	26.0	32.0	29.9
ENC3		24.0	30.0	26.6	32.0	35.0	34.1	5.0	11.0	7.4
ENC4		BDL	25.9	12.3	21.0	29.0	24.9	BDL	9.0	4.9
AMC		BDL	BDL	<1	BDL	17.0	8.9	BDL	6.0	2.7
KST		26.0	31.0	28.6	27.0	41.0	37.1	26.0	36.0	32.4
KRR		4.0	10.0	7.1	5.0	25.0	19.2	BDL	10.0	4.3
BUCN	Municipal sewage discharge	20.0	29.0	25.5	22.0	31.0	29.0	25.0	36.0	31.3
BUCS		3.6	29.4	13.4	9.0	14.0	11.1	BDL	15.0	7.0
RYSO		1.3	26.3	7.7	1.0	5.0	3.0	4.0	5.0	4.5
CST1	Offshore	30.1	34.0	32.2	31.7	34.9	34.2	28.0	29.5	29.0
CST3		30.3	35.0	33.0	32.2	34.8	34.3	28.9	29.5	29.2
CST5		30.6	34.0	33.0	33.1	34.8	34.3	29.1	29.3	29.2
CST7		30.1	34.0	32.7	34.2	34.7	34.5	28.8	29.3	29.0
CST9		31.0	34.0	32.9	34.1	34.7	34.5	28.4	29.1	28.7
CST10		31.1	34.0	32.7	34.2	34.7	34.5	28.9	30.4	29.6
CST2	Nearshore	30.6	34.0	32.7	31.2	33.8	33.3	29.0	29.5	29.2
CST4		30.7	34.0	33.0	32.5	34.8	34.3	28.1	29.1	28.9
CST6		30.5	34.0	33.0	34.0	34.8	34.5	28.9	29.2	29.1
CST8		31.1	34.0	32.9	33.4	34.7	34.4	29.0	29.4	29.2
ETCW	Industrial sources	29.0	32.0	29.8	31.0	36.0	34.3	21.0	25.0	24.0
ETAS		28.5	32.0	30.1	27.0	35.0	32.5	22.0	25.0	24.3
NCTPC		27.0	35.0	30.8	35.0	38.0	36.5	31.0	36.0	34.3
MRL		BDL	BDL	<1	2.0	7.0	4.5	2.0	10.0	6.3
MPL		13.0	18.0	14.5	5.0	30.0	20.3	5.0	22.0	11.0
TPL		BDL	BDL	<1	BDL	7.0	3.5	4.0	5.0	4.8
NCTPS1		-	-	-	-	-	-	31.0	36.0	33.0

- The salinity values measured in the creek varied between 0 and 41 ppt. The high salinity of 41 ppt was recorded at KST during the month of May. This is attributed to the accumulation of flood tide waters in the saltpans of the upstream areas and subsequent evaporation due to closure of the Ennore Creek mouth. The low salinity values in the inner creek (ENC4 and AMC) show the influence of freshwater, which is largely due to baseflow in the monsoon/post monsoon periods. Salinity gradients observed in the Ennore creek during the post-monsoon may be used for modeling a conservative parameter.

- Range of salinity values measured in coastal samples was 30.1 – 35.0 ppt during February and May 1999, while lower ranges of 28.0 – 30.4 ppt were measured during the December 1999 survey. However, no spatial salinity gradients were found in the coastal waters, suggesting that the freshwater inflows from the land-based sources were relatively low.
- The February 1999 salinity variations in BUCS suggest that the wastewater from the canal is prevented from discharging into the creek during flood tide and discharges primarily during the ebb tide. However, the salinity variations in May and December are low with lower ranges suggesting the creek waters are adequately mixed with the wastewaters.

5.3.4 Total Suspended Solids (TSS)

The TSS ranges in each of the systems are given in Table 5.10 and the in the individual sites are summarized in Table 5.11.

Table 5.10 TSS (mg/L) ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	9.6 – 232	12.1 – 258.0	6.4 – 499
Municipal discharges	12.2 – 623	27.2 – 174	85.3 – 441
Point sources (industrial discharges)	12.2 – 20241	11.0 – 19975	19.9 – 6361
Offshore waters	4.4 – 77.3	2.5 – 42.6	12.5 – 86.3
Nearshore waters	8.0 – 64.5	5.5 – 26.6	20.7 –58.7

Table 5.11 Seasonal variation of TSS (mg/L) – stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	108	232	189	19.8	94.6	43.0	24.64	65	41.3
ENC2		94	144	112	13.3	57.4	33.6	37.6	76.44	56.3
ENC3		13.0	58.0	31.8	19.2	60.1	32.6	51.4	141	89.8
ENC4		125	102	83.8	27.6	77.0	44.7	49.0	116	80.2
AMC		16.2	29.6	21.5	35.6	71.3	57.8	6.4	12.0	9.2
KST		20.8	85.4	49.0	129.0	258.0	177	241	499	345
KRR		9.6	12.7	10.7	12.1	45.9	25.3	7.08	34.6	21.3
BUCN	Municipal sewage discharge	21.2	158	68.0	27.2	102.0	57.5	242	441	355
BUCS		12.2	127.0	69.1	31.7	96.0	68.4	85.3	115	99.3
RYSO		364.0	623	528	110	174.1	143.0	248.7	440	320
CST1	Offshore	10.8	53.3	32.1	2.5	14.4	9.1	23.8	54.1	38.6
CST3		9.0	15.0	12.0	6.5	27.6	17.7	20.4	49.1	30.7
CST5		13.2	13.4	13.3	11.2	39.6	25.0	13.8	39.1	31.2
CST7		6.7	72.1	39.4	2.5	11.4	7.0	12.5	38.9	24.2
CST9		54.8	70.0	62.4	4.0	31.0	12.7	22.8	86.3	52.5
CST10		4.4	77.3	40.9	6.4	42.6	26.9	47.5	68.3	58.1
CST2	Nearshore	12.8	21.8	17.3	5.5	26.6	16.7	31.2	58.7	49.6
CST4		30.3	45.4	37.9	5.8	10.3	8.6	21.6	52.2	37.2
CST6		8.0	64.5	36.3	9.8	18.2	12.4	20.7	41.1	30.4
CST8		9.0	52.8	30.9	8.7	14.7	12.1	29.1	55.7	41.9
ETCW	Industrial sources	12.2	64.2	32.5	24.0	78.1	43.1	42.0	73.3	51.4
ETAS		9513	20241	16060	3994	19975	12902	1116	6361	3780
NCTPS		23.3	242	90.1	24.6	97.8	64.1	163.8	357.	243
MRL		19.6	33.2	24.7	13.8	34.6	24.2	21.2	56.1	34.9
MPL		31.6	546	260	16.9	111	74.1	308	346.1	325
TPL		32.1	59.9	43.7	11.0	74.9	31.7	19.9	96.1	52.0
NCTPS1		-	-	-	-	-	-	-	-	-

- The suspended solid concentrations in Ennore creek are tidally influenced depending on flood and ebb flows and may be influenced by primary productivity in the upper reaches. Flood period concentrations tend to be lower with the influx of lower concentrations coastal waters.

- In general, the creek samples have higher TSS concentrations than the coastal water samples.
- High TSS values were measured at KST sampling location during the May and December 1999 surveys. This signifies overflows of ash slurry from the ash dikes from the North Chennai Thermal Power Station, located between KST and the Pulicat Lake. This corroborates the inference made in Section 2.2.2 that water enters the Ennore creek from Pulicat Lake when the creek mouth is closed. The color of the water was gray in most cases supporting this hypothesis.
- The high TSS discharge from ETPS does not appear to result in a distinct sediment plume. In fact, for the February 1999 survey, the current direction suggests that the suspended solids originate from Ennore Port dredging, given that CST9 and CST10 recorded high concentrations. Resuspension of dredged material may be the cause for high TSS concentrations as dredging and construction of breakwater were in progress during the first two surveys (February & May 1999).
- Localized high TSS concentrations were observed in RYSO samples, while high TSS values in BUCS were found to occur during ebb flows. These TSS values are associated with the municipal wastewaters and likely to be organic in nature. The settlement of these solids will result in decay and increase Sediment Oxygen Demand locally.

5.3.5 Dissolved Oxygen (DO)

The DO ranges in each of the systems are given in Table 5.12 and the variations in the individual sites are summarized in Table 5.13.

Table 5.12 DO (mg/L) ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	0.4 – 8.4	0.6 – 9.6	0.4 – 14.4
Municipal discharges	0.3 – 10.4	0.4 – 11.2	0.2 –5.6
Point sources (industrial discharges)	-	4.2 – 12.0	1.0 – 6.4
Offshore waters	5.7 – 10.4	4.2 – 7.5	5.5 – 6.4
Nearshore waters	6.1 – 9.8	4.5 – 7.5	5.4 – 6.4

Table 5.13 Seasonal variations of DO (mg/L) – stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	5.0	7.7	5.9	5.4	7.5	6.3	6.2	7.2	6.5
ENC2		0.4	0.6	0.5	0.6	2.0	1.5	5.8	6.8	6.3
ENC3		1.4	1.8	1.7	1.2	9.6	4.5	0.4	0.8	0.7
ENC4		1.0	7.0	3.4	0.6	2.4	1.2	0.8	5.2	2.5
AMC		7.4	8.4	8.0	2.4	9.4	6.7	6.0	14.4	10.1
KST		3.2	7.4	5.9	3.8	6.2	4.9	4.8	6.8	5.5
KRR		3.4	7.8	4.8	3.5	6.0	4.7	4.4	7.0	5.9
BUCN	Municipal sewage	6.8	10.4	8.3	4.2	11.2	6.6	4.2	5.6	4.9
BUCS		0.3	0.8	0.57	0.4	0.8	0.5	0.2	1.0	0.6

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
RYSO	discharge	ND	ND	ND	ND	ND	ND	ND	ND	ND
CST1	Offshore	6.7	8.4	7.8	5.1	7.4	6.4	5.9	6.3	6.1
CST3		6.8	7.9	7.3	5.5	7.5	6.5	5.8	6.3	6.1
CST5		5.7	10.4	7.6	5.5	7.3	6.4	5.9	6.4	6.2
CST7		6.4	7.8	7.0	5.3	7.2	6.3	5.8	6.4	6.2
CST9		5.7	7.4	6.6	5.5	6.7	6.3	5.8	6.4	6.2
CST10		6.2	8.2	6.8	4.2	6.9	5.7	5.5	6.4	6.0
CST2	Nearshore	7.3	8.7	7.8	4.5	6.5	5.5	5.4	6.3	6.1
CST4		6.5	7.0	6.8	5.2	7.5	6.4	5.8	6.4	6.1
CST6		6.2	9.8	7.4	5.0	7.2	6.3	5.8	6.4	6.2
CST8		6.1	9.4	7.6	5.2	6.8	6.3	5.9	6.3	6.1
ETCW	Industrial sources	-	-	-	5.2	5.4	5.3	1.0	2.4	1.7
ETAS		-	-	-	5.6	12.0	7.9	4.4	6.4	5.1
NCTPC		-	-	-	4.2	6.8	5.1	4.2	5.6	4.9
MRL		-	-	-	5.2	6.2	5.7	2.2	5.9	3.9
MPL		-	-	-	4.2	5.2	4.7	3.0	5.8	4.1
TPL		-	-	-	4.2	5.8	5.2	4.2	5.6	5.1
NCTPS1		-	-	-	-	-	-	4.4	5.4	5.0
ND – Not Detected; BDL – Below Detection Limits										

The Ennore Creek DO trends present a mix of very low DO values at a station throughout one survey (ENC3-Season-I), while a neighboring station has a high diurnal variation indicating Eutrophication (ENC4-Season-I). This leads to the hypothesis that high BOD loads result in the depression of DO, which upon oxidation provides nutrients for primary productivity. The primary BOD source is the Buckingham Canal, which collects both municipal and industrial wastewater. This is reflected by the high BOD values at BUCS and its nearby receiving water locations namely ENC2, ENC3 and ENC4.

There is a possibility that BOD concentrations at ENC4 are also influenced by productivity, since the BOD samples are unfiltered.

The transition from constant DO depletion to high diurnal swings is not fixed in location, changing from season to season. For instance ENC3 does not show any BOD swing for season-I & season-III, yet the DO values are extremely low at less than 2mg/L. For season-II, the DO swing ranges from 1.2 to a super saturation concentration of 9.6mg/L. For ENC4, this trend is exactly reverse of ENC3 where DO swings are seen for season-I and season-III, while season-II does not display any significant DO variation with an average of 1.2 mg/L. An attempt to explain these trends is made by presenting the variations of nutrients, DO ranges and chlorophyll-a through the length of the creek. (Fig 5.2) This overall perspective is followed by detailed description of each parameter, influencing DO

Water quality variations v/s Pigment concentration at Ennore creek during 1999

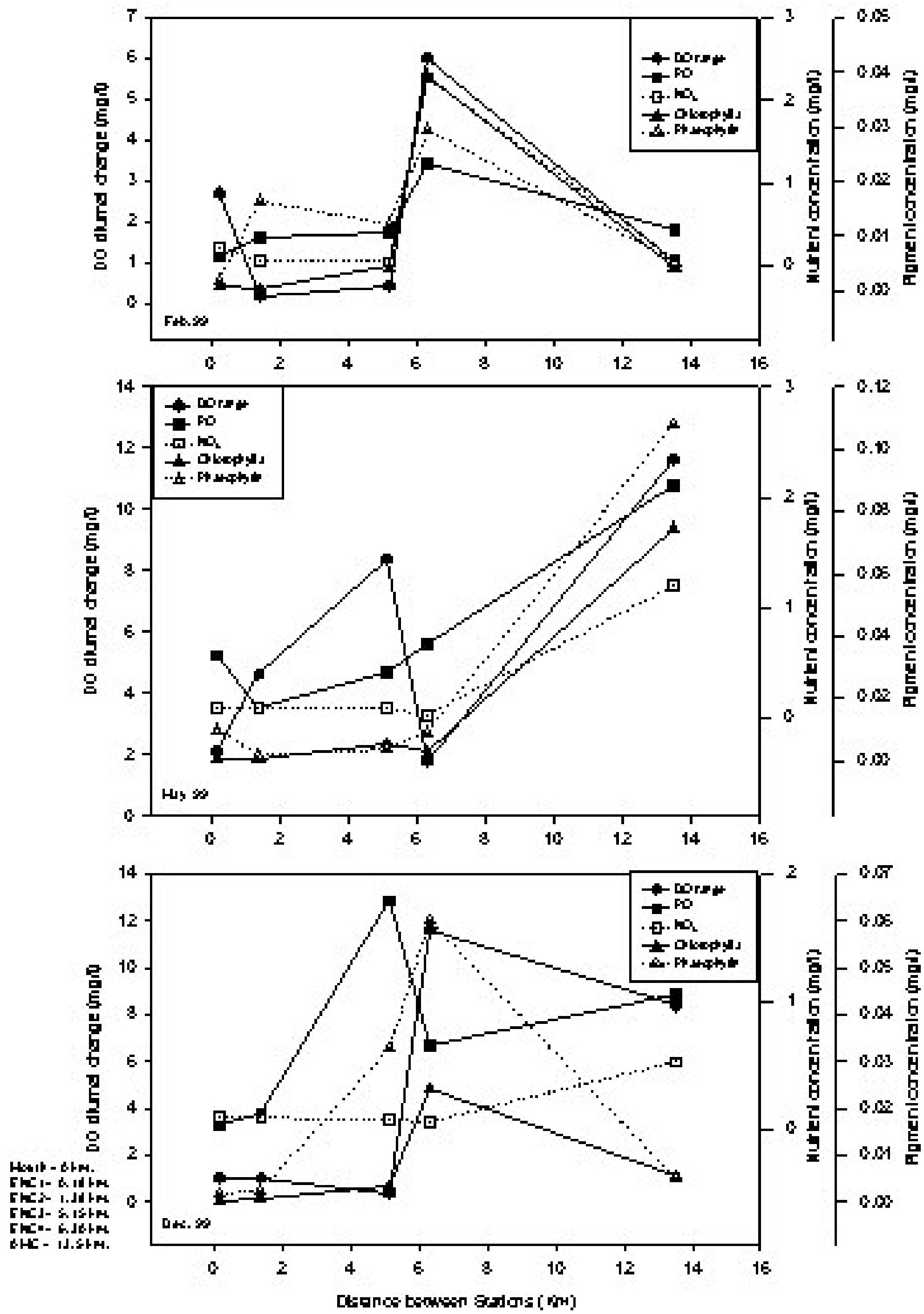


Fig 5.2

Fig 5.2 shows that nutrients, DO swings, Chlorophyll-a and Phaeophytin all showing general trend in increases towards the upstream sites indicative of dominant nutrient based productivity.

The small DO range at ENC4 for season-II (Fig 5.2) may be associated with the lower Chlorophyll-a and Nitrate values despite higher values both upstream and downstream at ENC3 and AMC. The data suggests that the growth increase to high levels at ENC3 and AMC, to the extent of exhausting nitrate and thus reaching the limiting nutrient concentration. It is important to note that when a DO swing is absent at ENC2, ENC3, ENC4 and AMC the DO values are always below 3mg/L. This clearly suggests that the organic loading is depleting oxygen levels below the MoEF standards. This suggests that BOD reduction is essential from BUCS.

The high diurnal DO variations in ENC4 and AMC may also be due to the nutrient inputs from the industries in the Manali Industrial area. The two major sources are overflows from the Madras Fertilizers Limited (MFL) and the solid waste (Calcium Chloride) from industries such as MPL. The MFL treatment ponds are open lagoons, running alongside the Amullovoyal Canal. The effluent characteristics in Amullovoyal canal are therefore likely to be influenced by seepage. The loadings from both these sources are difficult to estimate, and cannot be quantified in a WLA.

For coastal waters, DO concentrations do not indicate a trend, suggesting that wastewater loadings are assimilated adequately due to the large dilution capacity. It should be noted that the largest BOD mass loading enters the coastal waters from the ETPS which is in fact the cooling water withdrawn from the Ennore creek. In general, DO problems are not observed in coastal waters except minor decreases near outfalls.

5.3.6 Biochemical oxygen demand (BOD)

The BOD ranges in each of the systems are given in Table 5.14 and variations in the individual sites are given in Table 5.14.

Table 5.14 BOD (mg/L) ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	0.1 –26.0	0.3 – 34.0	0.1 – 64.5
Municipal discharges	1.0 – 320.0	1.3 – 250.0	0.8 – 428
Point sources (industrial discharges)	0.2 – 220	2.1 – 112.0	0.2 – 43.8

Offshore waters	0.1 – 4.0	0.1 – 1.0	0.6 – 2.6
Nearshore waters	0.1 – 5.2	0.1 – 0.8	1.0 – 2.4

Table 5.15 Seasonal variations of BOD – stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	0.4	4.8	2.1	1.1	10.4	5.3	0.8	1.2	1.0
ENC2		6.0	7.2	6.6	0.9	7.6	5.2	1.6	2.3	2.0
ENC3		1.0	14.4	7.2	2.3	8.2	5.2	42	64.5	53.3
ENC4		4.8	26.0	16.2	19.0	34.0	25.8	19.6	28.0	23.8
AMC		1.0	2.0	1.5	9.8	11.0	10.4	2.9	8.1	5.8
KST		0.4	1.2	0.8	2.4	4.0	2.9	0.1	2	0.8
KRR		0.1	1.0	0.6	0.3	1.7	0.9	1.4	1.7	1.6
BUCN	Municipal sewage discharge	1.0	1.4	1.3	1.3	3.0	2.5	0.8	1.6	1.2
BUCS		1.0	125.0	61.9	40.0	70.0	52.5	64	78	72.5
RYSO		310.0	320.0	315.0	210.0	250.0	228.3	92.5	428	304
CST1	Offshore	1.6	1.8	1.7	0.3	0.7	0.5	0.6	2.6	1.8
CST3		0.6	4.0	2.3	0.3	0.8	0.5	1	2	1.3
CST5		0.2	2.2	1.2	0.1	1.0	0.5	0.8	1.9	1.4
CST7		0.1	3.2	1.7	0.1	0.7	0.4	1.6	1.9	1.7
CST9		0.1	0.1	0.1	0.2	0.9	0.6	1.1	1.6	1.4
CST10		0.1	0.1	0.1	0.3	0.8	0.6	1.3	1.9	1.7
CST2	Nearshore	1.0	5.2	3.1	0.2	0.7	0.5	1.2	2.4	1.6
CST4		0.4	0.8	0.6	0.3	0.8	0.6	1.2	1.8	1.5
CST6		0.2	0.8	0.5	0.1	0.3	0.2	1	1.8	1.5
CST8		0.1	0.1	0.1	0.1	0.5	0.3	1	1.6	1.3
ETCW	Industrial sources	0.2	6.0	4.2	3.1	3.6	3.4	10.5	15	12.2
ETAS		2.1	6.0	4.1	2.6	3.2	3.0	8.4	17.2	13.6
NCTPC		0.8	6.0	3.0	2.1	4.5	3.2	0.2	1.4	0.9
MRL		190.0	220.0	208	75.0	97.5	86.3	27.2	43.8	36.5
MPL		0.9	21.6	11.8	16.0	112.0	58.5	11.3	24.8	18.8
TPL		17.1	22.0	19.5	2.5	8.5	5.8	5.3	25.3	12.6
NCTPS1		-	-	-	-	-	-	-	-	-

The BOD values are influenced by flood and ebb flows for season-I. BOD values in the creek are higher during ebb flows and lower during flood flows. This pattern has been distinctly observed in the Buckingham Canal samples also. Variations of BOD at ENC1 and ENC2 for season-I are indicative of the BOD loads from Buckingham Canal. However, for season-II the BOD concentrations at ENC1 and ENC2 are low supporting the hypothesis made in Section 2.2.2 (Zone II) that flows in the Ennore Creek are likely to be towards the ETPS intake if the Ennore Creek mouth is closed, irrespective of the tide. The high BOD values at ENC3 and ENC4 but low variations for seasons II and III indicate the low flushing rates due to the closed mouth. The reader may recall that the BOD loading from ETPS suggests that a significant portion of the BOD load to Ennore Creek remains unaccounted (Section 4.3). The ENC4 and AMC data suggest that the Manali industrial area contributes to the unaccounted source(s) significantly. Given the high BOD values and the low DO values, the modeling needs to focus on the BOD loads from BUCS and Manali industrial area. The option of simulating nutrients may be exercised if the first goal of meeting BOD standards is achieved.

For the coastal waters, high values of BOD inputs were measured at RYSO and ETCW. While RYSO is due to the municipal sewage, ETCW reflects ENC3 (Ennore Creek) water quality as the BOD load from ETCW is not generated by the thermal power plant. However, there is no distinct trend of BOD in the coastal waters suggesting that BOD loadings are not significant, relative to the large capacity of the coastal waters.

5.3.7 Nutrients

Ammonia Nitrogen

The Ammonia Nitrogen ranges in each of the systems are given in Table 5.16 and the seasonal variations in the individual sites are given in Table 5.17..

Table 5.16 Ammonia Nitrogen (μmol/L) range

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	0.8 – 148.0	BDL – 466.0	BDL – 305.0
Municipal discharges	2.9 – 203.0	BDL – 483.0	6.2 – 292.0
Point sources (industrial discharges)	BDL – 325.0	1.1 – 552.0	7.6 – 298.0
Offshore waters	BDL – 7.6	BDL – 12.5	BDL – 18.2
Nearshore waters	BDL – 21.5	BDL – 10.1	BDL – 5.4

In the creek ammonia values are higher than the coastal waters by two orders of magnitude. The highest values are at ENC4 and AMC indicating that significant source of nitrogenous BOD exist in the Manali industrial area. Such high loadings of ammonia are not amongst the known sources listed by the Pollution Control Board and therefore constitute an unaccounted or non point source. These high values indicate the presence of wastewater, which are likely to consume oxygen while being oxidized to nitrites and nitrates. The consequence would be lowered DO and Eutrophication.

Table 5.17 Seasonal variation of Ammonia Nitrogen (μmol/L) - stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	2.70	40.50	19.01	4.6	49.8	28.5	BDL	1	0.6
ENC2		0.80	82.50	32.00	8.5	247.0	118.9	5	47.4	21.5
ENC3		21.14	56	37.5	15.2	281.0	151.3	2.1	289	194.5
ENC4		85.00	145.00	109.23	42.2	216.5	104.7	193.0	259	222.8
AMC		20.00	148.00	82.93	150.0	466.0	292.4	275	305	289.5
KST		5.70	9.30	7.98	9.1	31.7	17.8	12.1	87	47.9
KRR		8.89	63.00	26.02	0.0	133.0	43.0	8.7	80.2	37.3
BUCN	Municipal sewage discharge	2.90	17.70	12.07	0.0	308.0	87.9	6.2	95.8	39.1
BUCS		14.10	142.50	76.63	13.8	483.0	247.0	225	292	266.
RYSO		104.00	202.50	139.8	165.0	402.0	302.3	47.5	259	153
CST1	Offshore	2.90	7.60	5.38	0.03	3.0	1.4	0.7	18.2	9.1
CST3		0.03	1.60	0.76	0.03	8.8	3.0	0.05	6.5	3.3
CST5		0.4	0.9	0.7	0.03	7.7	2.6	0.05	1.9	0.7
CST7		0.03	0.80	0.28	0.03	11.6	3.7	0.05	6.3	1.9
CST9		0.03	0.70	0.19	0.03	12.5	3.8	0.05	1.7	0.8
CST10		0.03	1.80	0.56	0.03	4.6	2.3	0.05	1.5	1.0
CST2	Nearshore	1.40	7.30	5.23	-0.98	7.8	2.0	2.7	4.7	3.9
CST4		0.03	21.50	6.46	0.03	8.9	3.0	0.05	2.7	1.0
CST6		0.03	4.30	1.19	0.03	7.1	2.5	0.05	2.3	1.0
CST8		0.03	2.00	0.64	0.03	10.1	4.3	0.05	5.4	1.8
ETCW	Industrial sources	25.21	145.	72.1	138.9	314.0	207.3	207	289	248
ETAS		19.32	208.	123.5	56.8	320.0	158.0	215	298	253.
NCTPC		0.03	18.10	8.18	41.1	58.5	49.2	7.9	111.8	38.1
MRL		183.50	325.	248	476.0	552.0	514.0	125	285	221
MPL		5.00	34.49	19.2	176.0	398.0	259.5	9.3	22.5	15.1
TPL		32.00	126.	62.79	1.1	228.0	101.3	7.6	165	75.4

Spatial variations in ammonia values in the coastal samples are observed, possibly due to localized pollution. However, concentrations are not significant enough to result in a DO demand.

Nitrate Nitrogen

The Nitrate Nitrogen concentration ranges in each of the systems are given in Table 5.18 and the seasonal variations in the individual sites are given in Table 5.19.

Table 5.18 Nitrate Nitrogen ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	0.68 – 291.14	0.2 – 84.0	0.1 – 34.9

Municipal discharges	0.6 – 278.8	0.5 – 42.1	0.1 – 8.8
Point sources (industrial discharges)	0.2 – 346.4	0.6 – 32.7	0.1 – 89.4
Offshore waters	0.8 – 30.3	0.7 – 4.8	0.1 – 6.78
Nearshore waters	0.5 – 22.6	0 – 2.4	0.1 – 4.5

Among the three inorganic forms of Nitrogen, Nitrate Nitrogen is most abundant at all stations, as it is thermodynamically the most stable oxidation level of Nitrogen in the presence of Oxygen in seawater and would accumulate in the sediments if left unutilized by plankton or bacterial decomposition.

Table 5.19 Seasonal range of Nitrate Nitrogen - stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	2.30	12.39	7.77	1.07	4.79	2.93	1.81	5.03	3.4
ENC2		1.78	2.52	2.05	2.25	3.40	2.93	0.48	6.11	3.3
ENC3		0.00	5.37	1.72	0.64	5.10	2.96	0.05	8.52	2.8
ENC4		4.95	147.02	81.13	0.59	1.10	0.74	0.05	4.31	2.1
AMC		1.32	5.46	2.87	11.80	84.00	42.63	5.87	34.94	19.0
KST		0.89	291.14	85.41	1.39	21.70	8.00	1.09	4.23	2.5
KRR		1.80	260.62	74.48	8.48	37.37	18.66	6.9	27.01	15.2
BUCN	Municipal sewage discharge	1.75	155.70	40.95	3.20	4.99	4.23	0.05	8.81	4.1
BUCS		1.72	62.10	17.65	0.52	42.06	13.24	0.37	1.72	1.0
RYSO		0.59	278.83	91.50	3.03	4.30	3.68	0.05	4.19	1.9
CST1	Offshore	1.22	5.55	3.00	1.43	4.76	2.43	1.03	6.78	3.7
CST3		1.13	1.47	1.30	0.90	1.93	1.26	0.79	1.99	1.3
CST5		0.82	2.90	1.70	0.70	2.50	1.59	0.05	-	2.7
CST7		1.23	2.57	2.01	0.88	1.70	1.18	0.05	2.98	1.4
CST9		1.87		11.71	1.02	3.18	1.79	0.05	1.68	0.9
CST10		1.12	4.76	3.20	1.48	3.30	2.15	1.05	1.93	1.5
CST2	Nearshore	0.64	2.44	1.52	-0.10	0.93	0.26	0.05	1	0.6
CST4		0.46		6.08	0.60	2.38	1.32	0.05	1.63	0.9
CST6		1.55		8.62	0.74	1.10	0.92	0.41	4.53	2.2
CST8		1.51	3.43	2.56	0.70	2.34	1.57	0.75	2.37	1.6
ETCW	Industrial sources	1.03	3.33	1.92	1.04	6.60	2.93	0.19	4.98	2.2
ETAS		0.21	1.05	0.52	2.10	5.80	3.50	4.43	4.43	4.4
NCTPC		6.89	56.27	24.65	0.56	5.70	3.80	1.69	7.65	5.0
MRL		14.62	346.40	227.34	10.90	11.00	10.95	0.05	89.39	38.9
MPL		38.61	60.34	52.07	0.66	1.90	1.48	11.18	47.27	34.0
TPL		3.81	79.80	30.11	8.80	32.69	21.35	16.32	37.34	25.4

Nitrate concentrations are not as high as the Ammonia levels, as it is possible that even after oxidation, primary productivity consumes the Nitrate, thus lowering Nitrate values. It would appear that DO swings increase when the Nitrate values are above 2 µmole/L. The sharp variations in nitrate concentrations from one station to another in the creek suggest that consumption by primary producers reduces nitrate concentrations and in some cases below the limiting nutrient concentration.

In general the coastal waters do not show spatial variations and thus significant impacts of the municipal wastewater discharge is not reflected.

Nitrite Nitrogen

The Nitrite Nitrogen ranges in each of the systems are given in Table 5.20 and the variations in the individual sites are given in Table 5.21.

Table 5.20 Nitrite Nitrogen ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	0.0 – 24.5	0.0 – 102.6	0.1 – 31.1
Municipal discharges	0.3 – 1.7	0.3 – 4.8	0.0 – 2.3
Point sources (industrial discharges)	0.3 – 49.0	0.3 – 58.5	0.0 – 59.6
Offshore waters	0.0 – 0.7	0.1 – 9.9	0.1 – 2.4
Nearshore waters	0.0 – 0.4	0.1 – 0.4	0.1 – 5.4

Table 5.21 Seasonal variation of Nitrite Nitrogen - station wise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	0.00	1.10	0.58	0.33	3.93	2.12	0.05	1.33	0.5
ENC2		0.10	0.60	0.33	2.10	4.45	3.05	0.82	1.57	1.2
ENC3		0.3	0.6	0.4	2.10	4.10	3.12	0.41	2.89	1.3
ENC4		0.05	8.10	2.88	0.20	0.51	0.41	0.75	11.9	4.2
AMC		1.80	3.00	2.70	55.0	102.6	79.8	14.5	31.1	21.2
KST		0.10	0.70	0.48	1.10	3.01	1.92	0.86	2.23	1.3
KRR		12.90	24.50	20.85	1.82	18.13	11.04	1.14	3.08	2.1
BUCN	Municipal sewage discharge	0.30	0.60	0.48	2.46	4.80	3.27	1.79	2.28	2.1
BUCS		0.30	1.70	1.10	0.34	3.93	2.34	0.1	0.8	0.4
RYSO		0.60	1.40	0.93	1.00	1.37	1.22	0.02	1.1	0.6
CST1	Offshore	0.20	0.70	0.38	0.05	0.34	0.18	0.2	0.45	0.4
CST3		0.00	0.20	0.13	0.05	0.20	0.16	0.2	1.25	0.6
CST5		0.00	0.10	0.08	0.05	0.14	0.09	0.2	1.13	0.5
CST7		0.10	0.20	0.13	0.05	0.32	0.12	0.1	1.1	0.4
CST9		0.10	0.30	0.18	0.05	0.38	0.20	0.1	2.43	0.9
CST10		0.10	0.20	0.13	0.22	9.92	4.50	0.2	1.55	0.7
CST2	Nearshore	0.20	0.40	0.30	0.00	0.00	0.00	0.34	1.75	0.8

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
CST4		0.00	0.30	0.13	0.05	0.12	0.08	0.6	5.37	2.0
CST6		0.00	0.10	0.08	0.05	0.15	0.08	0.1	0.89	0.4
CST8		0.00	0.10	0.08	0.03	0.36	0.14	0.1	1.27	0.5
ETCW	Industrial sources	1.00	19.50	8.00	2.00	9.06	4.45	0.32	1.09	0.6
ETAS		1.20	5.30	3.13	3.60	23.1	12.5	0.7	9.54	5.6
NCTPC		0.30	0.80	0.68	2.50	17.44	8.77	1.45	7.8	3.4
MRL		28.5	49.0	37.3	1.70	58.5	30.1	35.99	59.6	48.4
MPL		0.90	1.30	1.07	0.32	1.03	0.57	1.89	5.5	3.3
TPL		1.50	9.90	5.37	2.50	12.3	6.65	4.97	12.6	9.0

The higher nitrite values at ENC4 and AMC relate to the high ammonia concentrations.

Total Nitrogen

The ranges of Total Nitrogen in the different systems are provided in Table 5.22 and the variations in the various stations are provided in Table 5.23.

Table 5.22'Total Nitrogen ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	116.2 – 389.6	5.4 – 370.6	48.0 – 1067.4
Municipal discharges	132.6 – 405.6	51.7 – 247.1	60.6 – 741.4
Point sources (industrial discharges)	76.1 – 534.9	23.5 – 228.0	38.2- 1395.3
Offshore waters	5.9 – 268.2	58.4 – 126.8	75.4 – 938.3
Nearshore waters	17.6 – 257.8	63.6 – 188.0	53.0 – 503.6

Total Nitrogen

The high values of Nitrogen species of Ammonia, Nitrite and Nitrates at ENC4 can be attributed to overflow/seepage of effluents from the Madras Fertilizers Limited treatment ponds located along the Amullavoyal Canal and the solidwaste dumped in the canal and its banks by the fertilizer companies. Concentrations in the lower reaches of Ennore creek are influenced by tides and the Buckingham Canal discharges. In general, trends of total nitrogen values are similar to those of ammonia and nitrate.

Table 5.23 Seasonal variations of total Nitrogen - stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	217.8	281.9	243.9	31.4	49.0	40.9	48.0	460.5	241.5

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC2		268.1	298.1	289.4	75.0	288.0	155.5	49.9	621.0	370.9
ENC3		116.2	389.6	231.0	82.0	370.6	204.0	86.7	281.2	188.7
ENC4		141.4	376.0	295.0	5.4	56.5	36.6	63.9	166.9	106.3
AMC		221.4	316.7	266.1	32.2	55.5	42.0	51.7	297.0	185.4
KST		266.4	291.2	274.9	9.1	12.5	11.1	125.1	1067.4	480.9
KRR		260.6	285.1	275.6	22.8	24.6	23.6	272.0	462.0	379.5
BUCN	Municipal sewage discharge	150.2	163.8	158.4	96.5	247.1	170.2	202.9	741.4	421.0
BUCS		132.6	369.1	211.6	51.7	62.3	57.3	147.8	288.5	213.3
RYSO		164.0	405.6	283.0	54.3	62.0	57.9	60.6	227.9	114.0
CST1	Offshore	5.9	265.0	89.8	58.4	92.7	77.0	282.5	619.3	433.2
CST3		20.7	49.3	36.9	77.4	100.0	86.3	75.4	908.9	451.3
CST5		29.5	268.2	107.3	72.7	93.1	78.9	297.0	865.1	494.0
CST7		25.9	48.8	36.8	75.5	103.0	85.8	273.0	485.0	392.0
CST9		28.7	51.5	36.9	59.9	115.9	86.7	288.0	938.3	521.5
CST10		25.7	44.5	35.8	82.8	126.8	95.5	271.0	475.7	410.1
CST2	Nearshore	20.9	46.4	36.9	76.4	99.0	85.3	297.0	503.6	416.6
CST4		17.6	257.8	99.3	81.9	98.3	90.3	280.0	476.6	393.9
CST6		22.6	46.8	36.3	64.2	99.9	80.5	295.0	492.0	398.5
CST8		21.1	58.1	38.2	63.6	188.0	109.0	53.0	499.4	358.5
ETCW	Industrial sources	145.3	288.6	188.4	51.6	58.6	55.2	117.8	1395.3	549.3
ETAS		145.3	534.9	322.8	23.5	57.7	46.6	57.8	401.0	189.4
NCTPC		81.9	534.8	257.0	130.4	228.0	166.6	38.2	446.5	238.8
MRL		355.5	487.1	438.2	57.8	68.7	63.3	213.5	504.0	348.4
MPL		144.3	357.6	266.0	51.7	65.6	59.4	121.7	469.0	279.6
TPL		76.1	310.6	191.7	27.4	35.7	31.4	295.0	488.0	379.0

In the coastal waters, concentrations tend to be higher closer to Ennore port. Although a clear explanation is not available, correlations with dredging activities are being researched.

Inorganic Reactive Phosphorous (IRP)

The IRP concentration ranges in each of the systems are given in Table 5.24 and the temporal variations in the individual sites are given in Table 5.25.

Table 5.24 IRP Ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	0.7 – 65.0	0.5 – 77.9	0.4 – 69.6
Municipal discharges	1.6 – 99.0	6.5 – 91.3	1.0 – 80.5
Point sources (industrial discharges)	0.0 – 62.3	1.2 – 14.5	0.4 – 30.2
Offshore waters	0.0 – 2.1	0.0 2.4	0.0 – 4.8

Nearshore waters	0.1 – 2.0	0.0 – 1.2	0.0 – 2.6

Table 5.25 Seasonal variation of IRP - stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	1.00	7.50	3.48	1.9	38.8	18.2	0.56	2.43	1.4
ENC2		0.70	24.80	11.13	2.5	26.2	12.6	1.9	5.54	3.9
ENC3		3.30	22.70	12.73	8.5	19.2	13.4	39.85	69.6	57.8
ENC4		24.60	65.00	39.78	6.5	38.5	21.4	16.7	26.12	21.3
AMC		9.10	15.60	13.80	48.7	77.9	68.0	23.2	43.19	34.4
KST		1.80	5.20	3.20	0.5	4.1	2.7	1.57	4.94	3.5
KRR		1.10	2.30	1.68	1.2	2.7	1.9	0.4	0.69	0.6
BUCN	Municipal sewage discharge	1.60	7.50	4.65	6.5	11.6	9.2	1.02	3.88	2.5
BUCS		2.60	83.50	40.85	67.7	86.6	80.7	52.42	79	64.1
RYSO		20.50	99.00	70.63	78.8	91.3	83.3	77.48	80.51	78.8
CST1	Offshore	0.50	2.10	0.98	0.01	0.8	0.3	0.2	4.41	1.9
CST3		0.00	0.40	0.18	0.01	1.2	0.5	0.005	0.52	0.2
CST5		0.10	1.00	0.40	0.01	1.6	0.7	0.005	0.29	0.2
CST7		0.20	1.00	0.43	0.01	0.6	0.3	0.005	0.64	0.4
CST9		0.30	0.40	0.37	0.01	0.9	0.2	0.005	0.51	0.1
CST10		0.10	0.70	0.35	0.5	2.4	1.5	0.005	4.78	1.7
CST2	Nearshore	0.30	1.40	0.65	0.0	0.2	-0.5	0.13	1.5	0.8
CST4		0.20	1.30	0.73	0.01	0.8	0.3	0.23	2.64	1.2
CST6		0.10	0.50	0.35	0.10	0.5	0.3	0.005	0.57	0.2
CST8		0.10	2.00	0.68	0.01	1.2	0.6	0.005	0.53	0.3
ETCW	Industrial sources	3.50	13.40	6.75	9.3	14.5	11.3	22.79	30.23	26.2
ETAS		5.10	22.80	16.60	4.7	9.7	7.6	11.67	28.93	19.3
NCTPC		2.10	4.70	3.28	6.6	13.6	10.1	1.38	4.75	3.7
MRL		14.00	62.30	26.35	9.1	10.6	9.8	20.6	29.9	26.7
MPL		0.01	4.60	1.25	1.2	12.0	6.6	0.39	3.37	1.9
TPL		2.10	6.60	5.30	5.4	6.9	6.2	1.2	2.91	2.1

Total Phosphorous

The Total Phosphorous ranges in each of the systems are given in Table 5.26 and the temporal variations in the individual sites are given in Table 5.27.

Table 5.26 Total Phosphorous ranges

System	I Season (Feb '99)	II Season (May 99)	III Season (Dec'99)
Creek	1.2 – 68.0	3.1 – 88.8	3.0 – 72.7
Municipal discharges	1.8 – 99.4	6.9 – 107.4	4.5 – 106.4
Point sources (industrial discharges)	1.2 – 22.8	5.2 – 18.3	2.9 – 43.3
Offshore waters	4.9 – 40.2	0.6 – 7.4	2.5 – 12.5

Nearshore waters	5.1 – 24.3	0.7 – 7.3	0.4 – 5.3

Table 5.27 Seasonal variation of Total Phosphorous - stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	1.20	9.20	4.85	6.4	42.5	21.3	2.98	4.06	3.4
ENC2		2.60	68.00	22.98	3.1	29.5	13.8	3.31	6.51	4.8
ENC3		3.70	25.20	13.93	9.6	20.9	15.0	37.1	59.21	49.0
ENC4		27.40	68.00	43.25	7.0	70.4	32.6	19.8	72.7	34.7
AMC		10.80	20.70	17.23	80.2	88.8	86.1	26.1	44.6	36.4
KST		2.20	6.30	4.05	4.4	7.5	6.0	4.13	7.99	6.2
KRR		1.50	3.20	2.20	3.1	8.4	6.0	3.49	6.55	4.7
BUCN	Municipal sewage discharge	1.80	7.90	5.08	6.9	12.9	10.3	4.46	6.51	5.5
BUCS		2.90	89.5	44.8	71.6	101.2	89.6	36.0	81.7	64.7
RYSO		73.2	99.4	88.3	83.0	107.4	96.8	43.8	106.4	69.4
CST1	Offshore	4.95	10.2	6.55	1.6	2.4	1.9	2.54	12.5	5.8
CST3		4.98	6.95	5.90	2.5	2.7	2.6	2.63	3.02	2.8
CST5		5.52	6.84	6.14	1.2	7.0	3.2	2.63	3.39	2.9
CST7		5.12	9.81	6.57	0.6	7.2	3.1	2.72	5.23	3.7
CST9		5.43	26.7	16.2	1.1	7.1	3.9	2.78	3.64	3.3
CST10		5.96	40.2	16.2	0.9	7.4	4.2	3.18	5.8	4.0
CST2	Nearshore	5.59	9.28	7.70	1.5	1.7	1.6	0.39	5.28	3.0
CST4		5.87	24.3	12.9	1.1	7.1	3.1	2.58	5.24	3.4
CST6		5.12	6.26	5.72	0.7	7.1	3.3	2.6	3.57	3.1
CST8		5.49	7.58	6.06	1.7	7.3	3.5	2.71	3.76	3.0
ETCW	Industrial sources	4.80	21.0	14.9	9.4	15.4	12.4	18.37	27.9	24.5
ETAS		5.80	22.8	16.9	5.2	12.4	9.1	16.2	20.8	18.9
NCTPC		2.40	4.90	3.58	9.7	17.6	13.9	4.09	8.78	6.0
MRL		14.4	15.1	14.8	9.8	18.3	14.1	35.61	38.5	37.0
MPL		1.20	4.80	2.43	10.5	13.5	11.8	2.92	43.28	15.0
TPL		3.40	7.70	6.20	15.3	17.0	16.5	3.22	7.81	5.5

Phosphates in the Ennore creek system are the highest at ENC4 and BUCS. Similar to Nitrates, the source at ENC4 may be attributed to the fertilizer wastes, while the high concentrations at BUCS are related to the municipal wastewater. The total phosphorous and dissolved phosphate increases towards upstream (AMC). However, the primary productivity growth does not appear to be limited by the phosphate concentration in any of the surveys.

Phosphate signals in the coastal waters do not indicate any trends.

5.3.8 Biological parameters

Chlorophyll a

Chlorophyll a values are the highest at ENC4 and AMC. It must be noted that these values tend to be higher by an order of magnitude. Chlorophyll-a concentrations are directly related to the Nitrogen and Phosphorus measurements and thus WLA must eventually address reduction of nitrogen and Phosphorous loadings from the Ennore Creek.

The seasonal variations of chlorophyll-a concentrations in the individual sites are given in Table 5.28.

Table 5.28 Seasonal variation of chlorophyll-a concentrations - stationwise

STATION	Location	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	0.841	1.489	1.058	0.02	1.51	0.44	0.04	0.97	0.5
ENC2		0.018	0.954	0.252	0.02	0.84	0.41	0.21	1.17	0.7
ENC3		0.537	8.280	4.408	1.07	9.76	5.42	2.16	5.02	3.4
ENC4		0.137	62.652	39.448	0.37	6.16	2.54	21.13	28.05	24.2
AMC		1.034	7.315	4.213	34.85	104.55	74.77	2.45	8.49	5.6
KST		1.159	2.396	1.910	0.59	4.93	2.99	0.38	0.88	0.7
KRR		1.955	4.288	3.100	0.02	3.09	1.70	1.11	1.62	1.3
BUCN	Municipal sewage discharge	0.000	5.697	2.378	0.02	15.41	8.24	0.04	1.05	0.5
BUCS		-	-	-	-	-	-	0.04	0.08	0.1
RYSO		-	-	-	-	-	-	0.48	3.07	1.9
CST1	Offshore	4.800	9.801	7.139	0.02	0.92	0.63	0.32	0.92	0.6
CST3		0.000	6.378	3.514	0.02	2.24	1.08	0.07	0.78	0.4
CST5		1.275	2.585	2.087	0.02	2.31	1.08	0.01	0.65	0.3
CST7		0.000	1.490	0.769	0.02	0.74	0.23	0.06	0.82	0.4
CST9		0.000	0.072	0.036	0.02	2.03	0.68	0.06	0.47	0.3
CST10		0.000	0.568	0.346	0.02	1.25	0.75	0.09	1.12	0.5
CST2	Nearshore	1.026	7.870	5.225	-0.98	1.24	0.08	0.09	0.76	0.5
CST4		1.521	2.478	1.836	0.02	2.07	0.87	0.05	0.86	0.4
CST6		0.000	1.543	0.915	0.02	2.10	1.09	0.07	0.69	0.3
CST8		0.000	1.008	0.540	0.02	1.54	0.53	0.03	0.75	0.3
ETCW	Industrial sources	-	-	-	2.06	5.29	3.28	1.42	3.73	2.5
ETAS		-	-	-	0.64	4.76	2.12	1.05	1.68	1.4
NCTPC		-	-	-	0.02	2.48	1.48	0.38	1.41	1.0
MRL		-	-	-	9.16	9.17	9.17	5.84	13.06	8.4
MPL		-	-	-	0.02	0.02	0.02	0.14	0.85	0.4
TPL		-	-	-	0.02	2.54	1.51	1.30	2.06	1.6

There are no chlorophyll a variations in the coastal waters and thus eutrophication problems due to wastewater discharges need not be considered in the modeling exercise for WLA of coastal waters.

Phaeophytin

The temporal variations of Phaeophytin concentrations in the individual sites are given in Table 5.29.

Table 5.29 Seasonal variation of Phaeophytin concentrations - stationwise

STATION	LOCATION	I SEASON			II SEASON			III SEASON		
		MIN	MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN
ENC1	Creek	1.2	3.0	1.9	2.4	20.8	10.0	0.03	4.1	1.9
ENC2		1.4	33.5	16.5	0.7	2.4	1.6	0.04	6.1	2.6
ENC3		2.3	19.6	12.2	0.7	6.4	3.6	14.64	63.5	33.0
ENC4		18.2	47.7	29.5	4.9	15.6	8.9	3.74	129.3	60.2
AMC		3.4	7.7	5.4	87.8	157.0	108.3	0.96	8.4	5.0
KST		1.6	3.7	2.5	4.6	7.4	6.0	2.91	16.3	7.6
KRR		0.6	12.0	4.1	0.1	7.1	3.0	3.13	32.2	11.7
BUCN	Municipal sewage discharge	2.8	13.4	8.7	2.2	16.4	7.2	0.10	3.5	1.8
BUCS		6.2	72.6	41.1	26.4	37.0	32.9	2.60	27.6	15.8
RYSO		-	-	-	2.7	24.9	15.8	6.15	33.5	16.3
CST1	Offshore	1.9	16.8	6.8	0.3	42.7	14.6	2.36	16.1	7.2
CST3		2.8	11.4	7.4	0.7	52.8	26.8	1.81	14.4	8.1
CST5		0.2	8.0	2.8	30.7	30.7	30.7	3.95	31.8	13.0
CST7		0.3	8.4	3.6	0.1	53.4	18.5	1.80	28.2	13.9
CST9		0.3	9.5	4.6	2.2	31.7	17.0	0.16	6.2	3.7
CST10		0.1	7.7	3.1	1.9	40.7	21.3	0.71	3.5	1.8
CST2	Nearshore	2.9	13.0	7.9	-0.3	51.8	25.8	4.68	13.2	6.9
CST4		0.5	6.9	2.9	0.3	32.8	11.3	1.46	6.2	3.4
CST6		0.3	8.2	3.9	0.2	5.1	2.5	3.92	5.4	4.8
CST8		0.3	5.0	2.3	0.1	35.4	12.6	1.83	21.9	8.7
ETCW	Industrial Sources				1.1	2.1	1.6	0.57	22.9	9.2
ETAS					1.6	1.6	1.6	1.75	26.1	14.0
NCTPC					1.1	12.0	4.7	0.03	5.3	2.9
MRL					15.2	23.9	19.5	7.89	19.9	14.2
MPL					0.7	5.6	3.7	5.47	19.2	11.8
TPL					2.1	13.4	5.5	5.91	23.0	13.3

The Chlorophyll-a values and Phaeophytin measured in this study are directly related, although Phaeophytin pigments are measured to indicate the decay process of algae. Thus ideally Chlorophyll-a and Phaeophytin should be inversely related. Phaeophytin values tend to be high between AMC and ENC3 and are a function of the flow of tidal waters for instance, the post-monsoon concentrations of Phaeophytin are high even at ENC2 while for the pre-monsoon, the highest values are at Amullavoyal Canal. It may be recalled that the creek mouth remained almost closed during the pre-monsoon sampling and thus the stagnating waters tend to remain in the upper reaches.

Microbiology

The primary source of fecal coliforms and streptococci in the Ennore creek is the Buckingham Canal. All other inputs are relatively low. The Buckingham Canal signal is most distinct at ENC2. This signal from Buckingham Canal is also seen in other locations due to the tidal currents. ***The concentrations violate the criteria for SW-II, SW-III and SW-IV and thus the WLA for the creek must address the municipal wastewater discharge that enters through Buckingham Canal.***

The Royapuram sewage concentrations are the highest inputs to the coastal waters. Significant signal is also seen from ETCW reflecting the Ennore creek water quality. The pathogenic indicator concentrations are also measured in the coastal waters. This indicates that the input is high relative to the background concentrations and thus dilution does not lower the concentrations significantly. ***Violations of fecal coliform standards at ENC2, ENC3 and ENC4 are recorded and thus the WLA must address the municipal wastewater discharge into coastal waters.***

5.3.9 Biological Characteristics

Data collection & segregation

Plankton samples were collected using standard plankton nets with flowmeter. Samples were collected at all the water quality stations in the coastal and creek areas except at industrial point sources. The boat speed during the sampling was maintained at 2 knots. Samples were stored in formaldehyde solution for further analysis. In the laboratory, samples were observed under the microscope to identify organisms at species level and grouped as Bacillariophycee (diatoms), Dianophycee (dinoflagellates), Cyanophycee (blue-green algae) and Chlorophycee (green algae) in numbers/ml. Zooplankton major groups were Ciliates, Copepods, Calanoids, Harpacticoids, Cyclopoids, Cirritedians, Chaetognathas, and Chordates, larval and other forms expressed in numbers/m^3. Benthos was collected using Patterson grabs. After removal of larger organisms, the samples were sieved through 0.5mm mesh size sieve. The organisms retained on the sieve were preserved in formaldehyde and stained with rose Bengal solution for identification. The classification was at group level under amphipods, crustaceans, foraminiferans, mollusks, nematodes and polychaetes. Benthos population was expressed in animals/m^2.

Processing of the above data was done for identifying number of individual species percentage in the group, calculation of diversity index etc.

Analyses of parameters

Analyses of biological parameters such as phytoplankton, zooplankton and benthos were carried out using the (i) species diversity measurement (to study the abundance or richness of the species in the community) (ii) similarity coefficient by cluster analysis (to assess the relationship amongst the community samples) and (iii) spatial and seasonal distribution of species considered to be pollution indicators

Species diversity index measurements

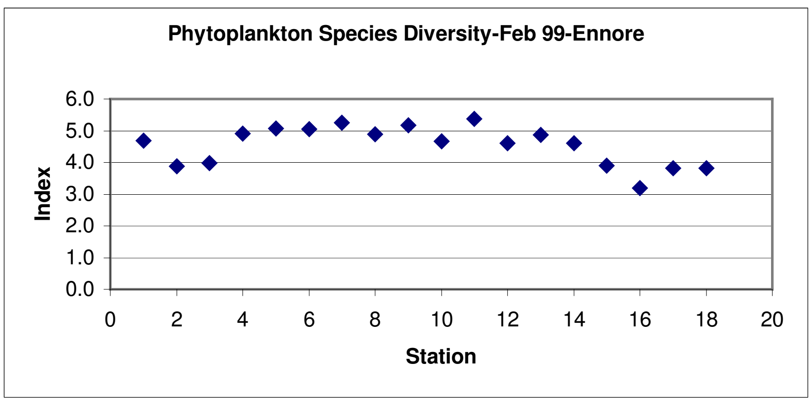
Species diversity is calculated by Shanon Weaver function for the phytoplankton, zooplankton and benthos data recorded in the coastal waters (CST1 to CST10) and creek locations. Shannon – Weaver index is widely used for assessing pollution levels in a system based on the estimate of species diversity. Accordingly, index values lower than 1 indicates critical degraded ecological status, and that above 3 indicates ecological stability of the component (Shannon, Weaver, 1963). Table 5.30 specifies the index ranges and pollution levels based on various researchers. However, these have been developed for temperate zones and its applicability to tropical regions is valid only after reclassification.

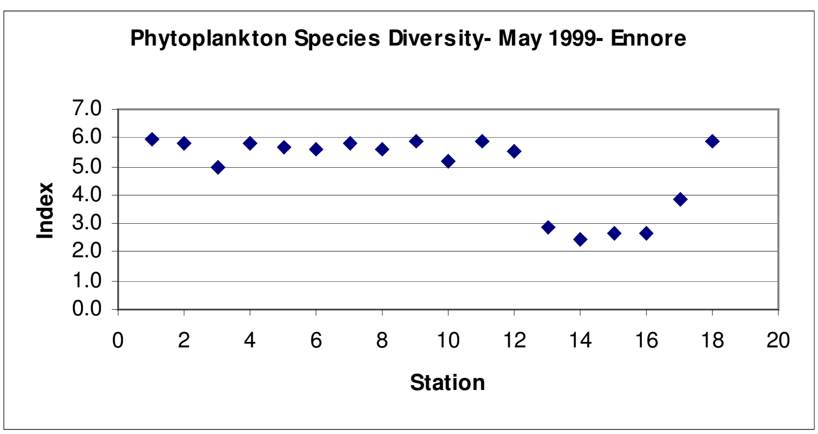
Table 5.30 Pollution classification based on diversity index

Wilhm and Dorris (1966)		Staub et al (1970)	
Diversity index	**Pollution level**	**Diversity index**	**Pollution level**
> 3	Clean water	3.0 - 4.5	Slight pollution
1 – 3	Moderately polluted	2.0 – 3.0	Light pollution
< 1	Heavily polluted	1.0 – 2.0	Moderate pollution
		0.0 – 1.0	Heavy pollution

PHYTOPLANKTON

The phytoplankton species diversity index indicated seasonal variations with ranges varying from 3.1 to 5.2 during February 1999, 2.4 to 6.0 during May 1999 and 2.5 to 5.6 during December 1999. In general creek stations, ENC3, ENC4, AMC, and BUCN recorded low diversity index values during all seasons, while coastal stations recorded rich species diversity. The index values plotted for the different seasons are shown in Fig 5.3





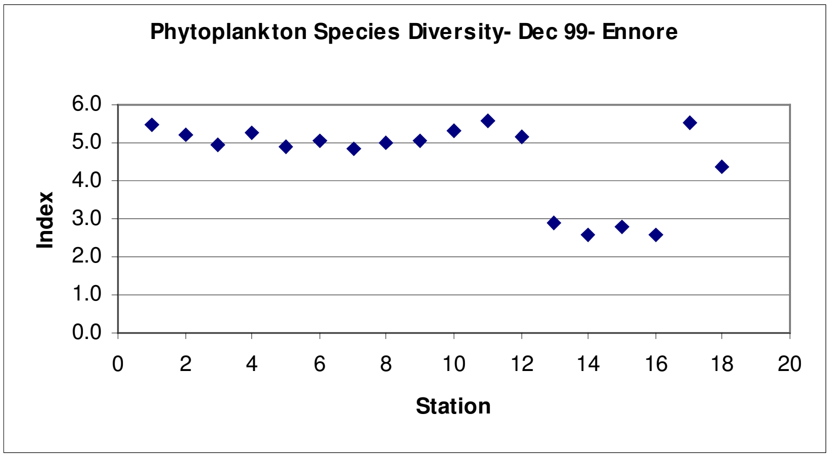


Fig 5.3 Phytoplankton Species Diversity

Note- 1 to 10 represent CST; 11 to 14 represent Ennore Creek stations 15 = AMC1, 16 = BUCN, 17 = KRR1, 18 = KST1

Species diversity index: It must be noted that the diversity index values in Ennore as per the classification of Willum & Dorris ( ) and Staub et al ( ), suggest that all locations fall either under 'clear water – light pollution / moderate pollution' classification. Since the results from the water quality analysis show extensive pollution and Eutrophication, classification systems are clearly misleading. Based on the water quality assessment of the Ennore region and due to fact that tropic zones are highly productive, attempt has been made to revise the diversity indices as follows:

<2.0	Heavily polluted;
2.0 – 4.0	Moderate pollution
4.0 – 5.0	Slight pollution
> 5.0	Clear water

Assessments of the coastal and creek locations were done according to the revised classification and the values are shown in Table 5.31.

Table 5.31 Phytoplankton Species Diversity indices

Station	Location	Feb 99	May 99	Dec 99
CST 1	Offshore	*4.7*	6.0	5.5
CST 3		*4.0*	5.0	5.0
CST 5		5.1	5.7	*4.8*
CST 7		*4.9*	5.8	*4.8*
CST 9		*4.7*	5.9	5.0
CST 10		*4.7*	5.2	5.3
CST 2	Nearshore	**3.9**	5.8	5.2
CST 4		5.1	5.8	5.3
CST 6		5.3	5.6	5.0
CST 8		5.2	5.6	5.0
ENC 1	Creek	5.4	5.9	5.6
ENC 2		*4.6*	5.5	5.2
ENC 3		*4.9*	**2.9**	**2.9**
ENC 4		*4.6*	**2.5**	**2.6**
AMC	River	**3.9**	**2.7**	**2.8**
BUCN		**3.2**	**2.7**	**2.6**
KRR		**3.8**	**3.9**	5.5
KST		**3.8**	**5.9**	*4.4*

NOTE: <2.0 - Heavily polluted; 2.0 – 4.0 -Moderate pollution; 4.0 – 5.0 - Slight pollution > 5.0 – Clear water

Stations were classified for pollution based on the species diversity index (Table 5.31) as follows:

ENC3, ENC4, AMC, BUCN - ***Moderately polluted stations***
KRR & KST - Slightly ***polluted Stations***
ENC1, ENC2 & CST 1 to CST10 – ***Clear water Stations***

The index values suggested by Staub et al. are likely to apply to temperate waters and not to tropical waters. It is therefore important that a relative measure for each site be used, as opposed to the absolute scale suggested by Staub et al. Assessment in eutrophic waters of Eastern Mediterranean by Karydis and Tsirtsis 1996 concluded that some of the commonly used indices such as the Simpson, Shannon's and Margalef's indices might to be unsuitable for identifying eutrophic trends. So further analysis on species composition has been carried out to study the degradation of the environment.

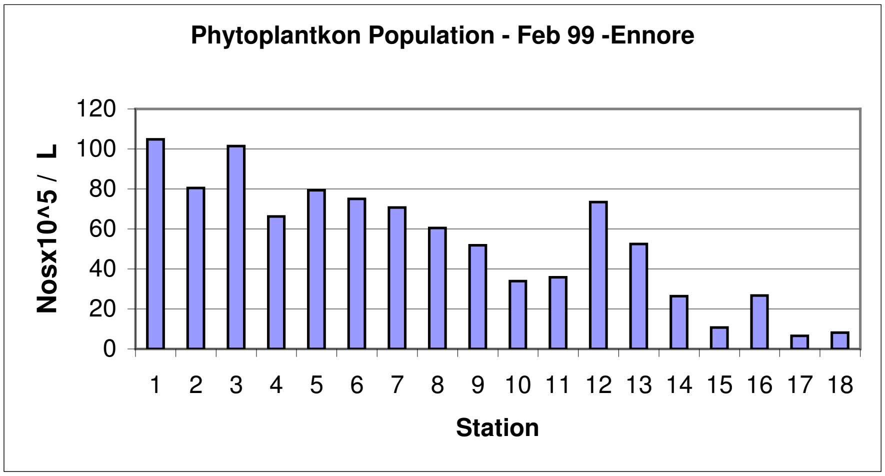
Phytoplankton Species Composition: In the present study (1999) 153 Phytoplankton species were recorded at Ennore coast and creek area. For all seasons and at all stations, diatoms were the dominant group (63%), with the other dominant groups being dinoflagellates (18%), Blue green algae (9%) and green algae (10%). Among the diatoms Coscinodiscus sp, *Ditylum* sp, *Skeletonema costatum*, *Thallassiothrix* sp, *Thallassionema* sp, *Chaetoceros* sp, *Rhizosolenia* sp were dominant and widely distributed in the study area. Among dinoflagellates, *Ceratium* sp was of common occurrence. Maximum number of species was recorded in the coastal stations and minimum species in the creek and river. The lower numbers of species in the creek are an indication of stress.

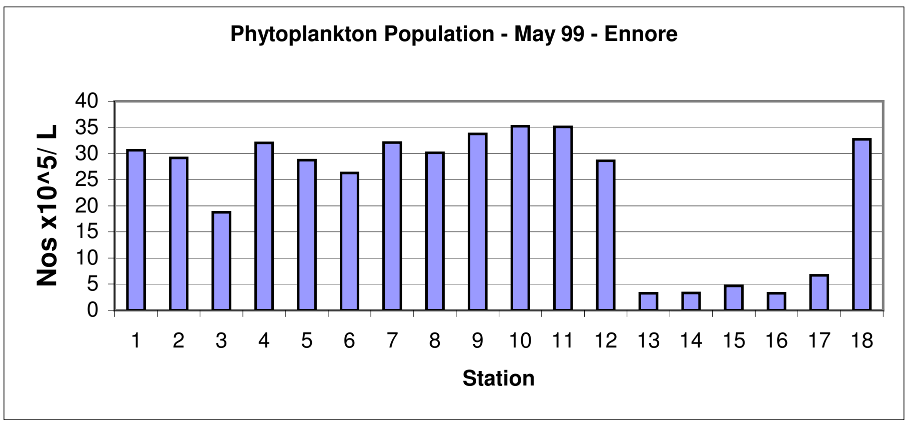
Dinoflagellate blooms can cause neuro toxicity in fish and thus widespread presence is undesirable. The present study recorded 28 species of dinoflagellates with growth of dinoflagellates and blue green algae considered dangerous to a healthy environment.

Plankton Biomass: The maximum density of phytoplankton recorded was 120 x 10^6/L in the coastal samples during February 1999. The density of phytoplankton was found to be higher in the coastal stations and low in the creek, canal and river. Among the phytoplankton species recorded, *Skeletonema costatum* was abundant in the coastal stations and creek stations except river locations ccounting for 33% of the total, indicating its high tolerance to pollution.

Phytoplankton numbers recorded during February 1999 were significantly higher than the May and December 1999 surveys (Fig 5.4)

Excessive nutrient and organic inputs from sewage and industry into the creek and coastal waters appears to have led to eutrophication, characterized by increases in phytoplankton biomass and nuisance algae blooms. This is revealed by the abundance of cells recorded in the 1999 survey viz., 8 million cells/L in the estuary and 12 million cells/L at coastal stations. In the Ennore Creek maximum phytoplankton population recorded was 60,000 cells/L, in a previous survey (Sivasamy 1985).





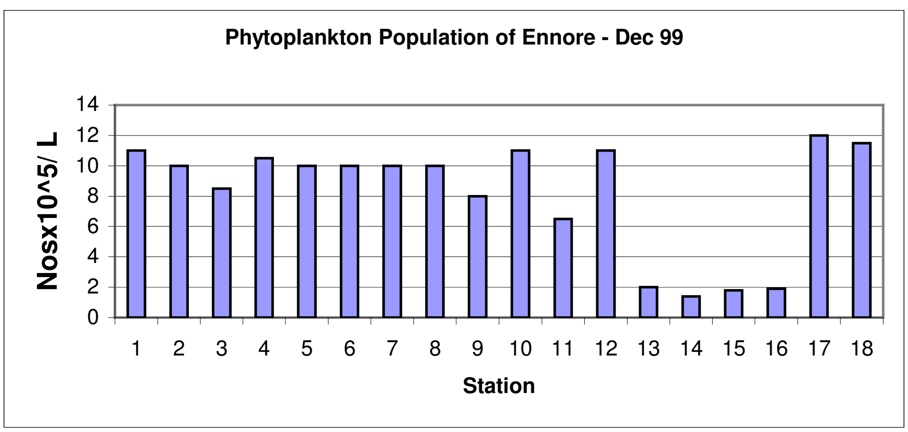


Fig 5.4 Phytoplankton population during the three surveys

Single species dominance: In general, single species dominance indicates a degraded environment where disappearance of pollutant sensitive planktons and recurrence of tolerant planktons dominate an ecosystem. Single species dominance was recorded at coastal stations CST 1 to CST 5 and all stations of Ennore creek and backwaters during February 99.

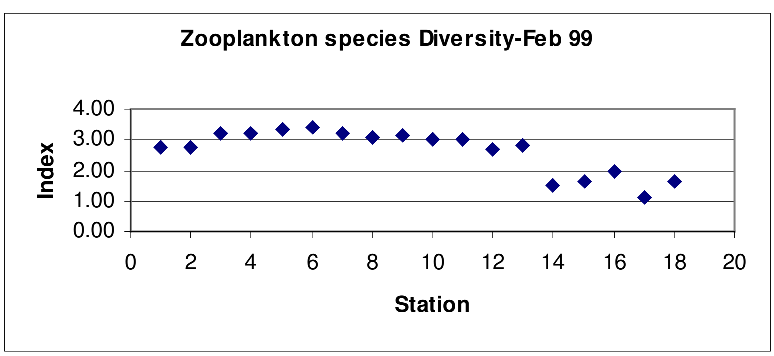
Skeletonema costatum was most dominant single species in these stations. However, this trend of single species dominance was observed to shift to multi species occurrence during the May and December 99 surveys.

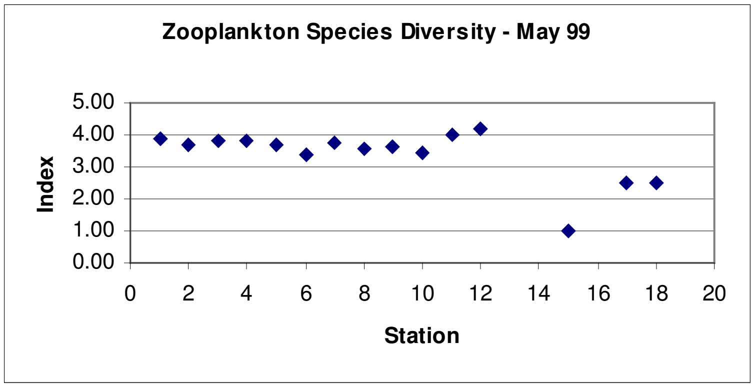
Toxic Phytoplanktons: Twelve potentially toxic phytoplankton species (Dinoflagellates and Blue green algae) were recorded during the 1999 surveys. In general, toxic dinoflagelates, Dinophysis uracantha, D. caudata, Noctiluca miliaris, Prorocentrum gracile, P maximum and P. micans were found to occur in the study area suggesting that the entire study area is under stress. The toxic blue green algae Anabaena sp, Lyngbya sp, Microcystis sp, Nodularia sp, Oscillatoria sp, Phormidium sp were occurring at the Buckingham canal and river station.

Eutrophication Indicators: Phytoplanktons such as *Microcystis sp*, (blue green algae) *Pediastrum sp* (green algae) which are good indicators of eutrophication (Zmijewska et al 2000) were found to be widely distributed in the Ennore creek, Buckingham canal and river locations, indicating Eutrophication of these areas during all three seasons of the 1999 survey.

ZOOPLANKTON

The species diversity index values of zooplankton ranged from 1.1 to 3.4 during February 1999, 3.4 to 4.2 during May 1999 and 1.2 to 4.7 during December 1999. Zooplankton species diversity showed seasonal variations similar to phytoplankton. While the highest species diversity was recorded at coastal areas, creek stations viz., ENC3, ENC4, AMC, and BUCN recorded the lowest species diversity irrespective of the season. Index values calculated are shown in Fig 5.5 for all three seasons.





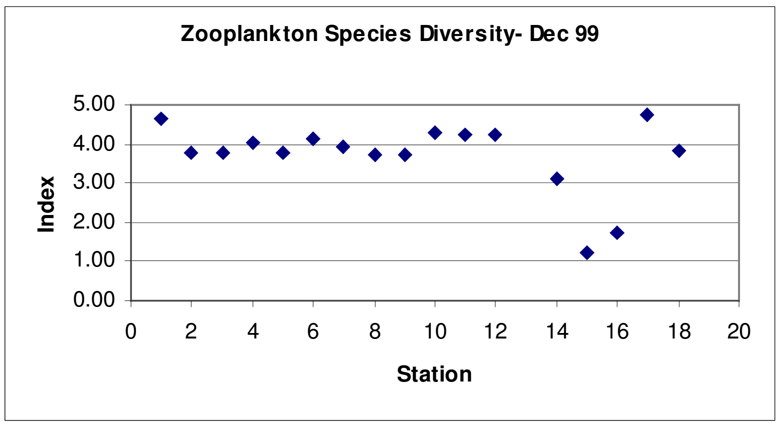


Fig 5.5 Zooplankton species diversity

Station- 1 to 10 = Coastal stations 1 to 10; 11 To 14 = Ennore Creek stations 15, 16, 17, 18 = AMC, BUCN, KRR, & KST respectively

Stations were classified for pollution based on the species diversity index (Table 5.32) as follows:

ENC4, AMC, BUCN, KRR and KST - ***Heavily polluted stations***
CST 1, CST 2, ENC 1, ENC2 & ENC3 - ***Moderately polluted Stations***
ENC1, CST 3 to CST10 - ***Slightly polluted Stations***

Table 5.32 Zooplankton species diversity index

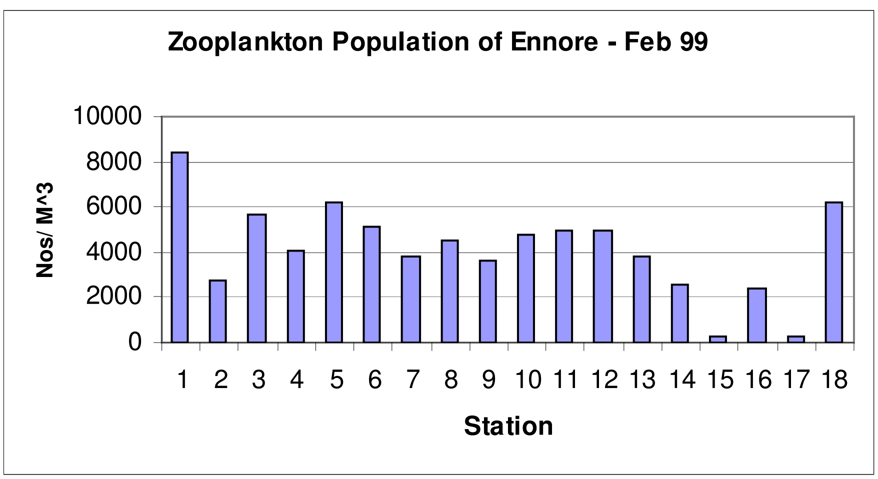
Stations	Location	Feb 99	May 99	Dec 99
CST 1	Offshore	*2.7*	*3.9*	4.6
CST 3		*3.2*	*3.8*	*3.8*
CST 5		*3.3*	*3.7*	*3.8*
CST 7		*3.2*	*3.8*	*3.9*
CST 9		*3.2*	*3.7*	*3.8*
CST 10		*3.0*	*3.4*	4.3
CST 2	Nearshore	*2.7*	*3.7*	*3.8*
CST 4		*3.2*	*3.8*	*4.0*
CST 6		*3.4*	*3.4*	*4.1*
CST 8		*3.1*	*3.5*	*3.7*
ENC 1		*3.1*	*4.0*	4.2

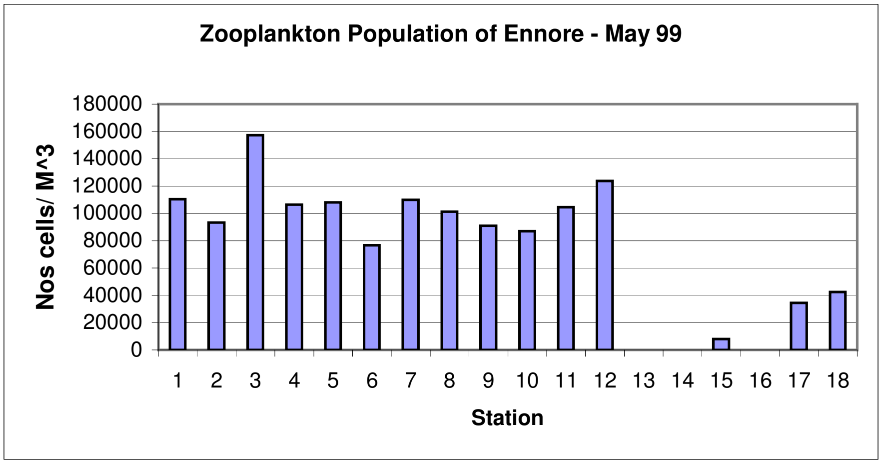
ENC 2	Creek	*2.7*	4.2	4.2
ENC 3		*2.8*	-	-
ENC 4		**1.5**	-	*3.1*
AMC	River	**1.7**	**0.99**	**1.2**
BUCN		**2.0**	-	**1.7**
KRR		**1.1**	*2.5*	4.7
KST		**1.6**	*2.5*	*3.8*

NOTE: <2.0 - Heavily polluted; 2.0 – 4.0 -Moderate pollution; 4.0 – 5.0 - Slight pollution > 5.0 – Clear water

Zooplankton species composition: In the present study (1999) 46 species zooplankton and 10 larval forms were recorded in the coastal locations and Ennore creek area. Copepods were predominant (14 sp), with cyclopods group (8sp), ciliates (6 sp), Harpacticoids (5 sp) and rotifers (4 sp) being the other dominant groups. Maximum numbers of species were recorded in the coastal samples and minimum in the creek and river.

Zooplankton Biomass: The maximum density of zooplankton recorded was 1.48 x 10^5 nos/m^3 in the coastal samples during the May 1999 survey. Density of zooplankton was found to be higher in the coastal stations and low in the creek, canal and river samples. Amongst the zooplankton recorded Acartia *sp* was abundant, 20000 nos/ m^3. (CST 3 – May 99) which is highly tolerant to pollution. Zooplankton was abundant during May 1999 when compared to the February and December 1999 surveys. (Fig 5.6)





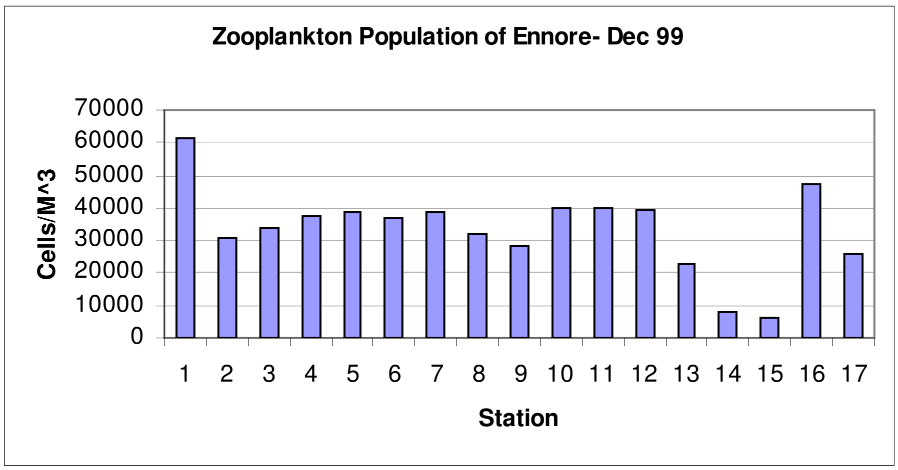


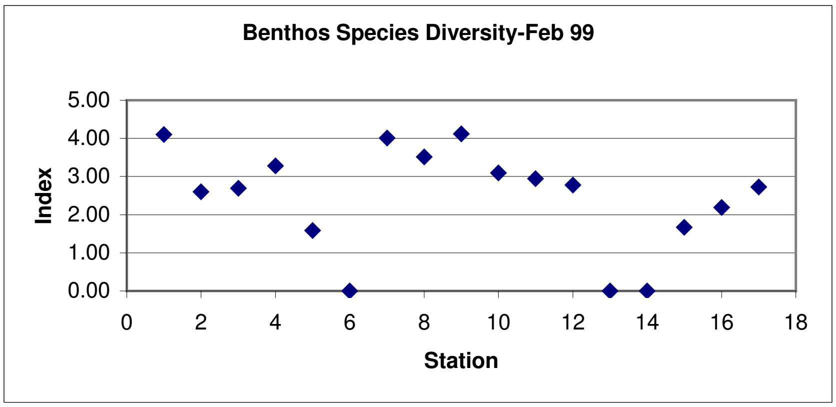
Fig 5.6 Zooplankton Population of Ennore 1999

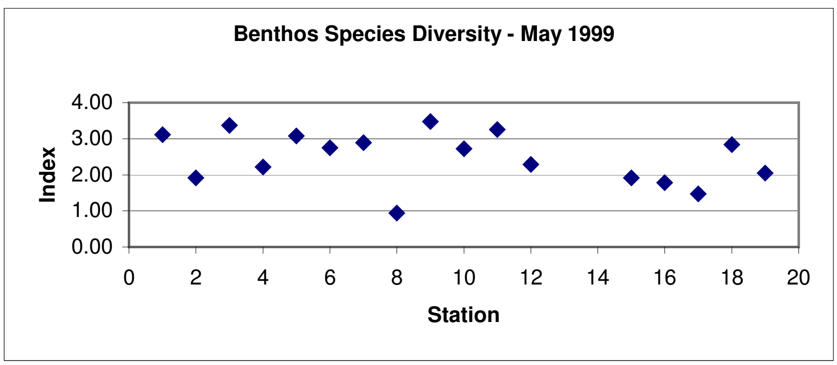
Eutrophication Indicator: Rotifers, which reproduce and grow well in Eutrophic waters (Liu engqi-1996) were found to be present at the Ennore creek locations during all three seasons in 1999, while the coastal stations did not record these indicators. The number of species and the counts were found to increase when the Ennore Creek mouth was closed especially in the December 1999 survey.

BENTHOS

The species diversity index values of benthos ranged from 0 to 4.1 during February 1999, 0.94 to 3.37 during May 1999 and from 0 to 2.8 during December 1999 surveys. Amongst the coastal samples, highest species diversity were recorded at CST1, CST 7 and CST 9 while CST 6 (Feb), CST8 (May), CST 10 (Dec) recorded the lowest species diversity. The creek stations ENC3, ENC4, BUCN also recorded low species diversity values. The index values for the three surveys for all the stations are shown in Fig 5.7. ENC3 and ENC4 were sampled three times during the study and in all three cases diversity is estimated to be zero. This further supports that ENC3 and ENC4 are severely stressed. Stations were classified for pollution based on the species diversity index as follows:

ENC 3, ENC 4, BUCN, BUCS, KST, AMC & CST6 - ***Heavily polluted***
ENC 1, ENC 2, KRR, CST2 to CST5, CST7 and CST8 - ***Moderately polluted Stations***
CST1 and CST9– ***Slightly polluted location***:





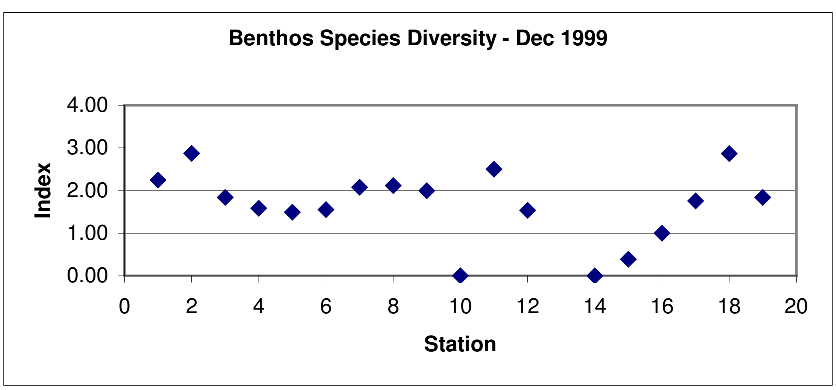


Fig 5.7 Benthos Species Diversity 1999

Note- 1 to 10 represent CST; 11 to 14 represent Ennore Creek stations 15 = AMC1, 16 = BUCN, 17 = KRR1, 18 = KST1

***Species composition*:** The range of benthic population in the coastal locations varied from 45 to 5230 Nos/m^2 with CST9 recording the highest value (5230 Nos/m^2) during May 99. Benthic organisms were mollusks, foraminiferans, polychaetes and nematodes in the coastal areas with mollusks being the dominant group during all seasons. The range of values in the creek stations was 23 to 4037 Nos/m^2. In the Ennore creek polychaetes and nematodes were dominant groups. The dominance of polychaetes is considered to be indicative of a disturbed environmental area, as this opportunistic species tend to replace the other organisms. (Samuelson, 2001 & Meksumpun et al, 1999).

CLUSTER ANALYSIS (SIMILARITY COEFFICIENT)

Methodology

Polychaetes, Nematodes and Mollusks were the group of benthos selected for cluster analysis. Similarities among sampling stations were established by means of cluster analysis, using benthos as variables as suggested by Carballo and Naranjo (2002). Average linkage clustering has been applied for the present study. The results were then graphically described using dendrograms with UPGMA (unweighted pair – group method using centroids) aggregation algorithm.

Results

The results show four types of clusters. The first group of cluster includes the offshore stations that are sufficiently away from anthropogenic disturbance. The second group of cluster were some coastal stations, which can be considered 'moderately disturbed due to their proximity to the Ennore and Fisheries Harbour. The next group was the estuarine stations under the influence of thermal and industrial outfalls considered as disturbed areas. The fourth group of stations includes the creek, Buckingham canal and river point under the influence of urban sewage and major industrial discharges. Classification of the station under the various clusters is as follows:

Cluster 1: CST2, CST3, CST4, CST7 and CST9
Cluster 2: CST1, CST8, CST10, and KST1
Cluster 3: ENC1, ENC2, and KRR
Cluster 4: ENC3, ENC4, AMC, CST5 and CST6

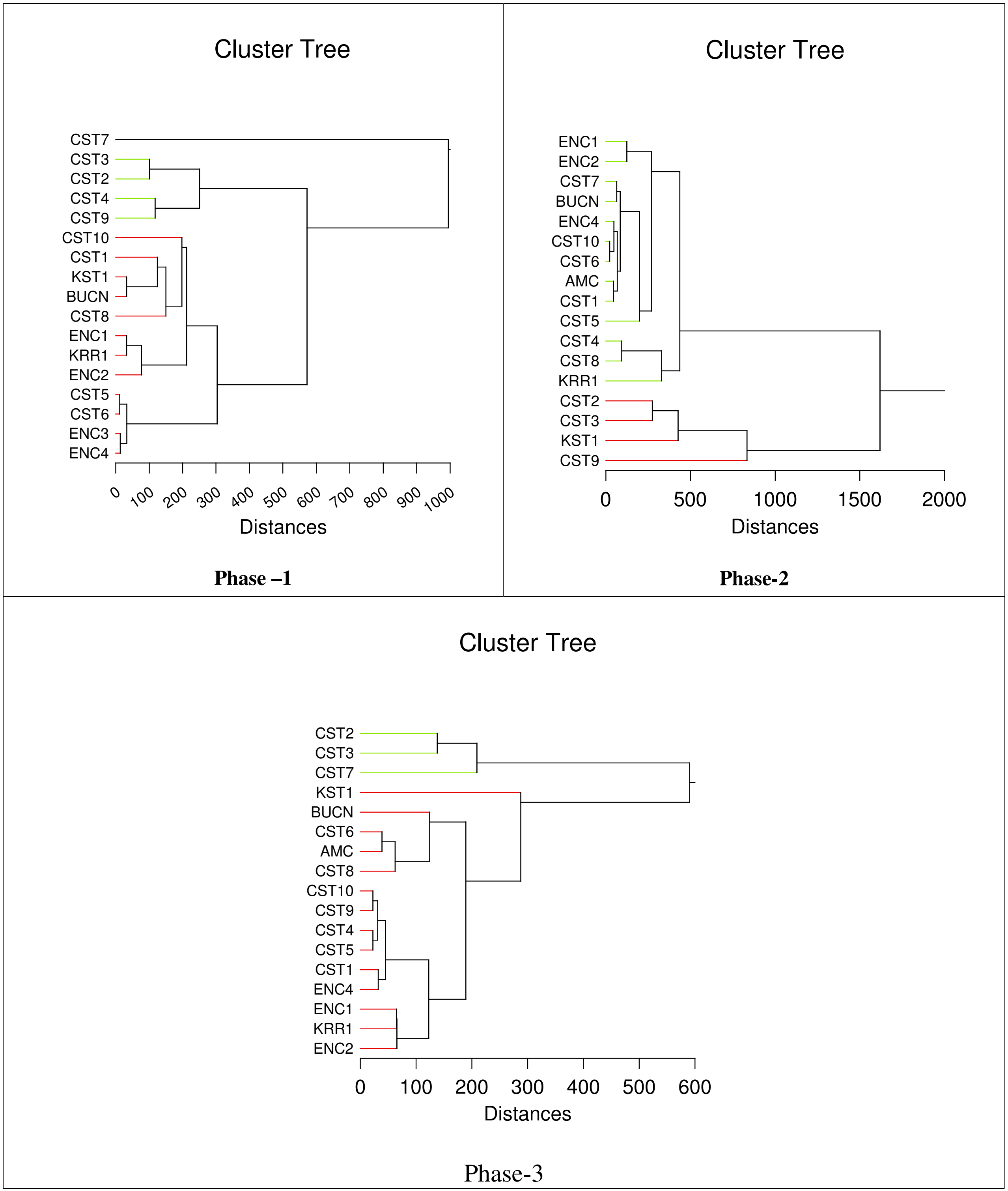


Fig 5.8 Results of cluster analysis carried out on biological characteristics

Summary of biological analysis

Criteria	Evaluation	Conclusion
		Phytoplankton
Diversity index	Range measured were 3.1 – 5.2 – February 1999 2.4 – 6.0 – May 1999 2.5 – 5.6 – December 1999	• Ennore Creek locations ENC3, ENC4, AMC and BUCN indicate lower diversity and hence depict relative pollution stress • Coastal stations fall under clear water category.
Species composition	Diatoms, diniflagellates, blue-green algae and green algae were dominant	• Coastal stations recorded maximum species. Lower number of species in the creek is an indication of stress • High numbers of dinoflagellates and blue green algae which are considered dangerous to an healthy environment were recorded in the study area
Plankton cell counts	Higher cell counts in the coastal stations and low in the creek	• Given that Chlorophyll-a concentrations are higher in the creek, the lower number of cells indicate higher cell size due to nutrient enrichment
Single species dominance	Skeletonema costatum was dominant during February 1999 survey	• Indicative of degraded environment with disappearance of pollutant sensitive species
Toxic phytoplankt on	Presence of dinoflagellates and blue-green algae	• Twelve potentially toxic species recorded suggesting that the entire study area is under stress
Eutrophicati on indicator	Presence of indicators of Eutrophication such as blue green and green algae	Widely distributed in the Ennore Creek, BUCN and river locations indicating eutrophication
		Zooplankton
Diversity index	Range measured were 1.1 – 3.4– February 1999 3.4 – 4.2 – May 1999 1.2 – 4.7 – December 1999	• Ennore Creek locations ENC2, ENC3, ENC4, AMC, BUCN, KRR, KST and CST 1 and 2 recorded low diversity index and hence depict pollution stress • ENC1 and Coastal stations CST 3 to 10 fall under slightly polluted' category
Species composition	Copepods are dominant	• Coastal stations recorded maximum species. Lower number of species in the creek is an indication of stress
Plankton cell counts	Higher cell counts in the coastal stations and low in the creek	• Acartia sp was abundant in coastal and creek locations
		Benthos
Diversity index	Range measured were 0.0 – 4.1– February 1999 0.94 – 3.37 – May 1999 0 –2.8 – December 1999	• Ennore Creek locations ENC1, ENC2, ENC3, ENC4, AMC, BUCN, KRR, KST and CST 2 and 8 recorded low diversity index and hence depict pollution stress • CST 1 and 9 fall under slightly polluted' category
Species composition	Polychaetes and nematodes dominant in the Ennore Creek Mollusks dominant in the coastal waters	• Dominance of polychaetes suggest Ennore Creek a disturbed area
Cluster analysis	Polychaetes, nematodes and mollusks selected for cluster analysis for Survey-I. No relationships for Survey-II and III	• Ennore Creek locations ENC3, ENC4, AMC and CST5 and CST6 represented linkage amongst themselves indicating discharges from Ennore Creek through ETPS as well as Manali industries and ocean outfalls

5.4 PRIORITIZATION OF ISSUES

5.4.1 Statistical Analyses

The first step towards modeling a system for water quality management is prioritization of the issues. Since the Ennore WLA measurements provided multivariate datasets, problem analysis was started with a substantial number of correlated variables. The Principal Component Analysis is a dimension-reduction tool that can be used in such situations by determining correlation amongst variables / sampling locations thereby enabling grouping of variables/stations. All the three season data were statistically processed using statistical package SYSTAT to determine correlations by carrying out Principal Component Analysis (PCA) and Discriminant Analysis (DA). In both the cases the objective was to prioritize issues on the basis of time (seasons), space (stations) and water quality issues (parameters)

- PCA was carried out to determine the correlation amongst parameters and also amongst sampling locations
- Discriminant Analyses was used for classification/grouping of the parameters and stations by discriminating them on the basis of seasons, parameters and locations (Creek, Coastal, Freshwater, Sewage etc.)

5.4.2 Classification using Discriminant Analysis (DA)

Discriminant Analysis (DA) uses a set of independent variables, for example water quality parameters; sampling locations and classifies them into predefined groups (nutrients, oxygen related, site types such as creek, freshwater, coastal, seasons). DA creates new variables based on linear combinations of the independent dataset provided. These new variables are defined so that they separate the groups as far apart as possible. Different combinations of the groups were explored to obtain the best possible separation amongst the variables.

For the Ennore dataset, grouping of variables/stations were done on the basis of scientific hypothesis. For example, DO and BOD were grouped together as they are significantly interrelated. All nutrients such as Ammonia, Nitrites, Nitrates and Inorganic Reactive Phosphorus (IRP) were grouped together. While Chlorophyll-a and Phaeophytin were grouped together as they area productivity issues, the Fecal Coliform concentrations were treated as a separate group. This hypothesis was tested for all season samples and stations using the DA tool of SYSTAT to determine whether a significant classification exists and how far apart or how closely the groups are classified. The farther the centroids of the groups, the more correct the hypothesis. The closeness/overlapping of the centroids of group indicates the incorrectness of the hypothesis i.e., the groups/variables are not really significantly different from each other. For sites, they may either represent the source points and for parameters they represent the level of pollution. The first canonical variable is the linear combination of the variables that best discriminates among the groups, the second canonical variable is orthogonal to the first and is the next best combination of variables, and so on

Discriminant analysis is related to both multivariate analysis of variance and multiple regressions. In discriminant analysis, Wilks' lambda, the same test statistic used in multivariate ANOVA, is used to test the equality of group centroids. Discriminant analysis is useful not only to test multivariate differences among groups, but also to explore:

- The discriminating variables amongst groups
- subsets of variables performing equally well as another
- groups that are most alike and most different

Two types of classification were tested for the Ennore samples

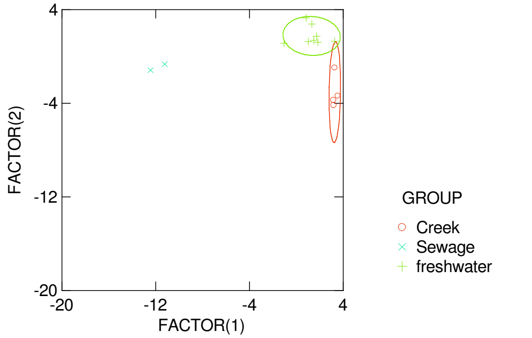
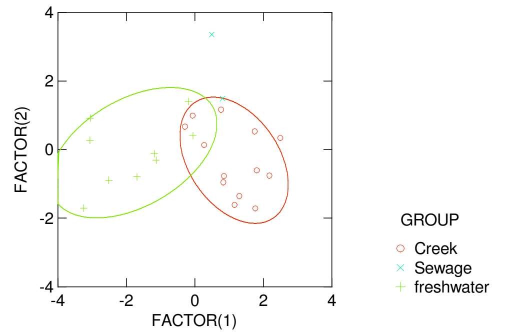
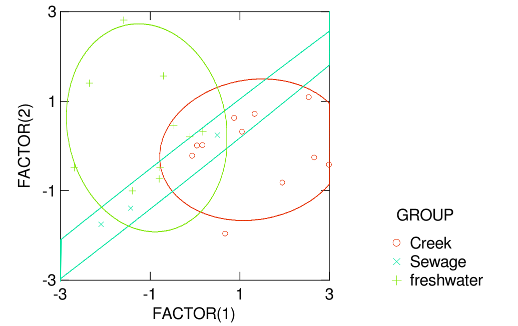
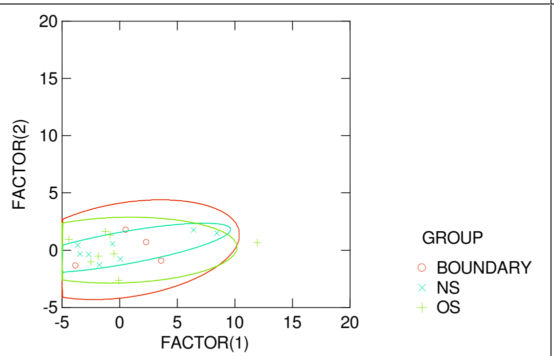
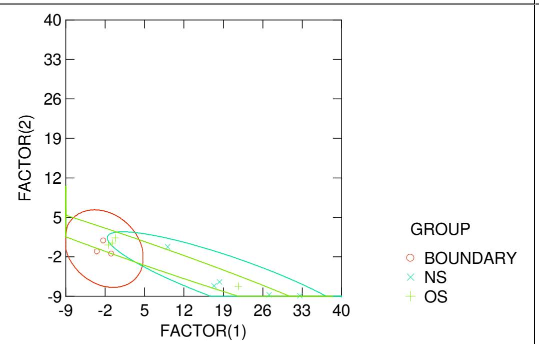
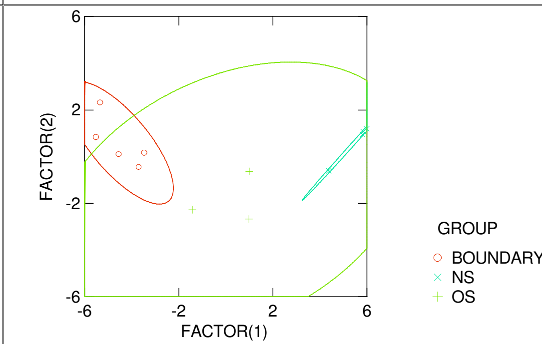
Case (i) WQ parameters were defined as independent variables and grouped on the basis of parameters viz., Nutrients, primary oxygen related issues such as DO/BOD, productivity metrics like Chlorophyll-a/Phaeophytin and anthropogenic pollution metrics like Fecal Coliforms separately in the creek & freshwater stations and coastal stations for each season and for all seasons together

Case (ii) Sampling stations formed independent variables and were grouped on the basis of the site type such as creek, freshwater, sewage and coastal locations. These grouping were tested season wise and all seasons together.

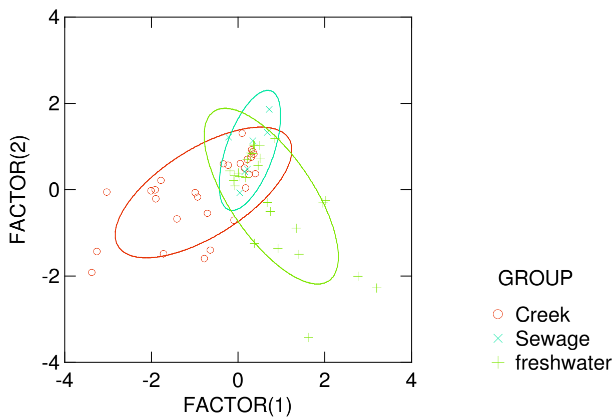
Prioritization on the basis of seasons and locations

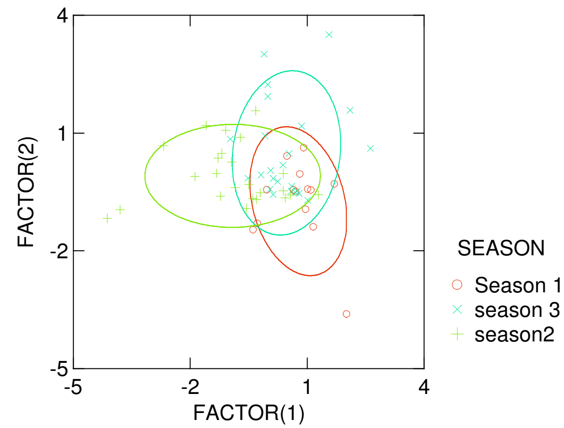
Results of DA are shown in Figs. 5.9 for the creek and coastal stations for each season. The grouping is done on the basis of station locations. The following conclusions were drawn from the statistical plots:

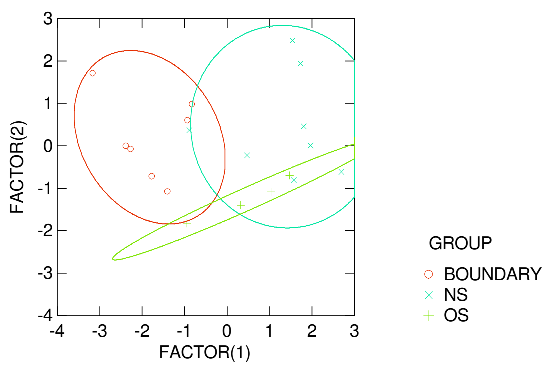
- Significant separation amongst coastal stations are not observed during the first and second season, while the boundary stations form a separate group during the third season
- For the creek stations a positive effect is observed during the first season (except sewage stations) illustrating flushing/mixing due to the mouth remaining open during the first survey

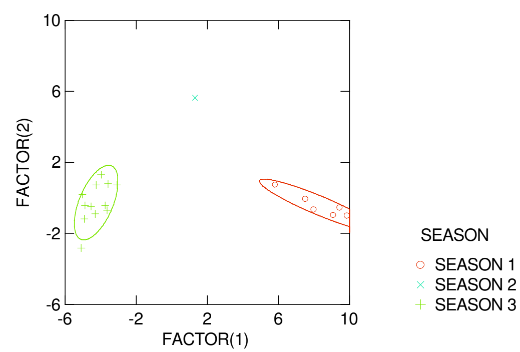
System	Phase 1	Phase 2	Phase 3
Creek			
Coastal			

.Fig 5.9 Grouping of variables for different phases of survey

<table>
<tr><th>System</th><th>Location</th><th>Seasons</th></tr>
<tr><td>Creek System</td><td>

(a) Classification of Creek Stations (all seasons)</td><td>

(b) Classification of Seasons (all parameters)</td></tr>
<tr><td>Coastal Locations</td><td>

(a) Classification of Coastal Stations (all seasons)</td><td>

(b) Classification of Seasons (all parameters)</td></tr>
</table>

Fig 5.10 Classification location/season wise

__Prioritization on the basis of Water quality parameters__

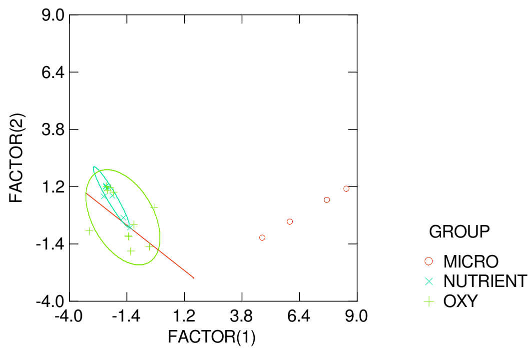
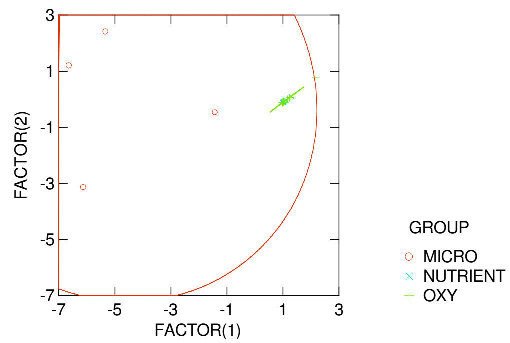
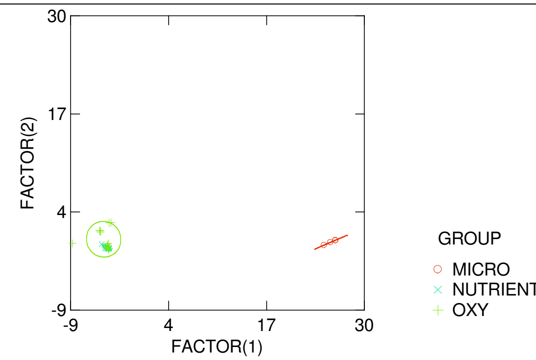
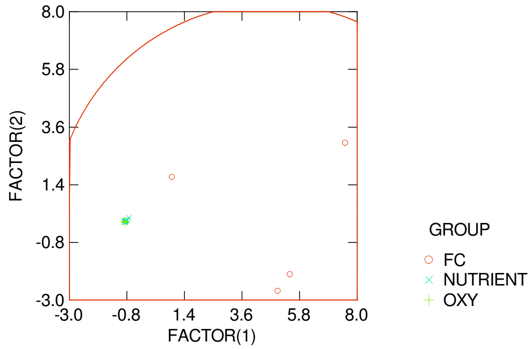
<table>
<tr><th>System</th><th>Phase 1</th><th>Phase 2</th><th>Phase 3</th></tr>
<tr><td>Creek</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Coastal</td><td>
</td><td>▪ No Significant classification</td><td>▪ No Significant classification</td></tr>
</table>

Fig 5.11 Classification using water quality parameters (for different surveys)

- During the second and third seasons, there is a significant shift towards the center and negative quadrants for the creek, sewage and freshwater stations, with freshwater stations shifting increasingly towards the left.

Observation of the results of the grouping on the basis of entire data set (Fig 5.10) for all the seasons indicate the following:

- The creek, freshwater and sewage stations have overlaps whilst being separated
- For creek stations, grouping on the basis of seasonal data show significant overlap whilst still being separately classified illustrating that the sampling has captured the most critical periods in all the seasons
- Alternatively it also indicates that the WLA for the creek system need not be based on seasons as the waters are severely polluted without options for recovery even during favorable seasons.

Grouping of the coastal stations vary significantly in time (seasons) and space (stations) showing a clear delineation and the necessity of time specific WLAs

Figs. 5.11 and 5.12 demonstrate the grouping / discrimination on the basis of water quality parameters measured in the creek and coastal locations collectively for all seasons and season wise respectively.

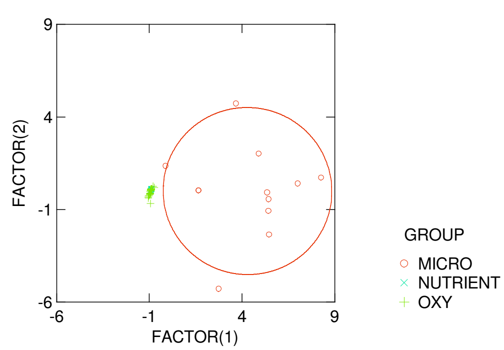
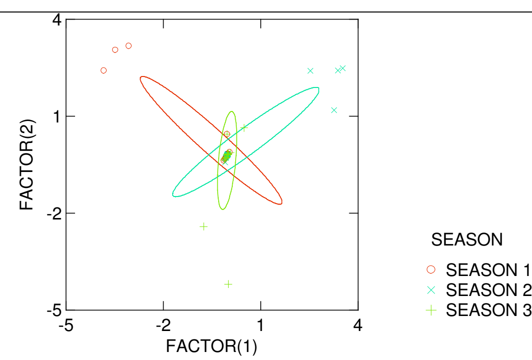
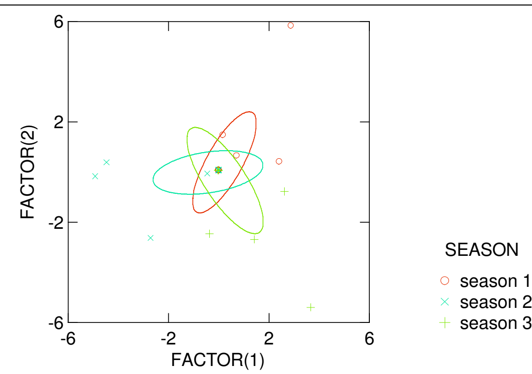
System	Parameters	Seasons
Creek		
Coastal	No significant separation	

Fig 5.12 Classification on the basis of complete dataset

- For coastal stations, the data sets are grouped on either side of season 2, while microbiological data (Fecal Coliform concentrations) are predominantly classified in comparison to negligible nutrient and oxygen concentrations. This demonstrates that Fecal coliform is a significant water quality issue in the coastal waters and needs to be addressed immediately. Therefore the first step would be to model Fecal coliform concentrations for the WLA
- For the creek system however, all seasons appear to overlap with data sets being scattered outside the groups. The classification using water quality measurements in the creek are not obtained as the canonical variables correlation of all the variables are 100% without significant separation. This demonstrates that the water quality problems in the creek are due to DO/BOD and nutrient related issues with further need to prioritizing them.

5.4.3 Results of Principal Component Analyses

Figs. 5.13 shows the results of factorization of the datasets carried out using Principal Component Analysis. The variables are loaded on three factors for both the systems. The factors have been interpreted by variables with high loadings on each of the factors. Together the three rotated factors explain more then 70% of the variance.

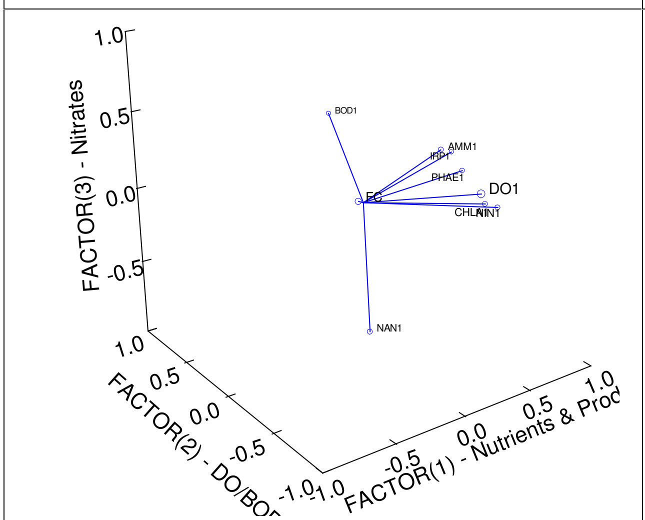
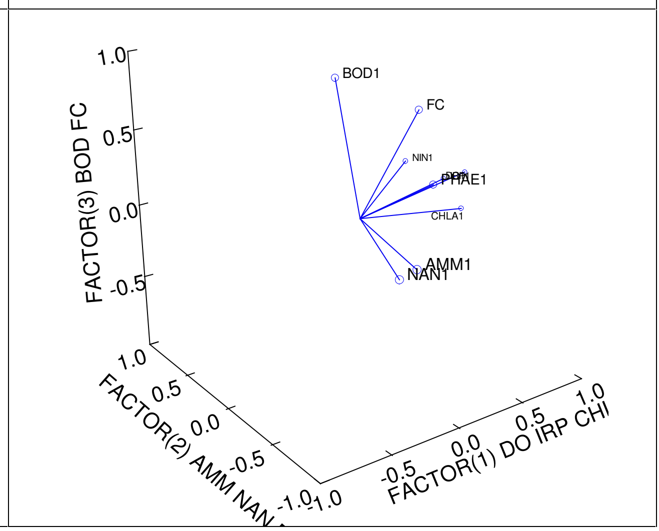
Creek Stations	**Coastal Stations**
	

Fig 5.13 **Factorization (of WQ parameters) using Principal Component analysis**

- For the coastal stations, BOD and FC load highly on Factor 3 and can be said to measure “sewage inputs”. DO/IRP and Chlorophyll-a load highly on Factor 1 while Nitrates and Ammonia load highly on Factor 2. This indicates that the immediate concern for coastal waters is the BOD/FC related issue, which needs to be modeled.
- For the creek stations, DO/BOD load high on Factor 3 and measure “Oxygen related issue”. Nutrients and productivity load highly on Factor 1 and can be said to measure “Growth”, while Nitrates load highly on Factor 3. This demonstrates that the creek related need to be handled in series of steps. The

first step would be therefore to model the BOD related issue, based on the results of which other nutrient related issues could be modeled.

The season wise factor analysis results are presented in Fig. 5.14

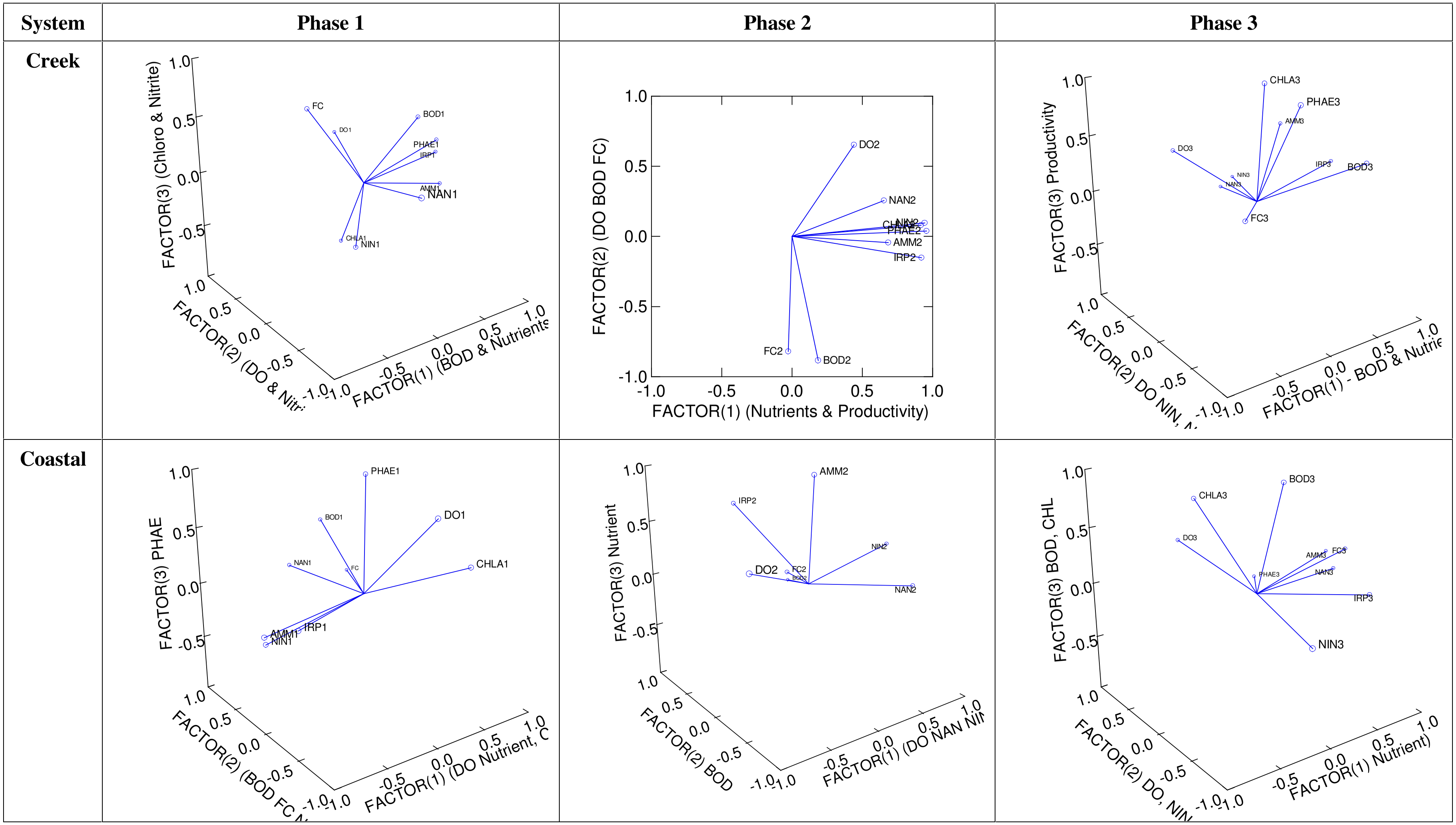


Fig 5.14 **Classification using PCA (Season wise)**

5.4.4 Biological classification

The creek stations were grouped season wise and station wise on the basis of macrobenthos data measured in the creek. The season 3 data is central to the measurements while the centroids of season 2 and season 1 are to the left and right respectively, indicating significant variations in seasons. Also the phytoplankton data classification indicates significant separation amongst locations and seasons as observed from Fig. 5.15.

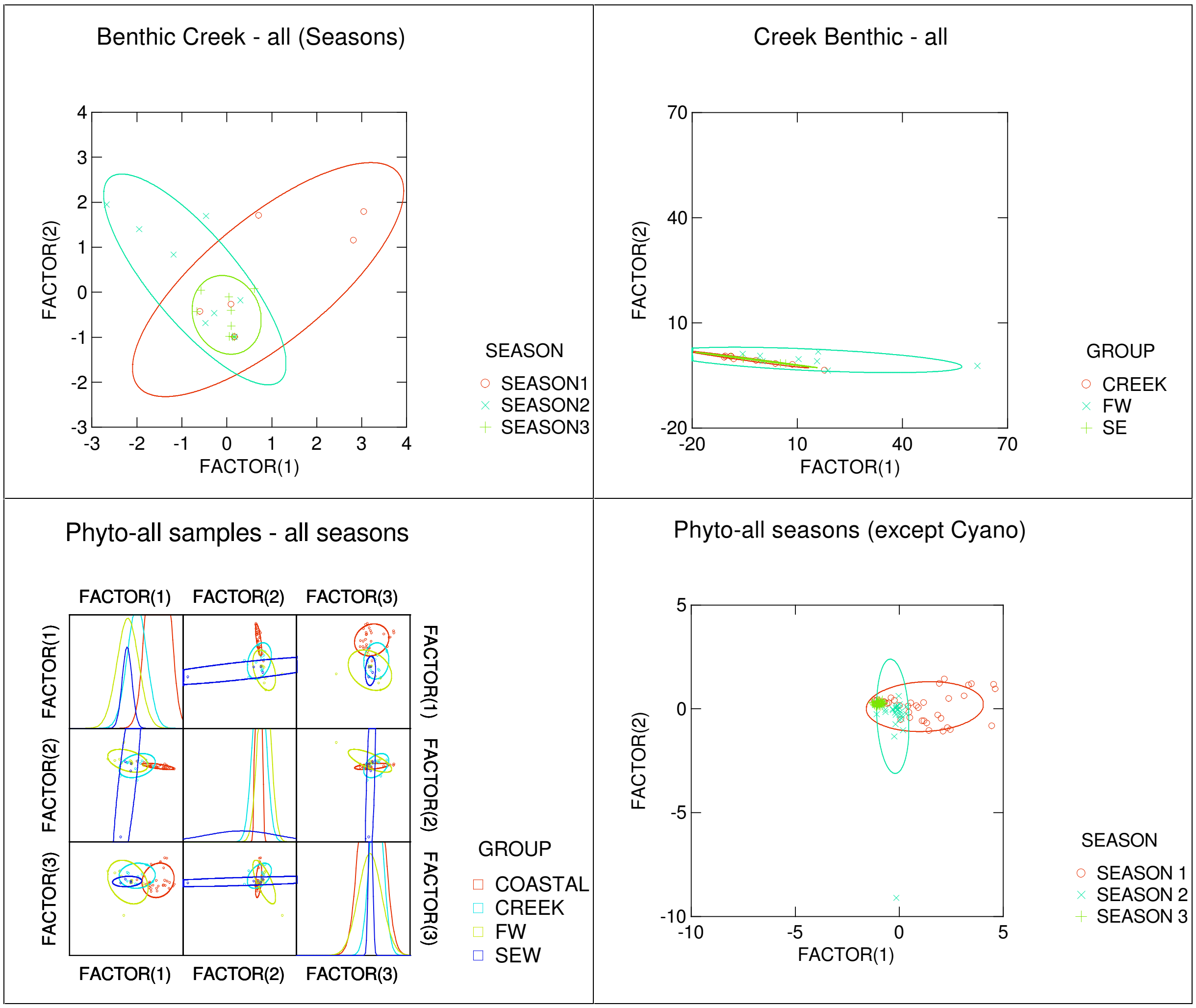


Fig 5.15 Classification using biological characteristcs

5.5 CONCLUSIONS

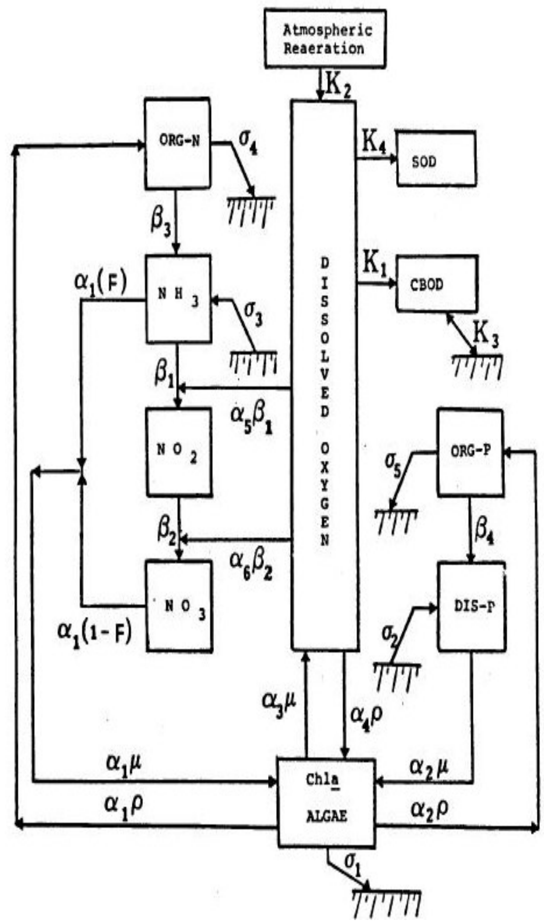
- While the highest input is from BUCS as a point source, the highest concentrations of pollutants are observed at ENC4 with a decreasing trend downstream. Given that the BUCS is the highest input, it implies that there are significant nonpoint sources in the upper reaches (as stated in the site description), which is not possible to quantify.
- Highest BOD signal is observed at ENC4, which however does not indicate sufficient inputs from upstream locations. This trend is corroborated by Ortho-Phosphorous concentrations and by Ammonia values except one anomaly at ENC3. The most likely reason is a source at ENC4.
- Analysis of biological characteristics suggest that the Ennore Creek stations ENC3 and ENC4 are heavily polluted due to excessive organic loading from untreated municipal waters from the Buckingham Canal and nutrient inputs from (fertilizer) industrial discharges from the Amullavoyal Canal.
- It is evident from the analysis of the biological characteristics of the system that the key issue is the presence of nutrients, while BOD and fecal coliforms are other major issues. This is further confirmed from statistical analysis of the datasets. For the coastal stations, Fecal Coliforms and BOD are the major issue, while for the Creek system, there is no significant difference amongst the concentrations of the various water quality parameters, indicating that the pollution levels in the creek are high in all aspects (BOD, Nutrients, Fecal coliforms). However, from the Principal Component Analysis of the entire dataset, the DO/BOD issue significantly separates out. Therefore the first step in modeling the creek system is to model DO/BOD as secondary treatment can remove BOD and fecal coliforms. Modeling of nutrients may be taken up based on the results of DO/BOD modeling, as removal of nutrients requires tertiary treatment.
- While secondary treatment would remove upto 30-40% of the nutrients, tertiary treatment of the waters is most essential for clean up of the system. However, the present use of the system does not warrant such high investments in tertiary treatment.
- The alternative to higher levels of treatment (involving high costs) would be to dispose of these nutrient rich waters sufficiently far away from the coast in deeper depths using marine outfalls.

6 EXPERIMENTS TO ESTIMATE KINETIC RATE COEFFICIENTS

6.0 DETAILS OF EXPERIMENTS

6.1 BACKGROUND

Dissolved Oxygen concentrations are increased by atmospheric reaeration and algal photosynthesis and decreased by sediment oxygen demand and algal respiration. Fig 6.1 shows the relationship between algal growth & production and DO.



N_1 = the concentration of ammonia nitrogen, mg-N/L

N_3 = the concentration of nitrate nitrogen, mg-N/L

N_4 = the concentration of organic nitrogen, mg-N/L

β_1 = rate constant for the biological oxidation of ammonia nitrogen, temperature dependent, day^{-1}

β_3 = organic nitrogen hydrolysis rate, day^{-1}

α_1 = fraction of algal biomass which is nitrogen, mg-N/mg-A

σ_3 = the benthos source rate for ammonia nitrogen, mg-N/ft^2-day

d = mean depth of flow, ft

F_1 = fraction of algal nitrogen uptake from ammonia pool

μ = the local specific growth rate of algae, day^{-1}

A = algal biomass concentration, mg-A/L

P_N = preference factor for ammonia nitrogen (0 to 1.0)

Fig 6.1 Major constituent interactions for DO

Experiments were conducted in the Ennore creek to estimate the rate coefficients of these parameters in tropical waters. Experimental determination of rate coefficients enables environmental management as decision-making is based on data obtained from site-specific parameters that provides confidence in predictions.

Experiments were conducted to determine rate coefficients for the following:

- Reaeration
- Sediment Oxygen Demand (SOD)
- Bacterial decay rate
- Photosynthetic and respiration rate

Analysis of available literature reveals that there are limited estimates of these parameters for tropical waters. In-situ experiments were carried out in the Ennore creek and in nearby coastal waters. A brief description of each of these experiments are given in the following sections

6.2 REAERATION COEFFICIENT

Reaeration is the process of oxygen exchange between the atmosphere and water. Wastes that are discharged to the water bodies consume oxygen during decomposition and cause depletion of oxygen below saturation level in the water bodies. The process of oxygen diffusion occurring simultaneously from atmosphere, called reaeration, nullifies this deficit. While decomposing organic matter in the water acts as primary sink for oxygen, reaeration and primary production by phytoplankton and benthic plants act as prime sources.

The rate of reaeration, under constant conditions of temperature and turbulence, is directly proportional to the oxygen deficit in water. The oxygen flux or rate of diffusion (D_{in}) of oxygen from atmosphere depends upon the degree of saturation of the inflowing water and is given by

$$J = K_L (C_s - C) \qquad \text{[Eq. 6.1]}$$

and the net rate of change of oxygen due to diffusion in flowing water is given by,

$$V [dC/dt] = KL\ A\ (Cs - C) \qquad \text{[Eq. 6.2]}$$
$$dC/ dt = K_2 (Cs - C) \qquad \text{[Eq. 6.3]}$$

where

J = oxygen flux ($g/m^2/day$); K_L = liquid film transfer coefficient (m/day),
C_s = saturation concentration of oxygen (g/m^3);
C = oxygen concentration in water (g/m^3);
K_2 = reaeration coefficient (K_l/H); H = water depth (m)

The exchange coefficient, K_L is more fundamental measure of the rate of reaeration, which has the dimensions of a mass transfer coefficient (LT^{-1}). The magnitude of K_L (and thus K_2) is influenced by internal turbulence that acts to reduce the thickness of the diffusion layer.

Some equations used in the river and estuarine environments are listed in Tables 6.1 and 6.2.

6.2.1 Purpose

- To determine reaeration coefficients for shallow tidal waters of the Ennore Creek and compare it with reported values (from literature) in order to check its suitability for DO modeling of tropical waters
- To incorporate estimated values of reaeration coefficients in water quality models and use them for the WLA studies

6.2.2 Procedure

Simultaneous measurements of DO, temperature, salinity (using YSI probe) and velocity (using floats) at a pair of locations in the Ennore Creek were carried out.

- Studies were carried out in the Kosasthalaiyar segment (Kosasthalaiyar river mouth to Kosasthalaiyar Bridge) and the Buckingham Canal South (BUCS mouth to ETPS) segment of the Ennore Creek.
- The segments chosen were away from discharge points and had more or less uniform cross sections so that homogeneous flow conditions and hence uniform characteristics with regard to oxygen balancing mechanisms could be assumed during the study period.
- Assuming uniform flow conditions along the reach, the slope of the energy gradient line is equal to the slope of the channel bottom. Under uniform flow conditions the flow takes place under the datum head difference (difference in tide heights), pressure and velocity heads being zero for the reach.
- Slopes were determined using Manning's equation for the measured values of velocity and channel characteristics. The slopes calculated were corroborated using the tide data obtained from tide gauges deployed along the creek. The tide heights plotted against time were overlapped for different stations along the stretch from which tidal height difference was estimated. The slope of the gradient line was obtained by dividing the tidal height difference by the distance between the two stations
- The longitudinal dispersion coefficient of a creek is an indicator of turbulence intensity and is found using salinity as a tracer of the tidal mixing. Salinity data was obtained at various distances upstream from the creek mouth and the dispersion coefficient was obtained using the equation ( ) [Thomann & Mueller]

  $$S = S_o \, EXP\,(U X / D_L) \qquad \text{[Eq. 6.4]}$$

  $$\ln (S/S_o) = (U/D_L)\, X \qquad \text{[Eq. 6.5]}$$

  where

  S = salinity in ppt on the upstream side at any distance 'X'm,

  S_o = Salinity at the creek mouth, ppt,

  U = Velocity of flow, m/sec

  D_L = Longitudinal dispersion coefficient, sq. m/sec

  X = distance from the creek mouth, m;

- Dissolved oxygen values were measured prior to sunrise and after sunset and plotted against time to estimate the coefficient. In addition diurnal dissolved oxygen data collected from the fixed stations during 48 hour sampling for the current waste load allocation program was used in the estimation of the coefficient.

6.2.3 Results & Discussion

Existing conditions of the creek such as negligible fresh water inflows and variation of tidal influx due to partial closure of creek mouth, wastewater inputs through Buckingham Canal were reflected in the irregular variations in measured Oxygen concentrations. As a result only limited data from few stations along the creek was considered for evaluating the shape of the Oxygen curves during the 48-hour sampling program. Table 6.3 gives a summary of the experiments carried out in the Ennore creek and Fig 6.1 shows the comparison of observed and predicted values.

- The rate coefficients for the creek were found to be varying between 0 and 1 (day^{-1})
- Comparison of observed and predicted reaeration coefficients from various formulae revealed that predicted rates were significantly higher.

Table 6.1 **Selected equations derived for 'river' environments**

Eq. Code.	Equation	Depth range (m)	Velocity range (m/s)	REFERENCE
	$K_2=3.9\ U^{0.5}H^{-1.5}$	0.3-9.1	0.15-0.49	O'Connor and Dobbins
	$K_2=5.01U^{0.969}/H^{1.673}$	0.61-3.4	0.55-1.5	Churchill et. Al.
	$K_2=5.35U^{0.67}H^{-1.85}$	0.12-0.73	0.030-0.55	Owens et al.
	$K_2=15200(SU)$	0-0.91	Any	Tsivoglou and Wallace et. al.
	$K_2=543xS^{0.6236}U^{0.532}/H^{0.7258}$	0.05-2.0	0.1-1.5	Smoot et al.
	$K_2=1740U^{0.46}S^{0.79}H^{0.74}$	0.2-1.2	0.01-1.7	Moog and Jirka

K_2(/day) Reaeration Coefficient, U (m/sec) Velocity, H(m) depth, S(no units) Slope

Table 6.2 **Equations for 'estuarine' environments**

Eq. Code	Equation	REFERENCE	DESCRIPTION
7	$K_2(day^{-1})=(D_m x\ U_o)^{1/2}/H^{3/2}$	O'Connor (1960)	U_o = mean tidal velocity over complete cycle, m/day D_m = molecular diffusivity of oxygen, m^2/day H = average depth, m
8	$K2=\frac{13Ut0.5}{H^{1.5}}+\frac{3.281}{H}\left[0.728V_w^{\ 0.5}-0.317V_w+0.0372V_w^{\ 2}\right]$	Thomann and Fitz Patrick (1982)	V_w = wind speed, m/sec H = depth, feet U_t = depth averaged velocity, fps
9	K_2(/day) = 4 .56$U_t^{4/3}$/H	Yasar F. Ozturk (1979)	U_t = tidal velocity, m/sec H = av. Depth, m

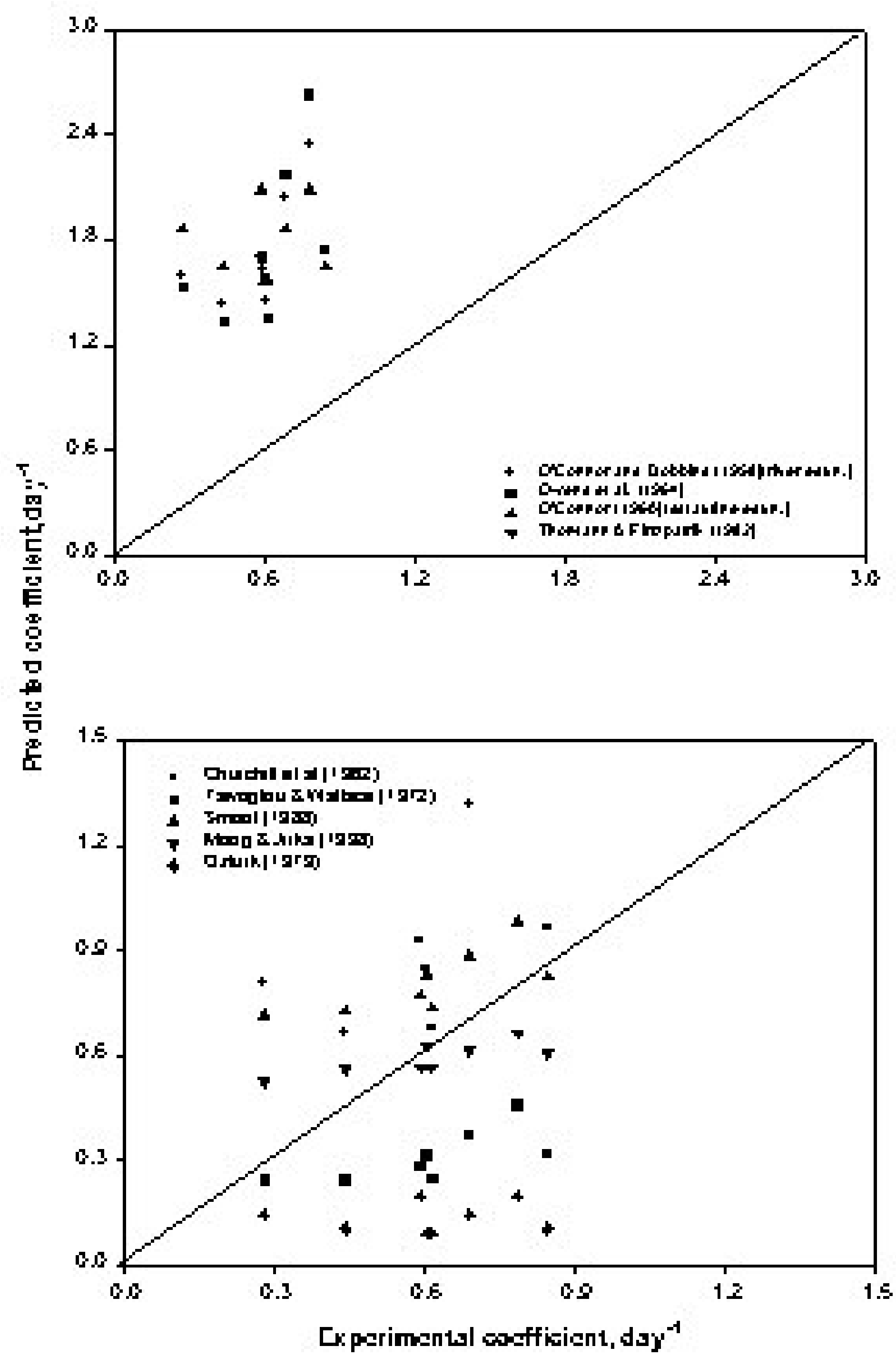


Fig 6.2 Comparison of observed and predicted reaeration coefficients

Table 6.3 Summary Ennore creek reaeration coefficient experiments

Station	No. of Trials	Velocity range (m/sec)	Depth range (m)	Reaeration* (K_2, Day^{-1}) @20^{o}C		Comparative values*(k_2, Day^{-1}) At 20^{o}C								
				Trial I	Trial II	1	2	3	4	5	6	7	8	9
KSTM	2	0.101-0.35	0.89-1.26	0.29	0.59	1.0-2.2	0.5-2.2	0.9-2.7	0.1-0.9	0.4-1.12	0.2-1.08	1-2.5	0-0.25	3-4.51
KSTB	2	0.168-0.354	0.84-1.06	0.68	0.78	-	-	-	-	-	-	-	-	-
BUCS	2	0.121-0.29	0.6-0.92	0.61	0.84	1.2-1.9	0.45-2.3	1.1-2.4	0.1-1.0	0.4-1.0	0.2-1.1	1-2.5	0-0.25	3-4.5
ETPS inlet	2	0.112-0.25	0.55-0.84	0.44	0.61	-	-	-	-	-	-	-	-	-
CR1	2	-	-	0.8511	0.511	-	-	-	-	-	-	-	-	-
CR2	2	-	-	0.963	0.127	-	-	-	-	-	-	-	-	-

Reareation*(K_2, day^{-1}) Odum's method

Comparative values 1. O'Connar and Dobbins (1958)(equation No.1), 2. Churchill et al.(1962) (equation No. 2) 3. Owens et al.(1964) (equation no. 3), 4. Tsivoglou and Wallace (1972) (equation No.4), 5. Smoot (1988) (equation No. 5), 6. Moog and Jirka(1998) (equation No. 6), 7. O'Connor (1960)(equation code 7), 8. Ozturk(1979)(equation code 8), 9. Thomann and Fitzpatrik(1982)

6.3 SEDIMENT OXYGEN DEMAND (SOD)

Sediment Oxygen Demand (SOD) may be defined as the oxygen demand by the bottom sediments from the overlying water due to oxygen consumption. Oxygen depletion can occur in nutrient-rich relatively shallow coastal waters where SOD is substantial and therefore SOD is a critical parameter in water quality models and can be a significant component in the DO budget of the overlying waters (Thomann and Mueller 1987). Marine sediments can impose severe impact on DO and nutrient concentrations (Whittemore 1986).

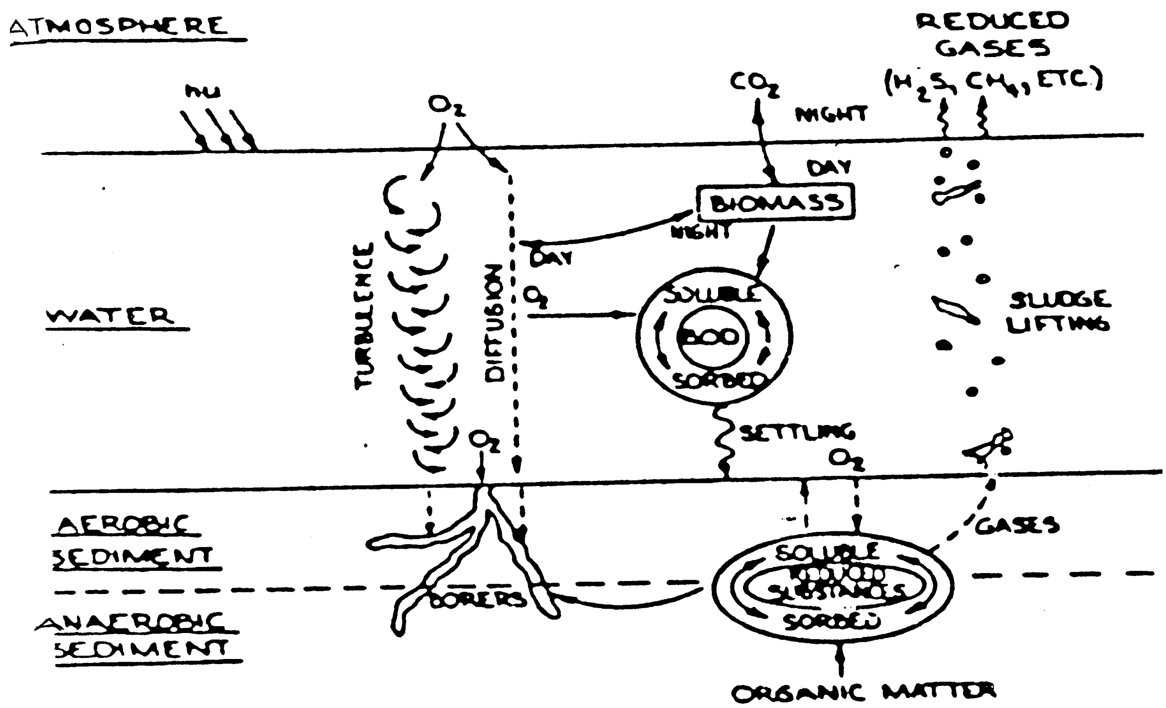


Fig 6.3 Schematic diagram of oxygen utilisation process by sediments

Fig. 6.2 (Preston *et al.*, 1980) describes the influence of different processes on benthic oxygen demand. The first is the rate at which oxygen diffuses into the bottom sediments. This is governed predominantly by molecular diffusion. In addition gas production from organic rich deposits may cause further disturbances of the sediments via sludge lifting thereby increasing oxygen demand in the water column.

6.3.1 Purpose

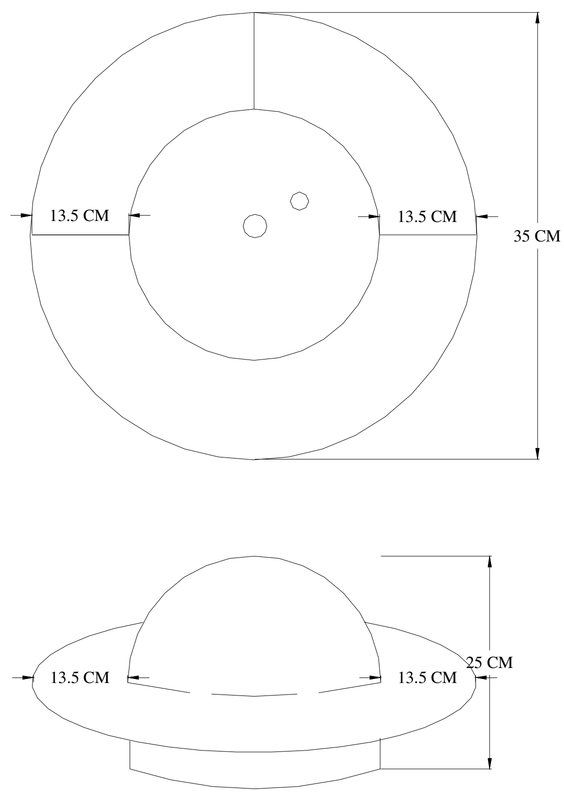
- To determine SOD demand rate in Ennore Creek and compare it with reported values (from literature) in order to check its suitability for DO modeling of tropical waters
- To incorporate estimated values of SOD in water quality models and use them for the WLA studies

6.3.2 Equipments & instruments

Test Chamber

The test chamber is an opaque Plexiglas respirometer consisting of a hemispherical dome of diameter of 39.5cm. The dome isolates a volume of 15.4 liters and covers the bottom sediment area of 0.1453 square meters. Two small openings with a diameter of 2cm are made on top of the dome for inserting DO probes and removing entrapped air. A sketch of the SOD is shown in Fig 6.3

Fig 6.4 Sketch of SOD test chamber



A flange plate of width 13.5 cm is fixed around the dome at a height of 7.6cm form the lower edge of the cylinder. This flange could prevent the chamber from excess sinking into the sediments. The extension of the chamber into the sediments prevents the transfer of interstitial water in and out of the area beneath the dome and also provides a seal for the chamber. Two mouthpieces with a diameter equivalent to silicon rubber tubing (8mmx11mm) were provided in the dome for suction and delivery. Circulation within the dome is accomplished with a 12 VDC peristaltic pump.

DO meter

Calibrated multi-parameter probe (YSI 85) with sufficient cable to reach the sediments and capable of measuring DO with a precision of 0.01mg/L was used. This meter measures water temperature to a 0.1^{o}C reading.

Boat and supplies

Boat was used to deploy and retrieve the apparatus and to conduct readings (Fig. 6.3). In order to install and inspect the chamber certified divers also conducted limited diving operations.

Fig 6.5 View of SOB chamber deployment

6.3.3 Procedure

Measurements of SOD were made in the Ennore Creek and other backwaters of Chennai, i.e., Adayar and Muthukadu to provide an understanding of the water quality and parameters that can be used for developing numerical water quality model for the system.

The experiments were conducted in different sediments such as 1) muddy bottom: 2) sandy bottom and 3) organically enriched bottom sites and measurements were made continuously for 2 hours (Cadwell 1994). Rapid decrease in DO within the chambers was occasionally noticed in the first 5 to 10 minutes of the assay. This was attributed to the slight disturbances of the bottom sediment caused by deployment of the SOD chambers and thus not used for SOD estimation. Oxygen consumption data was plotted against time and the slope of the oxygen depletion line is used to calculate SOD from equation 6.1

$$SOD = 1.44\ [V/A]\ b \qquad [Eq.\ 6.6]$$

Where

SOD is the Sediment Oxygen Demand rate in g/m^2day

b is the slope of oxygen depletion curve in mg /lit/min

V is the volume of the chamber in litres

A is the area of the chamber in sq. meters

1.44 is a units conversion constant

Measured SOD were corrected to 20°C using the equation

$$SOD_{20} = [SOD_T / 1.065^{\ T-20}] \qquad [Eq.\ 6.7]$$

Where

SOD_{20} is the Sediment Oxygen Demand rate at 20oC temperature

SOD_T is the measured SOD at ambient temperature

1.065 is the temperature correction coefficient (Thomann & Mueller)

6.3.4 Results and discussion

Experiments were conducted at 25 locations, of which 19 were in the Ennore Creek, 3 were in Adyar River and backwaters in Muthukadu. Temperatures ranged between 27.5 and 32°C when the experiments were conducted. Fig. 6.5 gives the SOD in the different water systems.

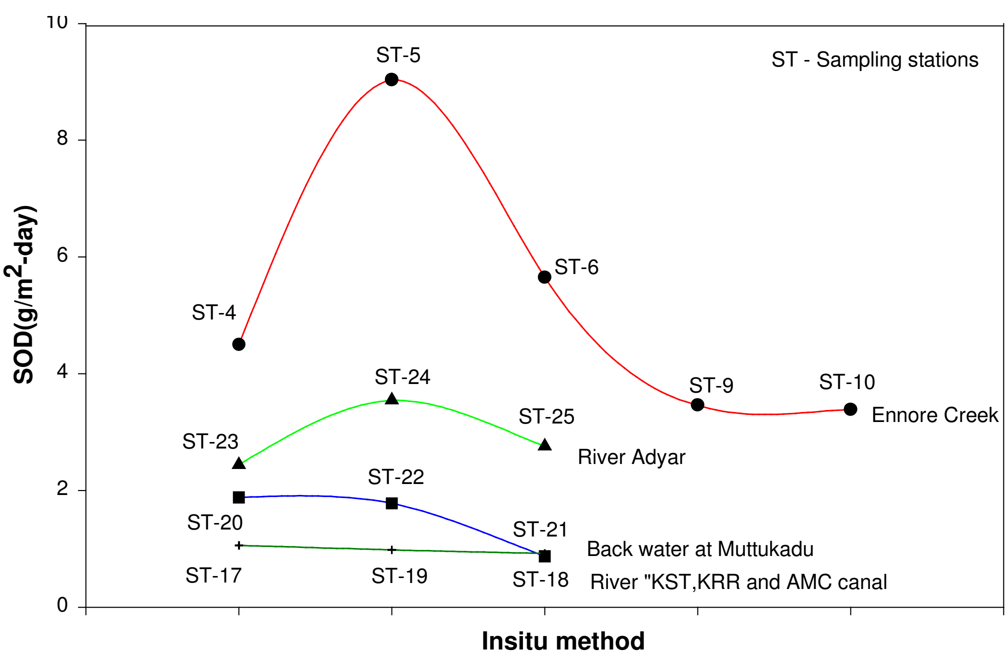


Fig 6.6 SOD uptake in the different water systems

- The observed uptake rate ranged from 0.19 to 9.03 g/m^2-day in the Ennore Creek. The highest uptake rate observed at the railway bridge is attributed to the untreated/treated municipal effluents from the Buckingham Canal as was observed by the high organic content in the sediment.

- SOD rates of 1.06, 0.92 and 0.98 g/m^2-day were observed at location in the Kosasthalaiyar, Korattaliyar Rivers and Amullavoyal canal respectively.
- It was found that the experimental results agreed well with values reported in literature

6.4 BACTERIAL DECAY RATE

Modeling of coliforms is essential for establishing the level of fecal pollution and potential pathogen contamination of the receiving waters. Environmental conditions determine the extent to which coliform regrowth or death can occur. Factors have been classified into physical, physicochemical and biochemical-biological by researchers (Kapuscinski & Mitchell – 1980 and Bitton – 1980). Table 6.4 gives the factors list

Table 6.4 Factors affecting bacterial decay rate

Physical	Physico-Chemical	Biochemical-biological
Photo-oxidation	Osmotic effects	Nutrient levels
Adsorption	pH	Presence of organic substances
Flocculation	Chemical toxicity	Predators
Coagulation	Redox potential	Bacteriophages
Sedimentation		Algae
Temperature		Presence of fecal matter

- According to Chamberlin and Mitchell, light is one of the most important factors and significant relationships between light intensity and coliform disappearance can be demonstrated. While viruses and enteric bacterial pathogens are sensitive to light, viruses are generally less sensitive than coliforms (Sieracki - 1980, Kapuscinski & Mitchell –1983. Lantrip – 1983)
- It is found that survival rates of E.coli are inversely proportional to salinity in seawaters. In general E.coli have been found to survive longer in lower pH salt solutions (pH<8) than under alkaline conditions
- When coliforms undergo transition from the generally low oxygen environment of sewage to the higher oxygen levels found in seawater, the oxygen shock promoted rapid decay (Kott – 1982)

Several researchers have traditionally used s simple first order kinetics approach for coliform modeling, which can be represented by the following equations.

$$\frac{dc}{dt} = -kC \quad \text{[Eq.6.8]}$$

or $C_t = C_o\, e^{-kt}$ [Eq.6.9]

where

C – coliform concentration, MPN or count/100ml
C_o – initial coliform concentration, MPN or count/100ml
C_t – initial coliform concentration at time t, MPN or count/100ml
k – disappearance rate constant, day^{-1} or hr^{-1}
t – exposure time, days or hours
Total decay rate R = average decay rate at night time + decay rate due to sunlight

6.4.1 Purpose

- To determine bacterial decay rate in Ennore Creek for (a) comparing it with reported values (from literature) in order to check its suitability for coliform modeling of tropical waters and (b) generate site specific data.

6.4.2 Procedure

- The experiment was conducted in 0.025 mm clear polyethylene bags with the mouth area being approximately 0.08 m^2.
- The outer rigs were tethered to bouys and the bags were filled with 50 litre natural water.
- Wastewater with coliforms from the Royapuram sewer system filtered through glass wool and stored in 4^oC was used. Wastewater was added to the bags until the E.coli concentration was approximately 10^4 colonies per 100 ml.
- Samples were collected every hour for 15 hours. Light penetration was measured using secchi disc (depth at which the secchi disc disappears).
- Other variables like pH, salinity, dissolved oxygen, chlorophyll content were measured using standard methods. The light intensity in terms of MJ/m^2 was obtained from the meteorological laboratory adjacent to the study area. The bacterial density at different hours was plotted against time and is given in Fig. 7.1.

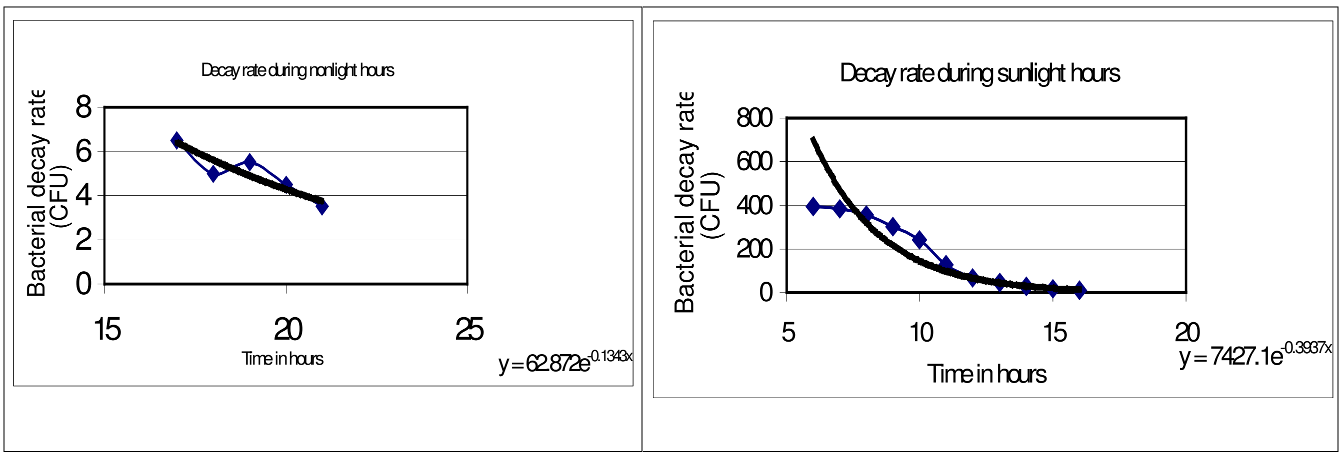


Fig 6.7 Bacterial decay rate during nonlight and sunlight hours

6.4.3 Results and discussion

- In general bacterial decay rates are found to be uniform during nonlight hours and increase with increase in sunlight intensity.
- From the study, the total decay rate has been estimated as 0.38767 (day^{-1})
- Measured decay rates were corrected to 20^oC using the equation

$$k_{20} = [k_T / 1.07^{T-20}] \quad \text{[Eq. 6.10]}$$

Where

k_{20} is the decay rate at 20^oC temperature

k_T is the measured decay rate at ambient temperature

1.07 is the temperature correction coefficient (Thomann & Mueller)

- Therefore the decay rate at 20^oC has been estimated as 0.1721(day^{-1})

- The observed decay rate for Ennore Creek compared well with values from literature. Range of E.coli decay rate has been specified as 0.08-2.0(day^{-1}) for seawater (Thomann & Mueller). In-situ measurements of coliform bacteria decay rates in freshwaters indicate variation between 0.21 and 26.4 ((day^{-1}) at different locations (Mitchell & Chamberlain 1978, Bowie *et al*).

7 MODELING – ENNORE CREEK

7.0 MODELLING APPROACH

The study area has two distinct areas – the Ennore creek and the coastal area. The choice exists for modeling both systems together or modeling each independently. This decision was considered important, as the flexibility of the modeling is higher if the systems are modeled separately, where the coastal waters can be modeled with a 2-dimensional model, while the creek could be modeled with a 1-dimensional model. If the two systems are to be modeled together, the grid size for a 2-D rectilinear grid model becomes critical , with computational time increasing.

For modeling both systems together, the water quality of both systems need to be influenced by each other. If the creek input variations to the coastal water shows little influence on coastal water quality, and if the coastal water quality at the entrance to the creek is not influenced by the coastal water wastewater discharges, the two models can be separated, where the creek model can be assigned a constant water quality value at the open boundary connected to the coastal waters.

The data interpretation indicates that CST8, representing the boundary water quality to Ennore creek is relatively similar to CST9 and CST10, i.e., offshore stations representing background water quality. This implies that the Ennore creek water has negligible impact on coastal waters and also that the coastal water effluent discharges will not impact the boundary condition water quality to the creek.

Thus, it is possible to delink the two areas Ennore creek and Ennore Coastal waters and model them as two separate areas. This approach was discussed with Limnotech, Inc (LTI), USA, consultants to ICMAM, during a visit to LTI. LTI was represented by Dr. David Dilks, Mr. Scott Dierks and , who agreed with the approach. Thus the models were setup from Ennore creek and coastal waters separately.

7.1.1 Water quality Issues

The main water quality issues considered for modeling were:

- Salinity
- BOD
- Fecal Coliforms

7.2 CREEK MODELING - EVALUATION OF MODELS

Given that the project is principally capacity building for the coastal environmental management community and for regulatory agencies, the choice of the model had to consider scientific representation of the processes, cost and user friendliness of the software package. Amongst the well-tested and referenced public domain (free) box models/one-dimensional models, USEPA's WASP5 and the CE-QUAL-WL model are highly referenced in literature. Significant effort was spent on modeling with both these models. WASP5 suffered from primitive hydrodynamics, poor documentation, poor user friendliness and negligible support from a user's perspective. The user would also need to have software and water quality kinetics expertise. Given that the research and higher education community in the country do not use such a model in their curriculum and that water quality modeling is relatively new to the regulatory and environmental research community, it is anticipated that the regulatory bodies may be not adapt to this system easily. However, the use of model like WASP5 must be encouraged in the curriculum as it provides a strong foundation in water quality modeling.

The US Army Corp of Engineers model CE-QUAL-WL is essentially a two dimensional model, but adopts a unconventional approach of a lateral averaged model with variations in the vertical and longitudinal directions. This model was expected to be well suited for estuaries and creeks, where mudflats and wetting-drying processes could be modeled efficiently. However, this model suffers from the similar lacunae of WASP5 with poor documentation, poor user friendliness and no support. A commercial user interface developed for CE-QUAL-WL by JE Edinger was also tested and was found to be difficult to use with the documentation provided.

Finally, NIOT settled for one of the best-known commercial models – Danish Hydraulics Institute's MIKE 11.

7.2.1 MIKE 11 Model Description

In rivers with relatively narrow cross-sections the flow may be assumed to be nearly one-dimensional. The effect of three-dimensional flow phenomena can be taken into account by numerical parameters using MIKE11, which is considered appropriate in such kind of numerical, tidal simulations.

MIKE11 is a one-dimensional modeling tool for simulation of flows, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies. Modeling is primarily carried out by dividing the rivers/streams into several segments, each of which are completely mixed. Transport of chemicals and water through the segments is by advection and dispersion.

The hydrodynamic (HD) module uses an implicit, finite difference computation method for modeling of unsteady flow in rivers and estuaries. This allows the model to be applied to branched networks, looped networks, and quasi two-dimensional flow simulations, such as for overbank flood plain flows. The computational methodology assumes a vertically homogeneous flow condition. Both sub critical and supercritical flow can be modeled with a numerical scheme that adapts according to the local flow conditions, allowing both steep river flows and tidally influenced estuaries to be simulated within the same model.

The advection-dispersion module is based on the one-dimensional equation of conservation of mass. This approach requires that the substance be completely mixed over the cross sections. The dispersive transport is assumed proportional to the concentration gradient. Simulation of behavior of conservative materials can also be carried out. The advection-dispersion equation is solved numerically using an implicit finite difference scheme, which has negligible numerical dispersion.

Characteristics of model

- Determination of locations of flooding
- Prediction of long-term environmental impact by changing pollution loadings
- Assessment of morphological changes in the river system by determination of locations of sediment deposition
- Estimation of peak concentrations of pollutants at specific locations

7.3 MODEL SETUP

7.3.1 Bathymetry and model network

In general, each bathymetry cross-section measured during this survey was used to set up the model segments. The segments are setup as link-node system, where the segment characteristics such as volume, length and depth are defined by the bathymetry at the two nodes at the end of each segment along with the geographical coordinates.

The width of the Ennore Creek varies from about 200m at the mouth to about 500m at KST/BUCN confluence and narrows down to less than 50m towards Amullavoyal canal. The average depths ranges were found to vary between 1.0m and 1.5m and therefore the one-dimensional model was found to be the most suitable for application. Fig 7.1 shows cross section at the mouth during each of the surveys and Fig 7.2 shows model network for the Creek.

The change in the bathymetry between each sampling period is limited to the mouth region and is a function of the accretion at the bar mouth and the capacity of the dredgers to keep up with the accretion. While the mouth was approximately 150m wide in February 1999 when the bathymetry survey was done, the open was almost fully closed during the May and December 1999 surveys. Since bathymetry details were not available during this period, various mouth openings were tried such that the tide and currents could be reasonably simulated.

7.3.2 Boundary Conditions

Tide

The principle source of water to the creek is through the Ennore creek mouth. The other major source is the Pulicat Lake through the Kosastalliyar backwaters. Both of these are tidally influenced. The Ennore creek mouth can be defined by the Chennai Tide, while the Pulicat Lake input may be defined as a dampened signal of the Chennai tide, assuming that the tidal variations are almost similar between Chennai and Pulicat Lake mouth. This boundary condition at Kosastalliyar needs to be established during the calibration process, given that tide gage readings were not available on the Kosastalliyar. The Chennai Tide data is available for high and low tides only. This data was interpolated for 15 minute intervals (based on the requirement for the model time step) using a Cosine function.

Freshwater inputs

The two sources of freshwater inputs are from the main stem of the Koratalliyar River and from the Red Hills reservoir surplus through the Amullovoyal canal. The PWD records were used to define these imputs. However, it is noted that the PWD data are from further upstream of the model boundaries and sub surface groundwater flow may be an additional input. To define this quantity of subsurface flows, salinity has to be used for calibration. The discharge quantities from the PWD records are presented in Table.

Wastewater inputs

The major wastewater inputs to the Ennore creek come from the Buckingham Canal South and from the industrial sources along the Amullovoyal Canal. The Buckingham canal water quantity and quality is defined based on measurements at BUCS. The Amullovoyal canal inputs are provided based on the measurements at the point sources and the measurements at Amullovoyal canal.

After October 1999, the NCTPS discharge location was changed from an offshore discharge to discharge in the Buckingham Canal North (Fig 2.4). This arrangement was suggested by CWPRS to NCTPS to meet its water requirements due to lowered inflows into the Creek caused by accretion of Ennore creek mouth. In addition, the NCTPS effluent channel on the coastal water side was also getting choked due to the accretion as result of Ennore Port construction.

Water Withdrawals

Withdrawals are due to ETPS and NCTPS, which used to subsequently discharge the cooling waters into the coastal waters. The withdrawal quantities from ETPS and NCTPS are m^3/s and m^3/s respectively.

Table 7.1 Boundary conditions for modeling

Boundary	Description	Data	Assumption
Creek mouth	Tide and water quality input from open ocean	Tide data from Indian Tide Tables, water quality from CST8	Limited inter-dependence of water quality between coastal and creek waters
Kosastilliyar	Backwaters from Pulicat. Tidal or steady	Calibration Parameter	Boundary condition function of levels in Pulicat Lake, for tide and water quality
Koratillayar	Freshwater from Thamaraipakkam	PWD data at anicut	No losses or sources between Thamaraipakkam and KRR station
Amullavoyal canal	Surplus water channel for Red Hills	PWD data from Red Hills	No losses or sources between Red Hills and AMC
Buckingham canal – South	Interceptor canal for wastewater discharges from North Chennai and Manali	Water quality info and secondary data. Calibration parameter	BUCS water quality represents the combined quality of industrial and municipal sources
Buckingham Canal – North	Leading to Pulicat Lake. Minimal inflow due to blockage	No data	Assume zero flows due the bund made by NCTPS

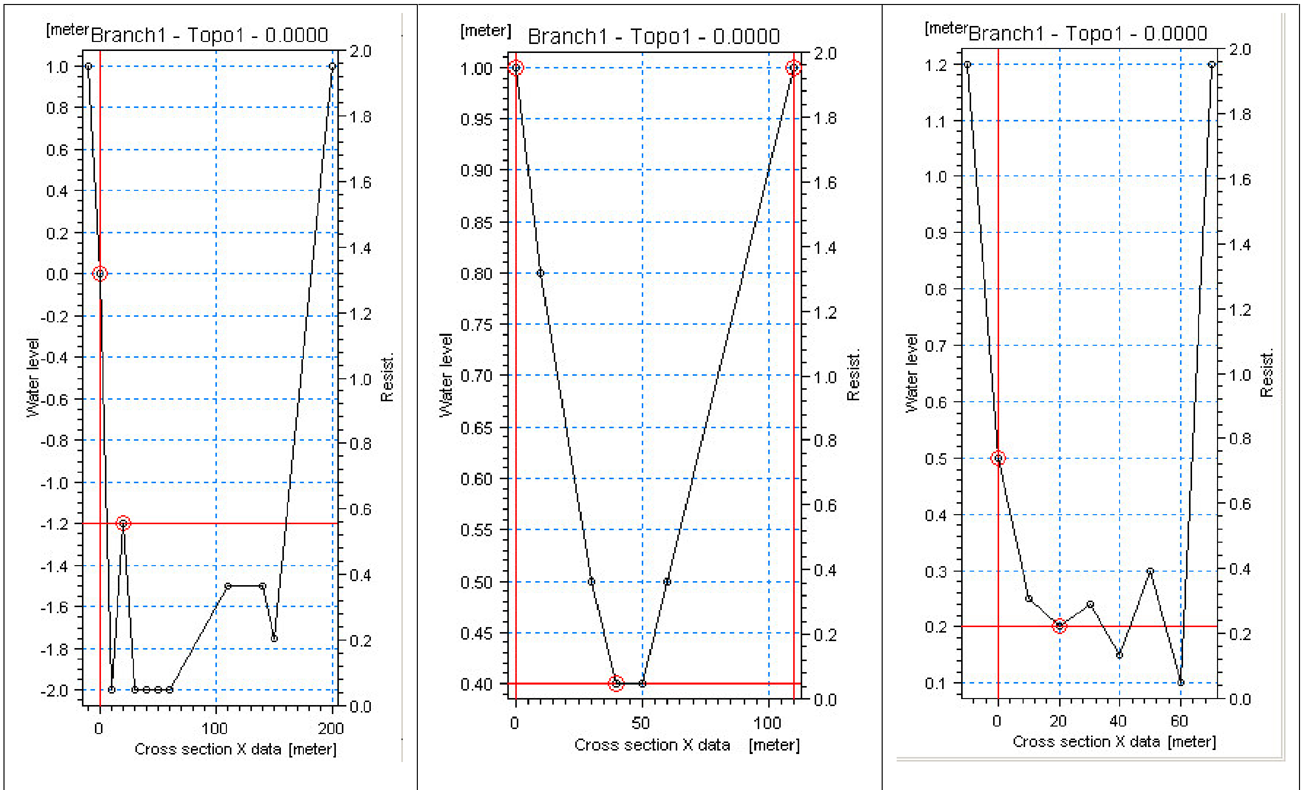
Therefore Kosasthalaiyar River input into the Creek was fixed by dampening the Chennai tide to 30% after several trials. The effect of KST was determined for the May 1998 data (with mouth closed) and calibrated for the other two surveys.

7.3.3 Model Inputs

Salinity, BOD and Fecal coliform concentrations at ENC1 (Creek mouth), BUCS (Buckingham Canal South) and AMC (freshwater boundaBoundary conditions are summarized in Table 7.1.

7.4 MIKE11 MODELING

7.4.1 Calibration and Validation



February 1999	May 1999	December 1999

Fig 7.1 Cross section of creek at the mouth

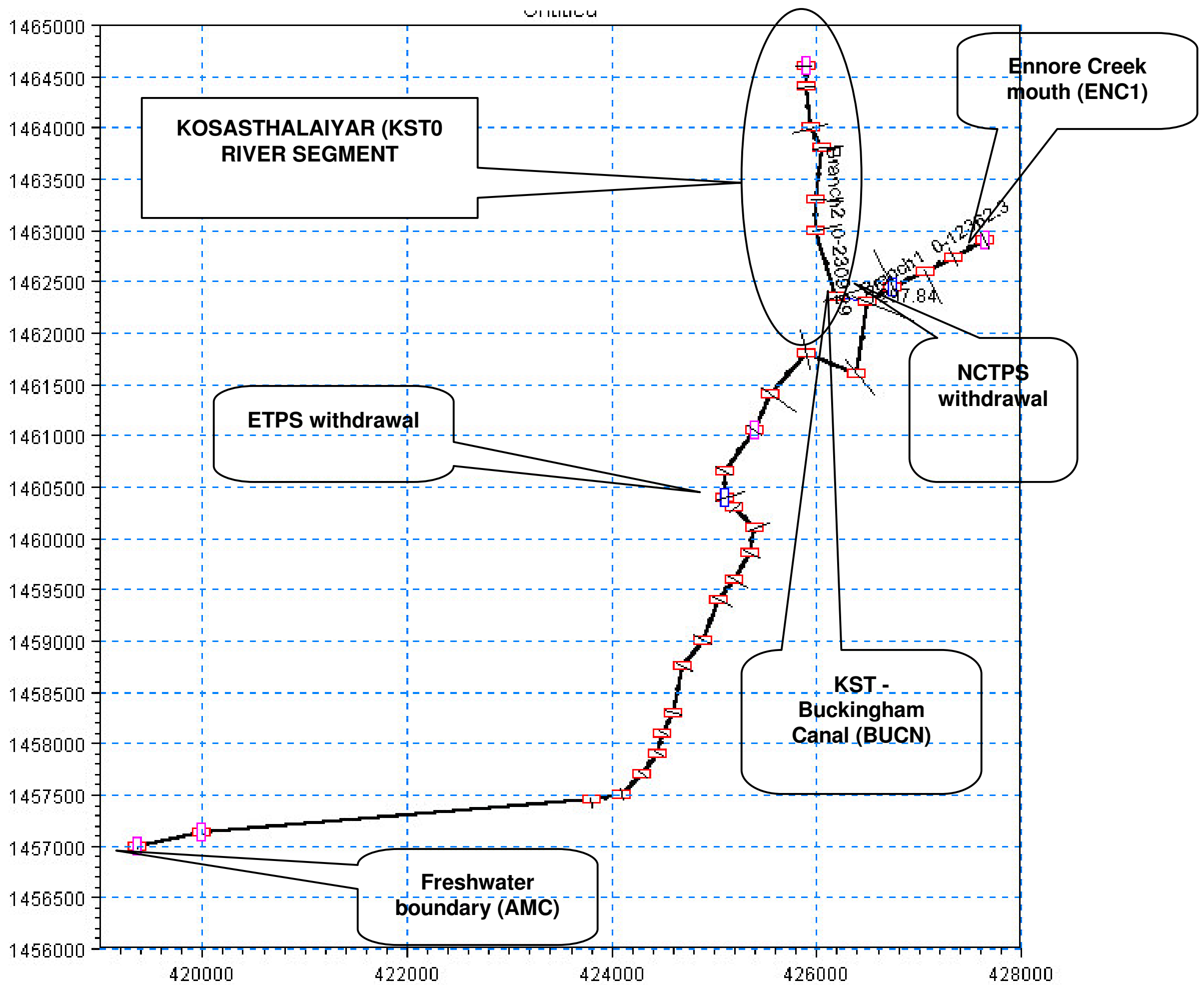


Fig 7.2 Model network for the creek using MIKE11

Hydrodynamics

The first task of modeling is to establish the flux of water, which translates to modeling of tides and velocities. In Ennore creek, modeling was challenged by the change in Ennore creek mouth and the unknown relationship with Kosastalliyar and Pulicat Lake. During the design of the study, the Kosastalliyar relationship was considered to be a calibration parameter, where the relationship with Chennai could be established with one survey and tested with the other two surveys. This design consideration was maintained by calibrating the tide and currents for the February survey with the bathymetry defined as measured, while the amplitude of the tide was varied as a factor of the Chennai tide at Kosastalliyar. This factor was 0.3 times the Chennai Tide as shown in Figure .

For the May and December validation surveys, the factor of 0.3 was retained, while the creek mouth bathymetry was used as a calibration parameter. The sensitivity of the 0.3 factor and the various creek openings were tested throughout the modeling of the water quality parameters. The important point to note is that the model would be tested for its performance for a variety of conditions, starting from a open creek mouth to a fully closed creek mouth.

The model gave best results for February 1999 data, when the unknown factors are limited to the Kosastalliyar boundary. The largest difference in the predicted and calculated water surface elevation were observed during December, when the mouth was partially open due to dredging.

The final calibration was established with Chennai tide applied at the mouth, the Kosastalliyar creek as 0.3 times the Chennai tide, while the creek mouth parameters are shown in Table . It is recognized that calibration could be improved with better data at Kosastalliyar and the creek mouth, in addition to more current meters in the creek. However, the resources and logistics did not permit such additional measurements.

Case	Period	Mouth condition	Level (with respect to Bed)	Mouth width
1	February 1999	Fully open	-2.0m	200 m wide
2	May 1999	Closed	+0.4m	110m wide
3	December 1999	Partially open	+0.15m	75m wide

Performance was measured by comparing the water levels (3 locations) and velocity (one location). The calibration of model was found to be satisfactory with the timing and trends of the predicted values matching the observed data.

It should be recognized that the conditions in the estuary were different for all three surveys. The relative magnitudes of the currents must be noted while comparing the model performance for each survey. NCTPS flows were changed in the Creek as water withdrawn from Ennore Creek was let back into the creek through the Buckingham Canal North, which traversed northwards and flowed into the system through Kosasthalaiyar. This was not simulated in the model. Instead the algebraic sum of the discharge and withdrawal i.e., zero withdrawal was considered.

Fig 7.3 shows calibration of hydrodynamics based on February '99 data while Fig. 7.4 shows model performance for December 1999. For the May 1999 survey, the measured current meters values are very lo and close to the detection limit and thus may show more noise than reality.

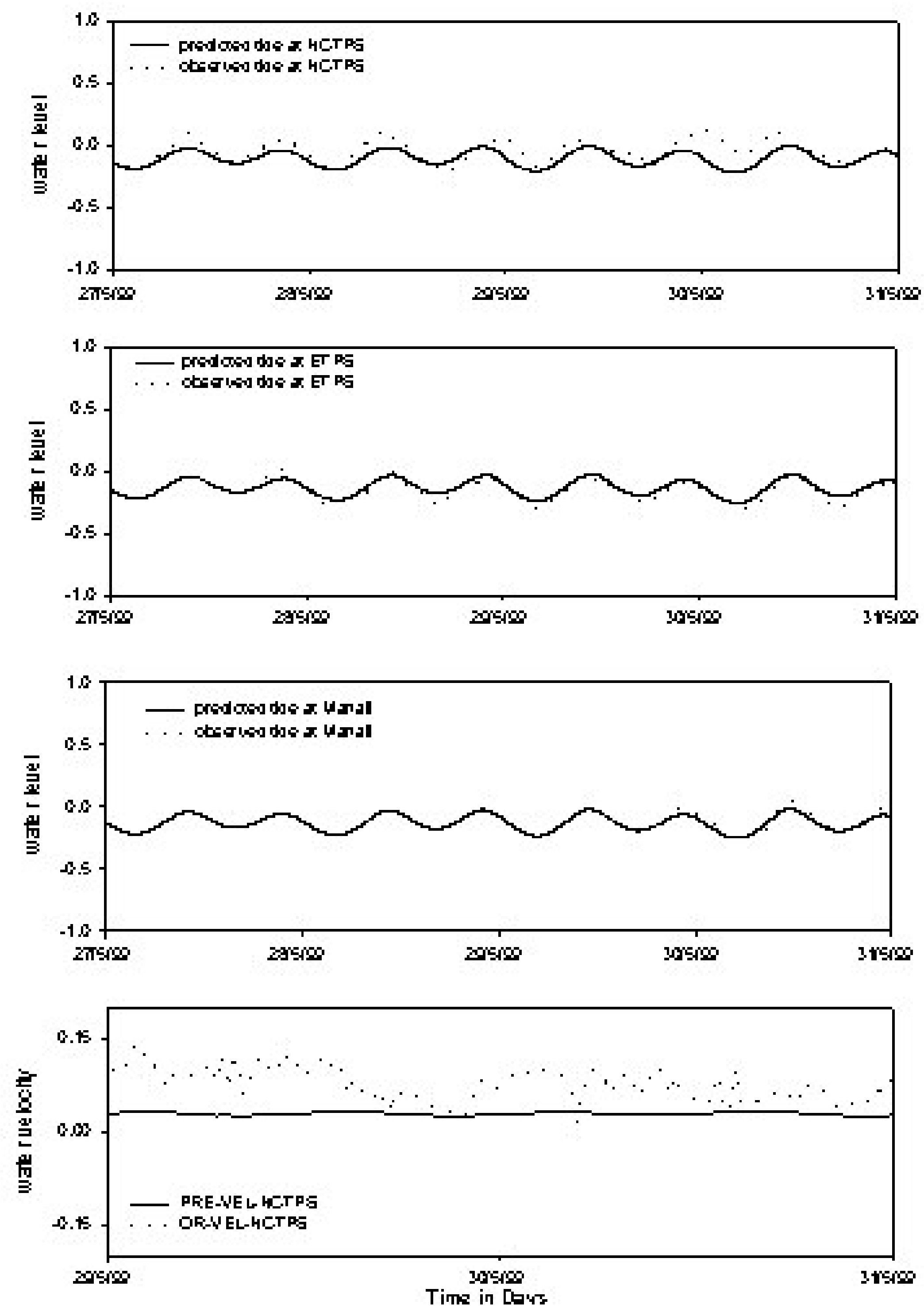


Fig 7.3 Calibration of hydrodynamics – February1999

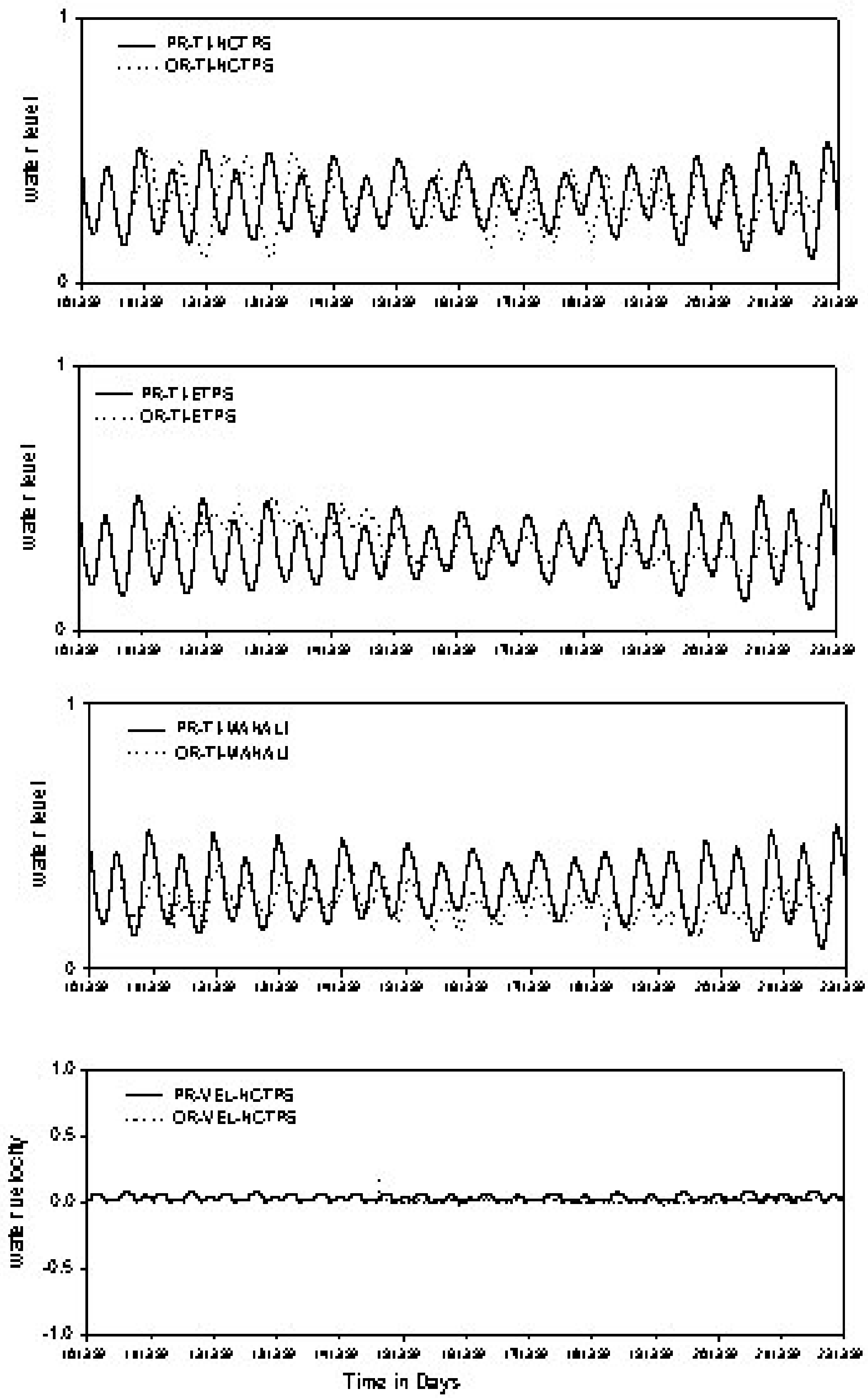


Fig 7.4 Validation of hydrodynamics – December 1999

Salinity

In order to check the conservation of mass, salinity was modeled. Salinity helps establish the assumptions made during the hydrodynamics calibrations, as well as establishes the quantity of freshwater and wastewater inputs. In a dynamic system like a tidal creek, it helps to establish the dispersion coefficients. The observed salinities at sampling stations ENC1 (Creek mouth), BUCS and AMC (freshwater boundary) were averaged for that period and input as the boundary concentrations.

Zero Salinity concentration was assumed at the freshwater boundary. However, while the PWD records indicated zero flows from Red Hills and Thamaripakkam, yet low salinity values are found in the AMC, ENC4 and KRR stations. Thus, a discharge quantity was added at AMC and KRR to represent baseflow from groundwater.

The results of spatial variation of salinity for the calibration and validation surveys are shown in Fig. 7.5. The figures show the similarity between observed and simulated salinities along the creek, indicating that the flows, velocities and dispersion coefficients are representative of the system behavior. For the validation surveys, the initial and boundary conditions were established in a manner consistent with the calibration study using observed salinity concentrations at the sampling locations. The inputs at AMC and BUCS as obtained from the calibration modeling were used. The model may be now used for calibration of the water quality parameters.

Finally the model was verified for WQ processes. The initial and boundary conditions were established for using observed data and an antecedent period simulation and all the constants used in the calibration study were used without modification in the verification study. The results of the simulation are shown in Fig 7.5. Comparison of measured salinity values and model inputs (Table 7.2) with the predicted values (Fig 7.5) indicate that the water quality simulation for salinity may be considered satisfactory.

Table 7.2 Description of salinity (mg/l) inputs

Period	Discharge/Boundary Location	Measured Value	Model Input	Deviation
February 1999	Mouth	30.26	30.26	0
	KST	28.61	28.61	0
	BUCS	3.6	0	
	AMC	0	0	0
May 1999	Mouth	35.43	35.43	
	KST	37.06	37.06	

	BUCS	9.0	9.0	
	AMC	0	0	
December 1999	Mouth	28.8	28.8	
	KST	32.43	32.43	
	BUCS	0	0	
	AMC	0	0	

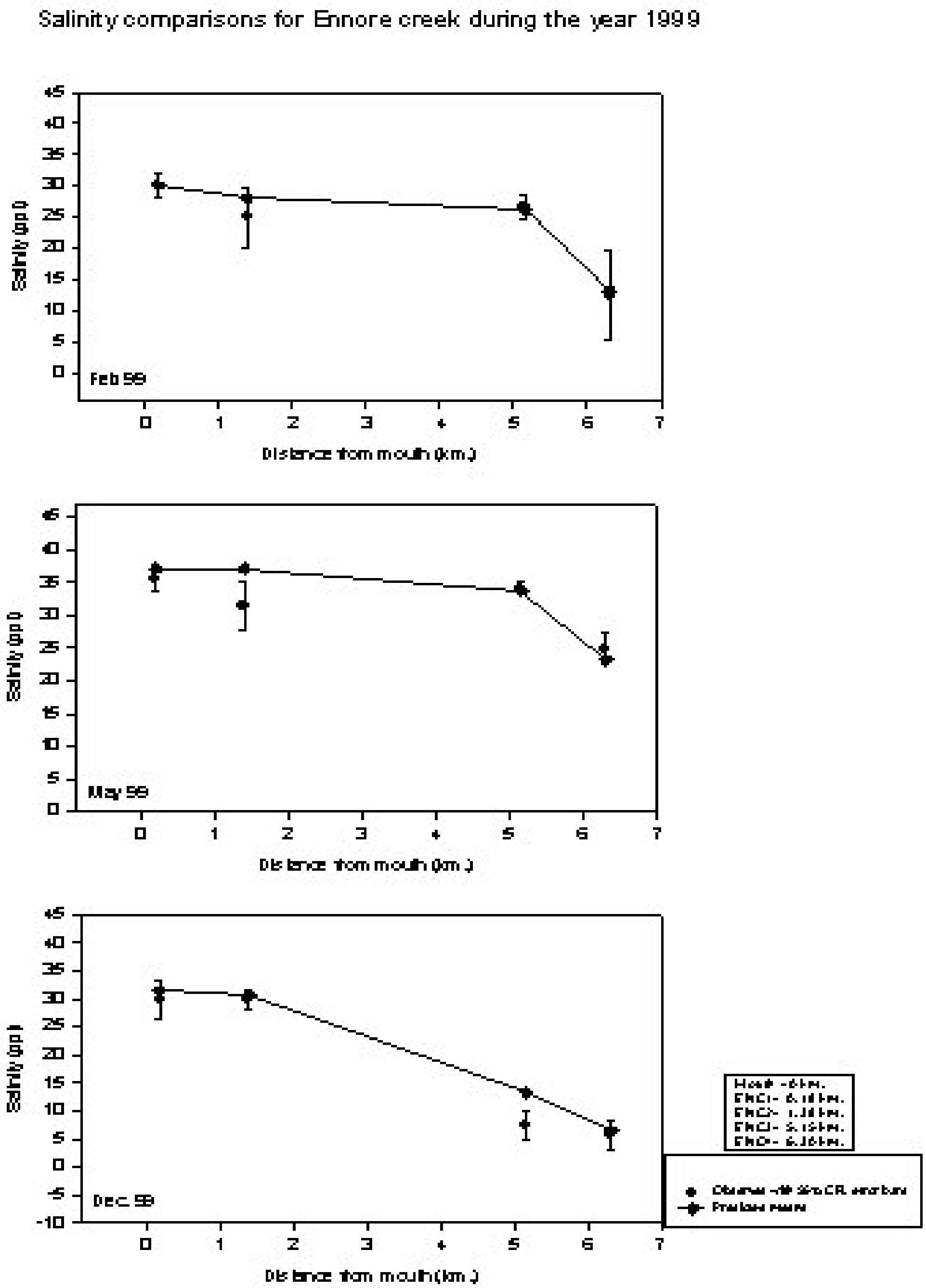


Fig 7.5 Spatial variations of salinity simulated from model

Biochemical Oxygen Demand

Average observed concentrations of BOD for each survey were applied at ENC1, BUCS and AMC. The decay rate coefficient was initially based on the site measurement of decay rate, while the temperature constants were retained at the model default value. Calibration was difficult and generally found to be under predicted. The many factors that complicated the calibration are:

- Multiple unknown sources of pollution as indicated in Section
- Point of discharge of Buckingham canal discharge complicated by the lock gates.
- The assumption of complete mixing in the lateral direction compromised by the extremely low velocities in the creek, due to mouth closure.

Of the three complications listed above, the issue of multiple unknown sources is bound to plague most water quality modeling efforts in India. From that perspective, it may be necessary to average the variations of BOD with a larger sample set and calibrate for the average condition. Given these complications, the general trends shown in the BOD modeling indicate the overall magnitude of pollution discharge. The results of the simulation are shown in Fig 7.6. Comparison of measured salinity values and model inputs (Table 7.3) with the predicted values (Fig 7.6) indicate that the water quality simulation for BOD may be considered satisfactory.

Table 7.3 Description of BOD (mg/l) inputs

Period	Discharge/Boundary Location	Measured Value	Model Input	Deviation
February 1999	Mouth	4.8	4.8	0
	KST	0.8	0.8	0
	BUCS	120	120	0
	AMC	1.6	60	
May 1999	Mouth	5.33	5.33	0
	KST	2.9	2.9	0
	BUCS	70	120	
	AMC	11	60	
December 1999	Mouth	1.3	1.3	0
	KST	0.8	0.8	0
	BUCS	78.0	120	
	AMC	8.10	60	

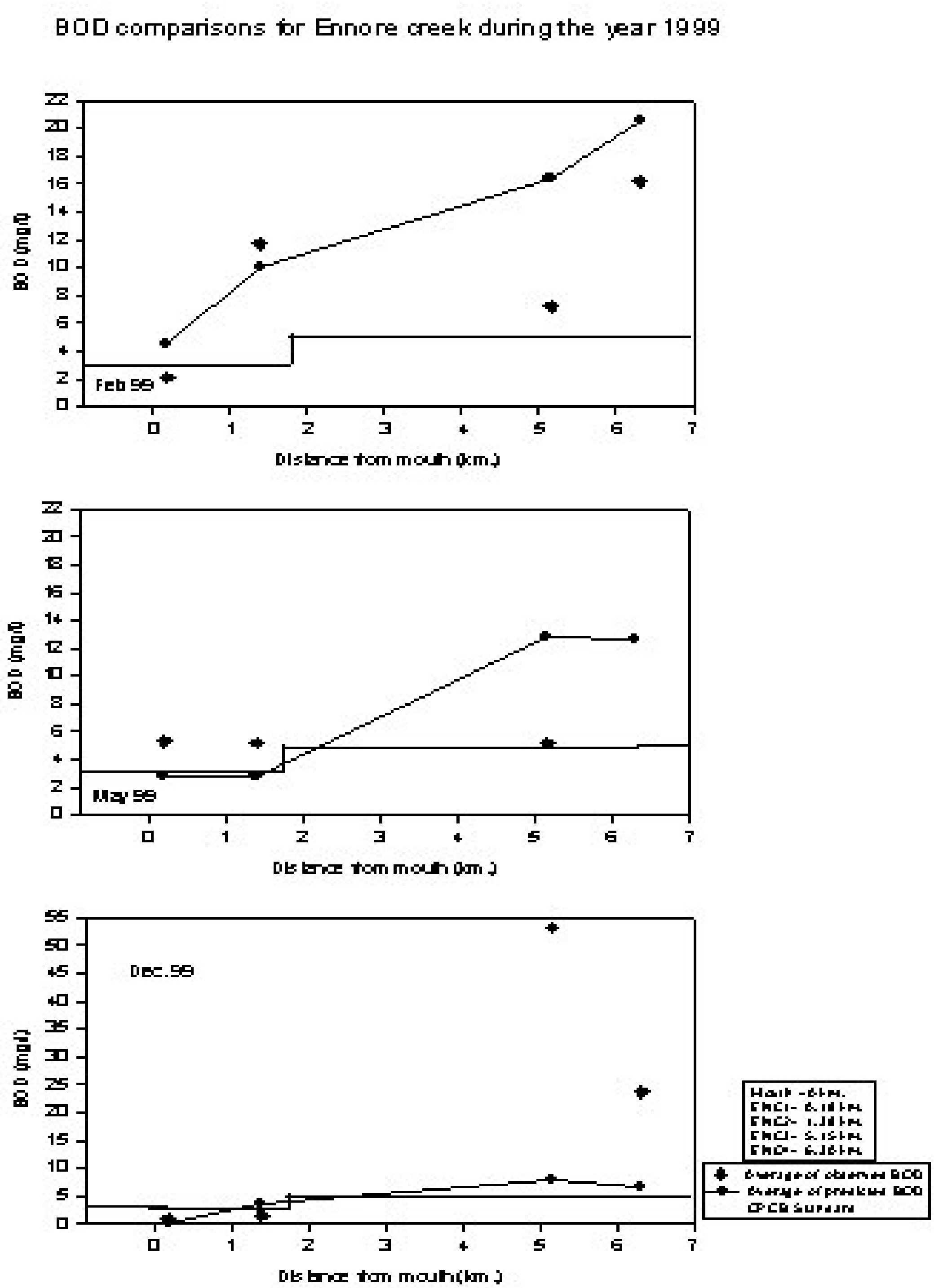


Fig 7.6 Spatial variations of BOD simulated from model

Fecal Coliforms

The major fecal coliforms input is from the Buckingham Canal. The input concentration at BUCS is 617000 (CFU/100ml). The model shows reasonable fit of the spatial variations, suggesting that there is no other significant input of fecal coliforms. Considering that additional inputs were required for BOD in the upper reaches of the creek, near ENC4, while fecal coliforms values at BUCS are adequate as measured, suggests that the BOD inputs are industrial in origin.

The results of the simulation are shown in Fig 7.7. Comparison of measured salinity values and model inputs (Table 7.4) with the predicted values (Fig 7.7) indicate that the water quality simulation for fecal coliforms may be considered satisfactory

Table 7.4 Description of F. Coli (CFU/100ml) inputs

Period	Discharge/Boundary Location	Measured Value	Model Input	Deviation
February 1999	Mouth	970	970	0
	KST	4800	4800	0
	BUCS	617000	617000	0
	AMC	7	0	
May 1999	Mouth	7038	7038	0
	KST	2251	2251	0
	BUCS	5810500	5810500	0
	AMC	82800	82800	0
December 1999	Mouth	7038	7038	0
	KST	130000	130000	0
	BUCS	2760000	2760000	0
	AMC	60300	60300	0

F-Coli comparisons for Ennore creek during the year 1999

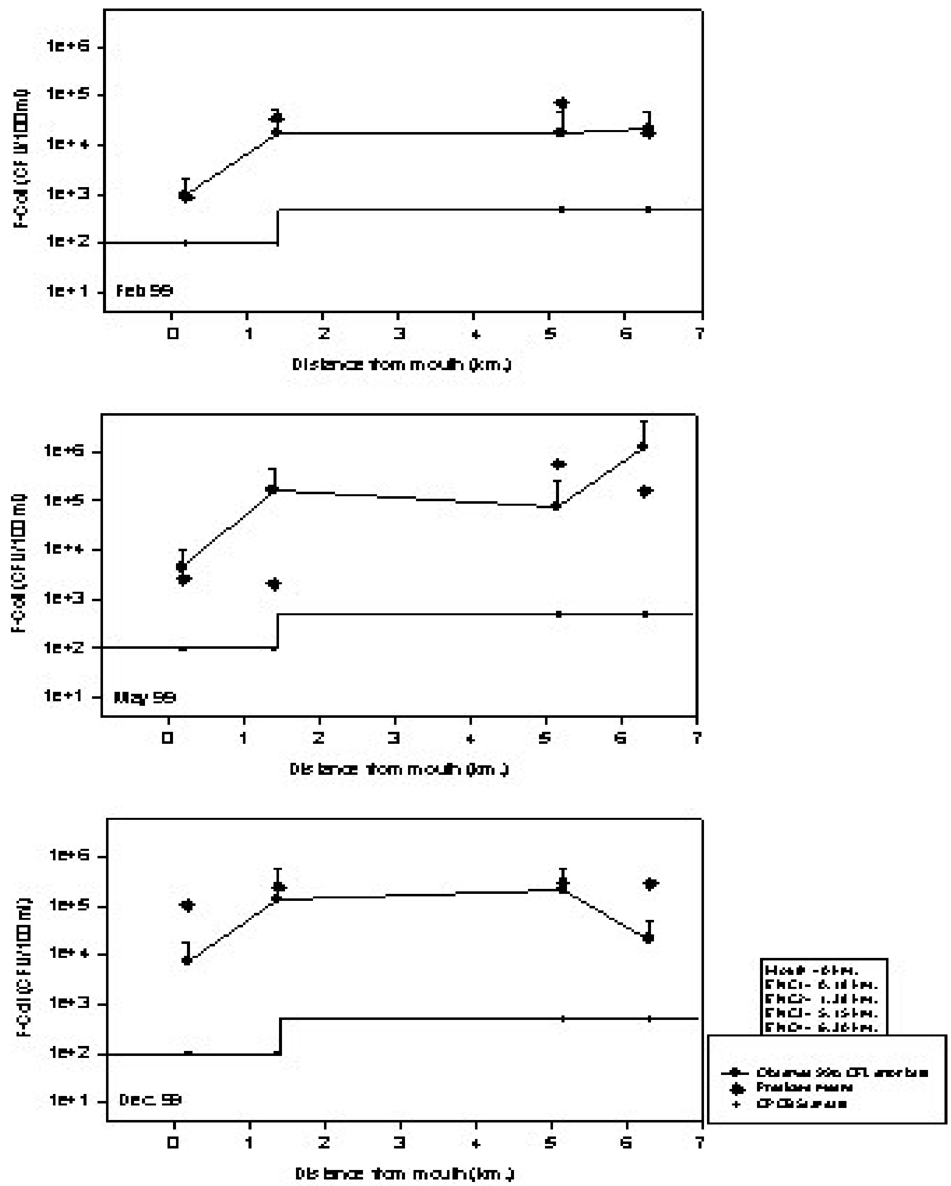


Fig 7.7 Spatial variations of Fecal coliform simulated from model

8 COASTAL MODELING

8.0 MODEL SETUP & RESULTS

8.1 COASTAL MODEL - THEORY

The simulation of flow field in the Ennore coastal area was carried out using hydrodynamic module and fecal coliform decay is studied using advection-dispersion module respectively of MIKE21.

8.1.1 Hydrodynamics

The hydrodynamic module is a general shallow water flow modeling system for simulation of water levels and flows in estuaries, bays and coastal areas. It simulates unsteady two-dimensional flows (vertically homogeneous) in fluids and the conservation of mass and momentum integrated over the vertical describe the flow and water level variations. The Alternating Direction Implicit (ADI) technique is used in the model to integrate the equations of mass and momentum conservation in the space-time domain. The effective shear stresses in the momentum equations contain momentum fluxes due to turbulence and vertical integration. They are included using an eddy viscosity formulation to provide damping of short wave length oscillations.

8.1.2 First order decay

The coliform die-off can be modeled by a first order decay. However the die-off rate can be constant or varying depending on interaction of environmental factors on bacterial die off. The main factors are light, temperature and salinity. As the light intensity, temperature or salinity increases, the death rate will increase. In most of the studies it is sufficient to assume a constant decay rate and MIKE21 advection dispersion (AD) module can be applied. In the AD module, the advection dispersion equation is solved for dissolved or suspended substances in two dimensions. This is actually the mass conservation equation where discharge quantities and compound concentrations at source sink points are included together with decay rate. The decay of coliform normally behaves like an exponential function and the decay rate is described by the parameter T90 that expresses the time elapsed until 90% of the initial concentration is decayed.

8.1.3 Grid setup

The digitized bathymetry covers the area from $13^0$2' to $13^{0'}$16'N and $80^0$18'to $80^0$24 E (Fig. 8.1). The key locations in the domain are given in Table 8.1. The important coastal points are Ennore port (NCTPS), ETPS outfall (ETPS) and Royapuram (RYSO) sewage outfall.

Table 8.1 Key stations and position

Locations	Lat	Long	X grid co-ord	Y grid co-ord
NCTPS	13^{0}15’25”	80^{0}20’11”	90	9
CST1	13^{0}07’20”	80^{0}18’50”	75	162
CST2	13^{0}08’20”	80^{0}18’40”	85	144
CST3	13^{0}08’17”	80^0 19’08”	72	146
CST4	13^{0}10’52”	80^{0}19’20”	82	94
CST5	13^{0}10’46”	80^{0}19’50”	75	96
CST6	13^{0}12’07”	80^{0}19’42”	84	70
CST7	13^{0}11’59”	80^{0}20’06”	76	76
ETPS	13012’11”	80019’21”	68	86
RYSO	13^{0}08’24”	80^{0}17’59”	90	140

The model is rotated 195 deg to true north for the following reasons:

1) A 15^0 rotation would make the coast parallel to y axis so that the flux at the northern boundary will be perpendicular to the boundary
2) An additional 180^0 rotation to have the origin of the grid in the offshore point. The domain is discretized into 100 × 270 points with 100m grid spacing along the X and Y directions.

Boundary conditions

There are three open boundaries in the model domain, i.e. in the northern, southern and the eastern boundaries. The conditions along these boundaries are specified after studying the field measurements on currents in certain locations along these boundaries.

- The Ennore port NCTPS is situated on the northern open boundary and the current measurements at this point show that for most of the simulation period the current direction is towards north. So the flux across this boundary is calculated and given as input to the model.
- At the southern open boundary, surface level variation is prescribed as negligible because the stretch considered is sufficiently far away from the northern boundary.
- At the eastern offshore boundary, a number of flux conditions are prescribed since most of the flux is along the northern direction only due to the northerly currents.

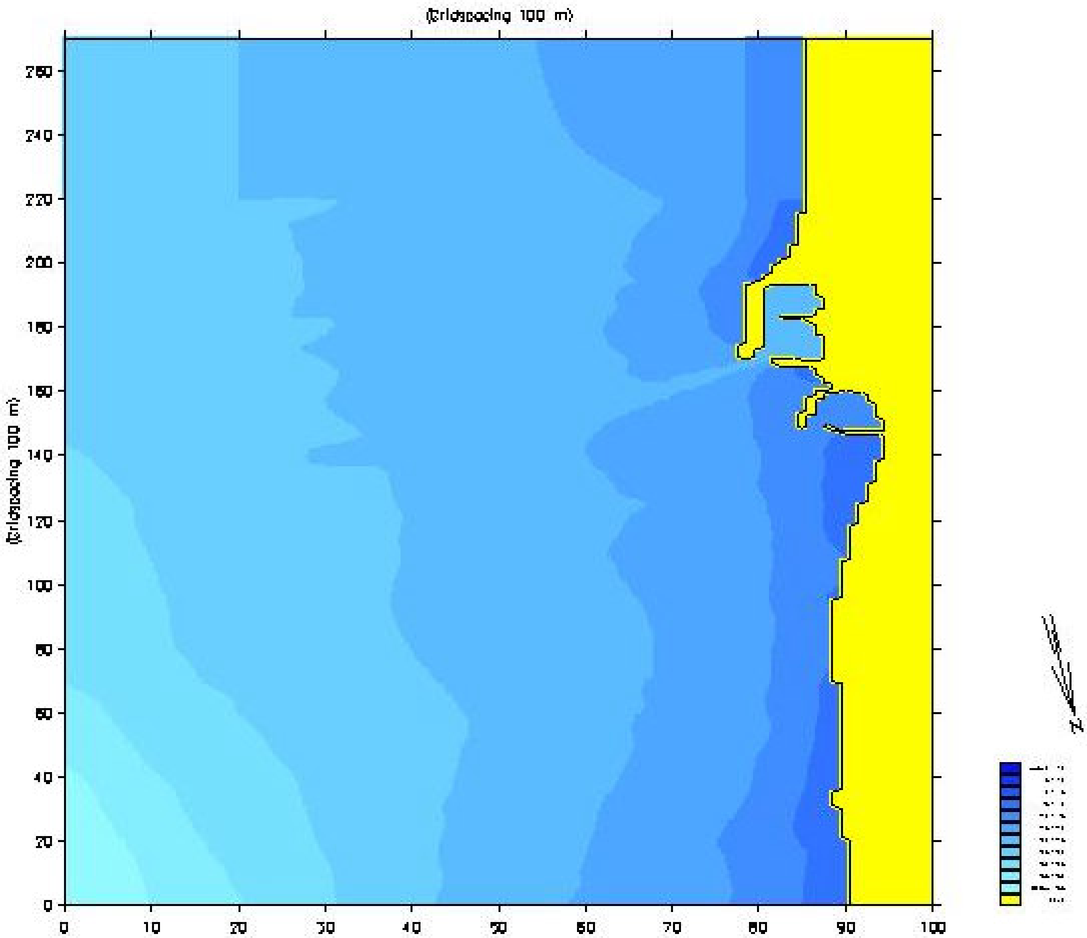


Fig 8.1 Digitized bathymetry of the study area

8.1.4 Point sources

The only point source considered is the Royapuram sewage outfall as this is the major discharging location in this coastal stretch and the average discharge at the location is specified using measured data.

8.2 MODEL INPUTS

8.2.1 Hydrodynamics

The currents in the Ennore coastal area are due to the tide, general ocean circulation in the Bay of Bengal due to the monsoons, local winds, and waves upwelling (if any) etc. The current meter measurements provide a lumped estimate of this complex phenomenon. For proper calibration of the hydrodynamics, each of these parameters may require estimates for inclusion. The field study was not focused to generate such specific estimates and thus initial efforts were to use the current meter data to generate estimates of flux. Hence wind driven currents are not specified separately as they are incorporated in the general circulation.

8.2.2 Fecal Coliform

Taking the initial concentration at the station CST7 and the source concentration at RYSO from the observed data fecal coliform decay was modeled. Boundary concentrations were specified as the background concentration of CST7.

8.2.3 Data availability

Table 8.2 defines the sampling periods for hydrodynamics and water quality measurements in the coastal waters.

Table 8.2 Data availability

Phase	Hydrodynamics	Hydrodynamic Data availability	Water quality	WQ data availability
I	19.2.99 to 19.3.99	Data available only from 10.3.99 to 19.3.99 for RYSO	19.2.99 – 20.2.99	All data available
II	28.5.99 to 5.6.99	Complete data sets available for NCTPS, RYSO and ETPS	28.5.99 to 29.5.99	
III	14.12.99 to 21.12.99		18.12.99 to 19.12.99	

- Hydrodynamics data for NCTPS, ETPS and RYSO are available for the entire study period for the second and third phase surveys while data at RYSO is partially available for the Phase I survey i.e., from 10.3.99 to 19.3.99 only

8.3 CALIBRATION MODELING

Complete hydrodynamic and coliform data are available for Phase II and therefore phase II data was used for calibration of hydrodynamic and the advection dispersion model. The model was then validated with Phase-I data first and then with Phase-III data.

8.3.1 Model calibration

Hydrodynamics

The flow field in the Ennore coastal region was simulated for a period of one week starting 28.5.99. The digitized bathymetric data and the boundary conditions are the primary input to the hydrodynamic model. The calibration parameters were the manning number and the eddy viscosity coefficient. The eddy viscosity was calculated using smagarosnki formulation which is most suited for eddy viscosity, keeping only the Manning number as the calibrating parameter. Model simulations were carried out for different values of Manning number. The bed resistance coefficient was chosen as Manning number and varied between 25 and 40. A point source is specified at the grid point (90,140), corresponding to RYSO, with flow magnitude specified at that point. The time step chosen was 35 seconds for which the maximum courant number is 6.9.

The computed velocity is compared with that of the measured velocity at ETPS point for all the simulations and the best comparison taken as the calibrated simulation. Figs. 8.2 and 8.3 show the calibration for current speed and direction.

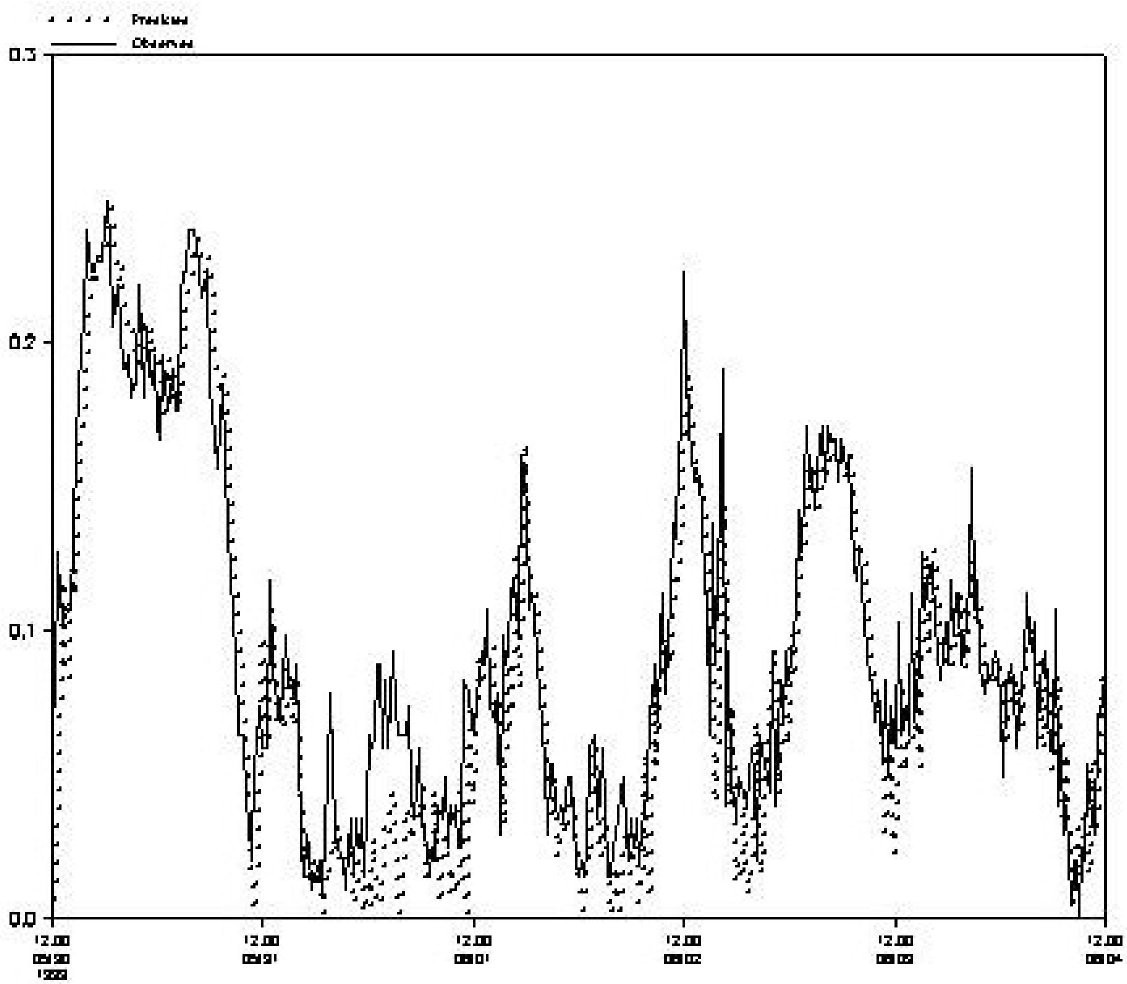


Fig 8.2 Calibration of current speeds for May'99 off ETPS outfall

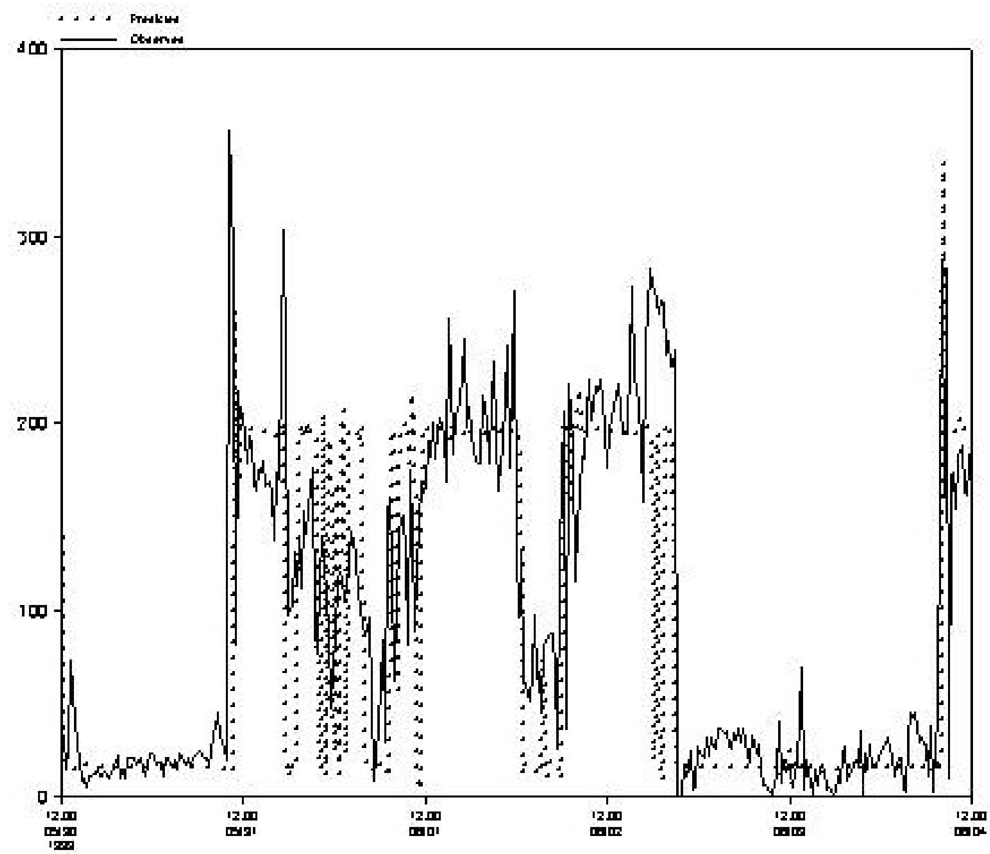


Fig 8.3 Calibration of current directions for May'99 off ETPS outfall

The flow field in the region is shown after one day of simulation in Fig. 8.4. Then phase III calibration is carried out and the results are presented in Figs. 8.5 and 8.6.

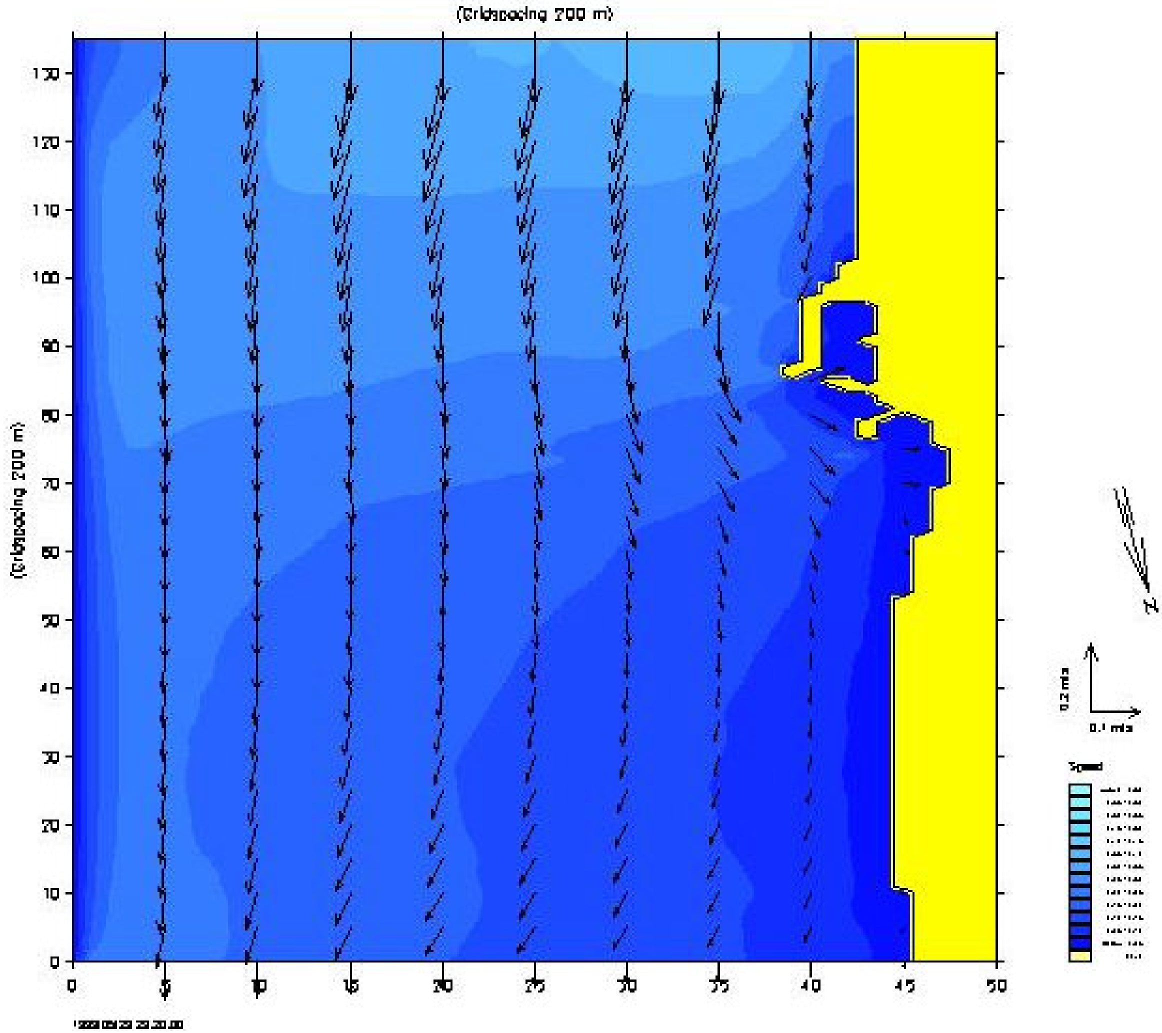


Fig 8.4 Flow simulation for May'99

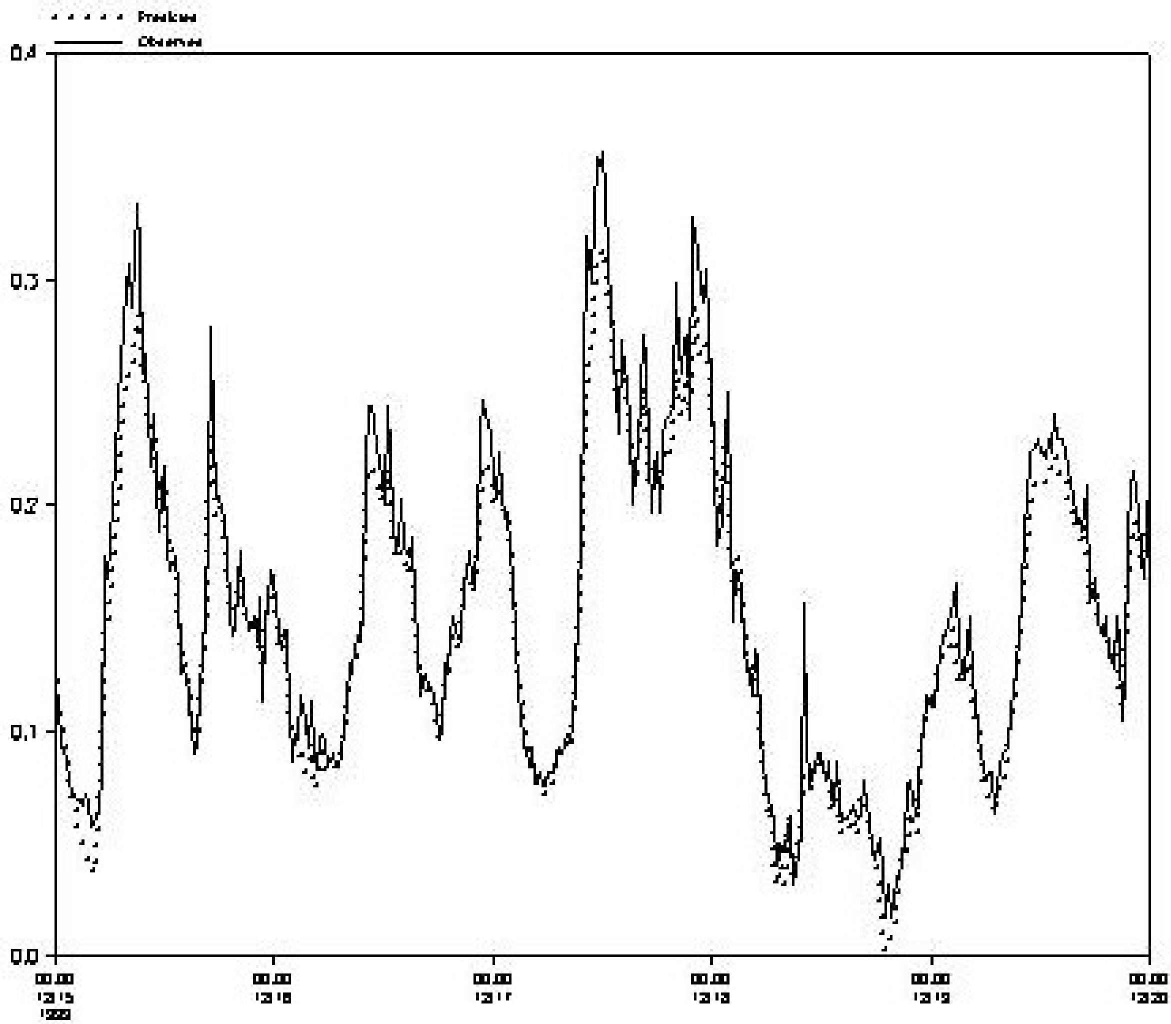


Fig 8.5 Calibration of current speeds for December '99 off ETPS outfall

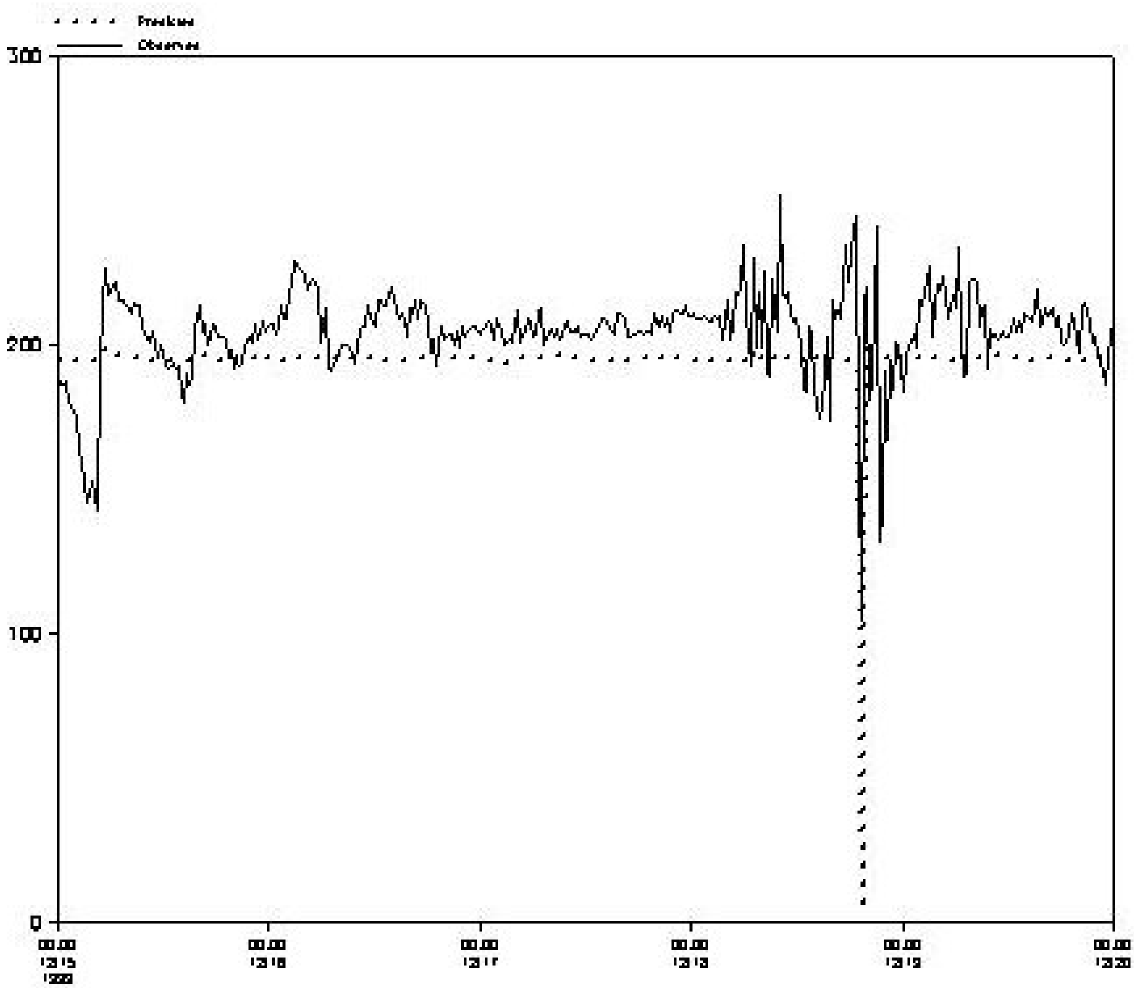


Fig 8.6 Calibration of current directions for December '99 off ETPS outfall

Fecal coliform

The average discharge at the point source Royapuram was input to the advection dispersion model and the coliform decay simulations were carried out. The model computed fecal coliform concentrations for various dispersion coefficients, which were compared with the observed coliform concentration in the station CST2 (Fig. 8.7). The dispersion coefficients in the x and y directions are varied between 1 and 5. The decay rate was specified as 12.8 hours which is the time taken for 90% of the coliform to die. For a dispersion coefficient of 1m^2/s in both, x and y directions the comparisons agreed very well and these coefficients were chosen as the calibration constants.

Figs 8.8 to 8.12 show the coliform concentration validations for the three phases of survey and Fig. 8.13 shows the validation of streptococcus fecalis concentrations for the December 1999 survey

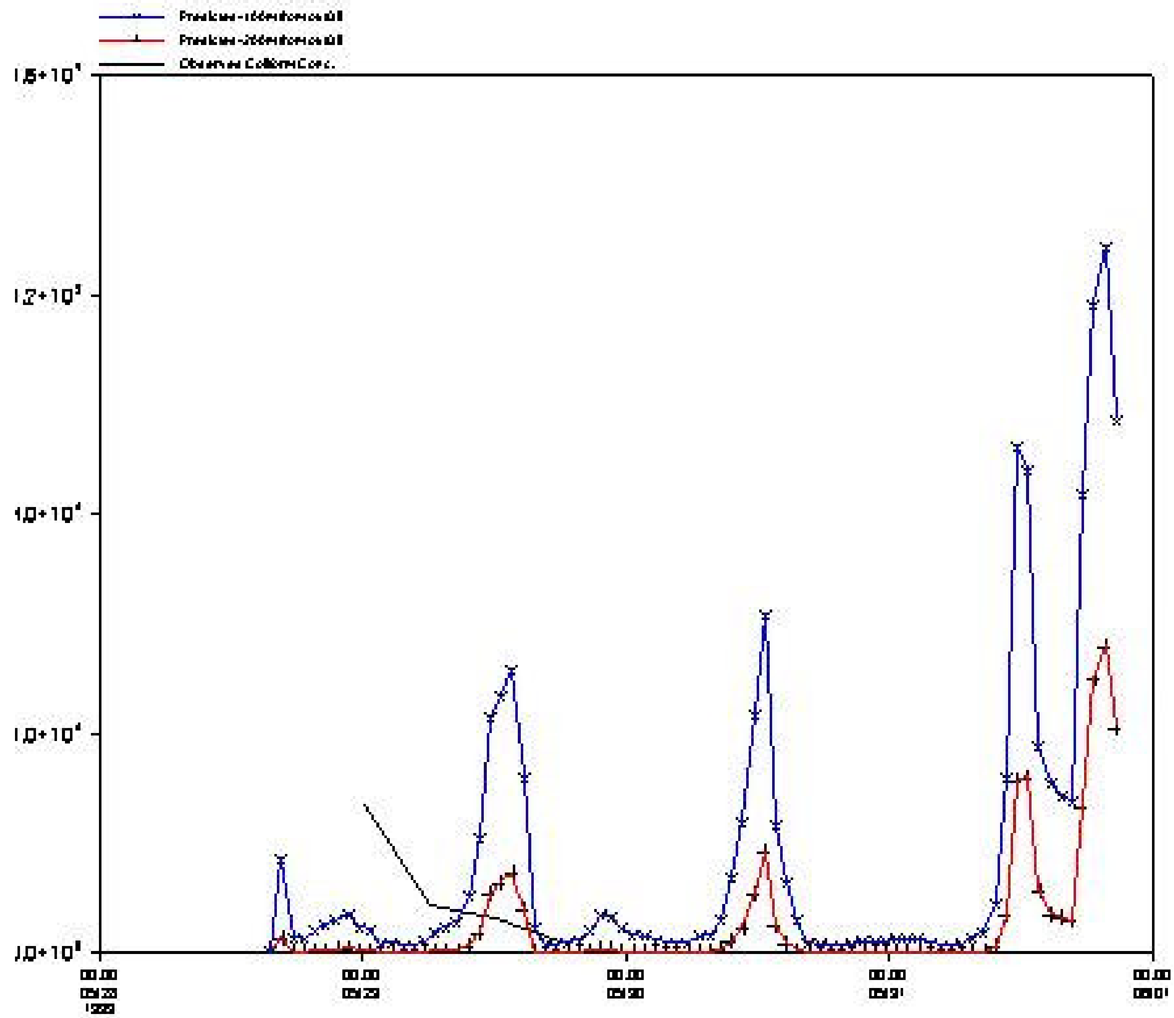


Fig 8.7 Calibration of average coliform concentration for May 1999

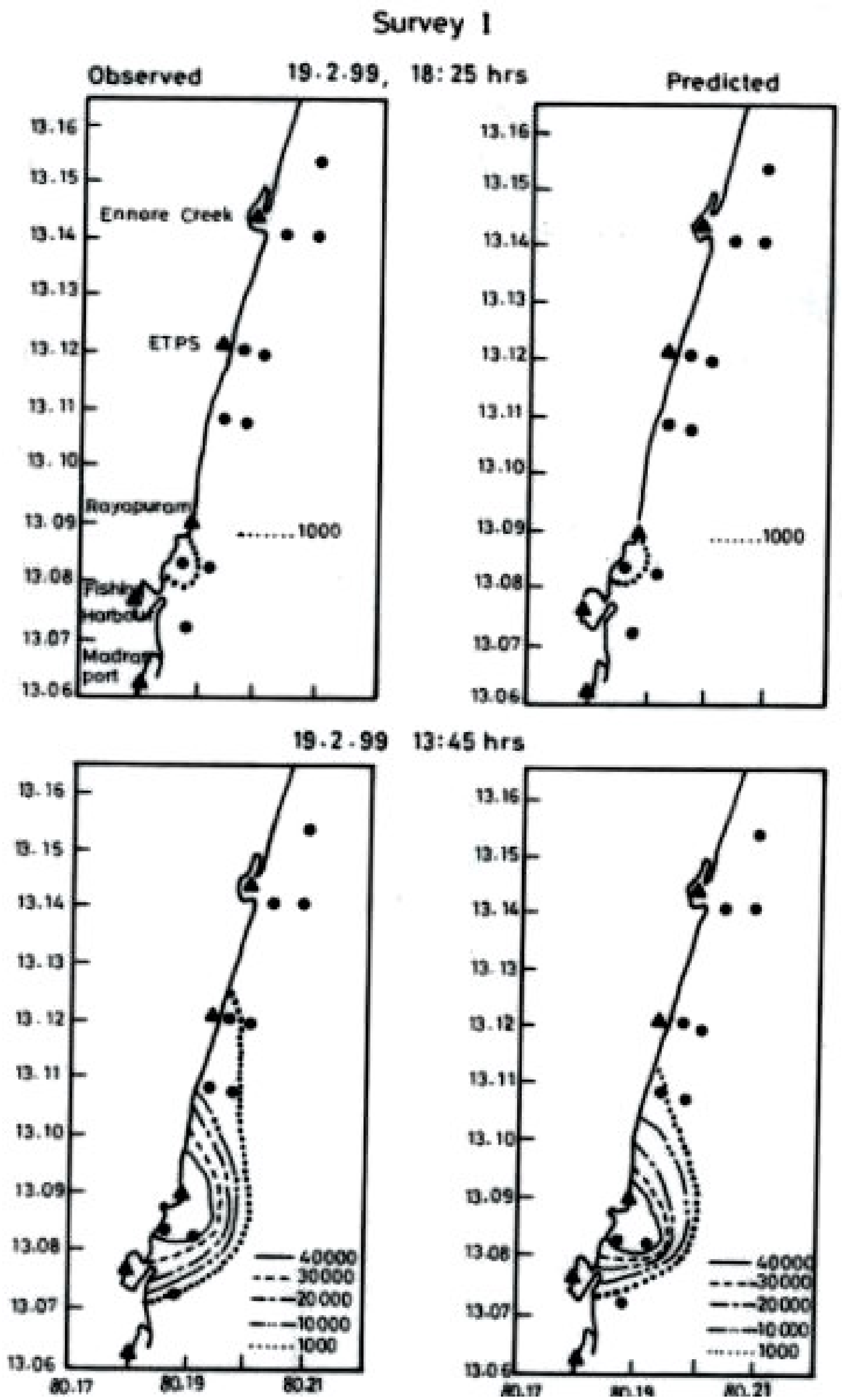


Fig 8.8 Comparison of Fecal coliform concentration for Feb'1999 (Runs 3 &2)

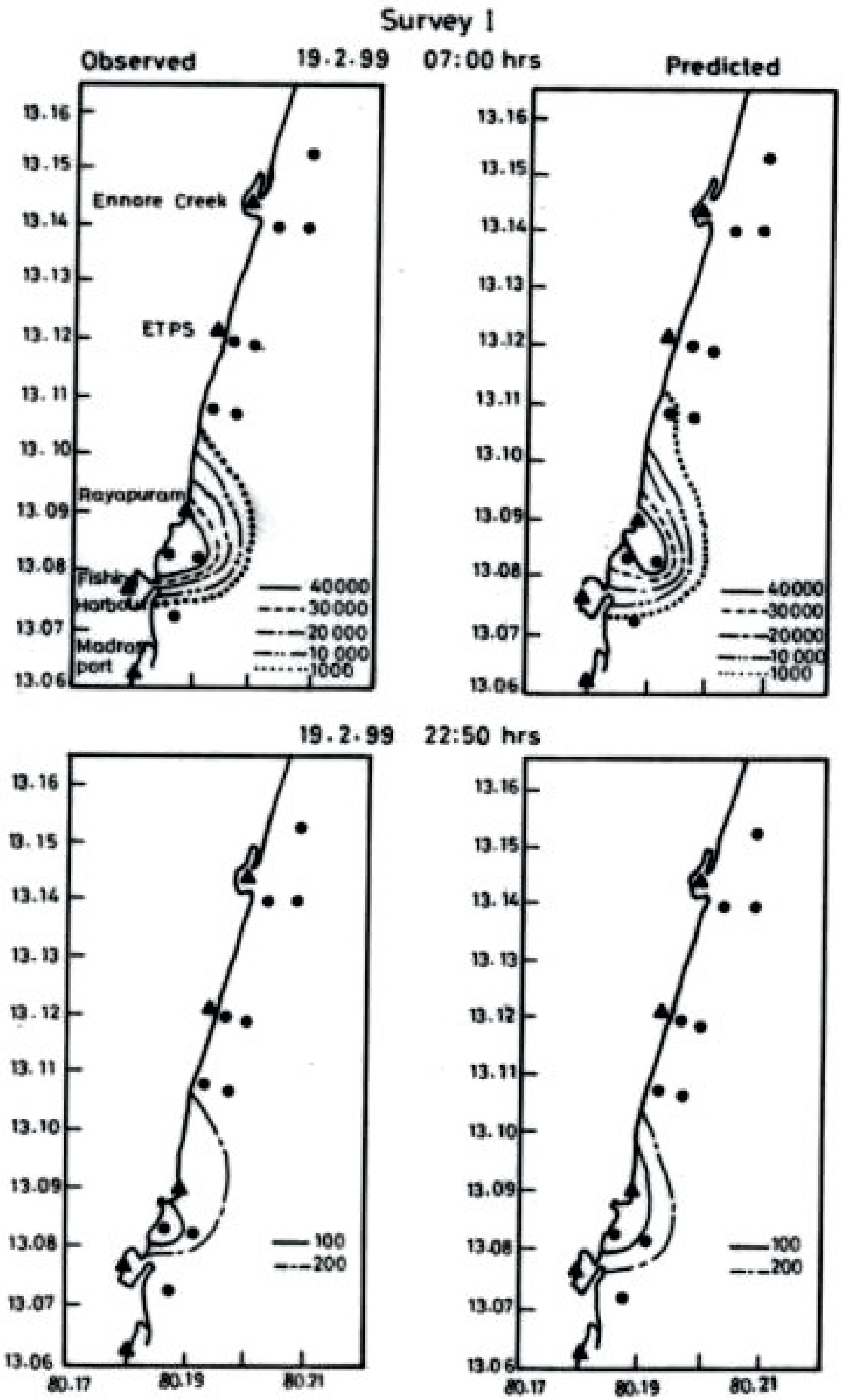


Fig 8.9 Comparison of Fecal coliform concentration for Feb'1999 (Runs 1 &4)

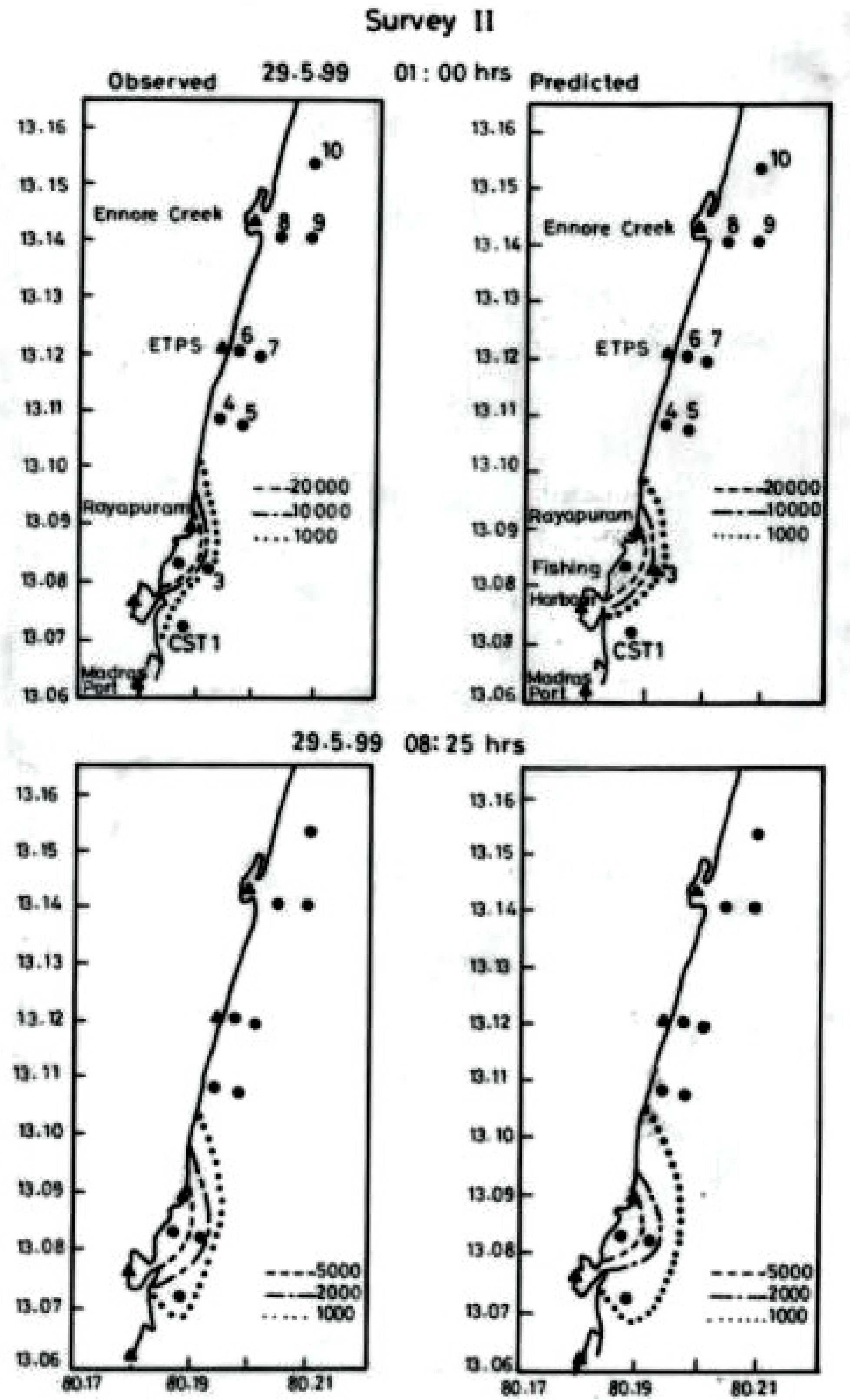


Fig 8.10 Comparison of Fecal coliform concentration for May 1999 (Runs 3&4)

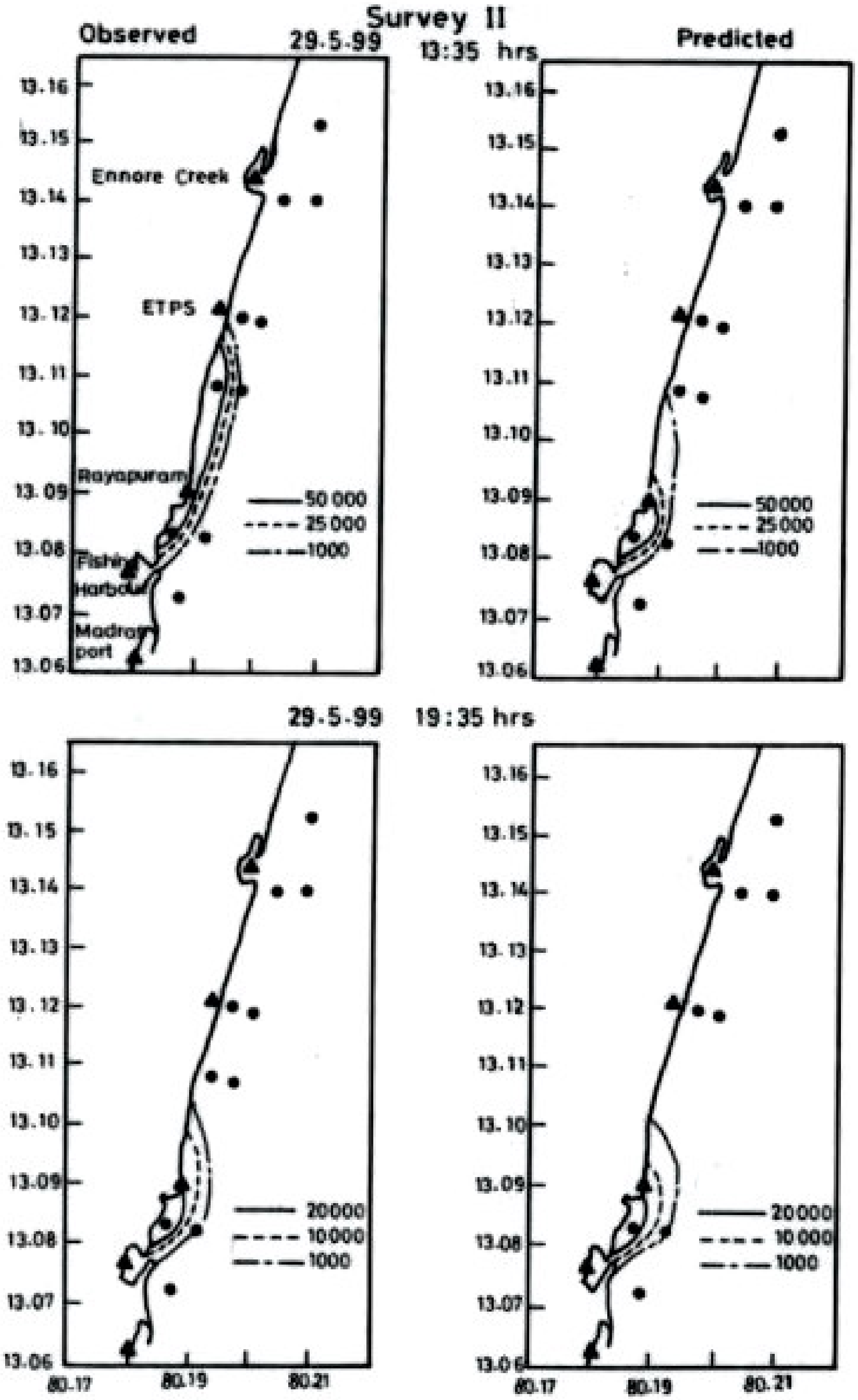


Fig 8.11 **Comparison of Fecal coliform concentration for May 1999 (Runs 1&2)**

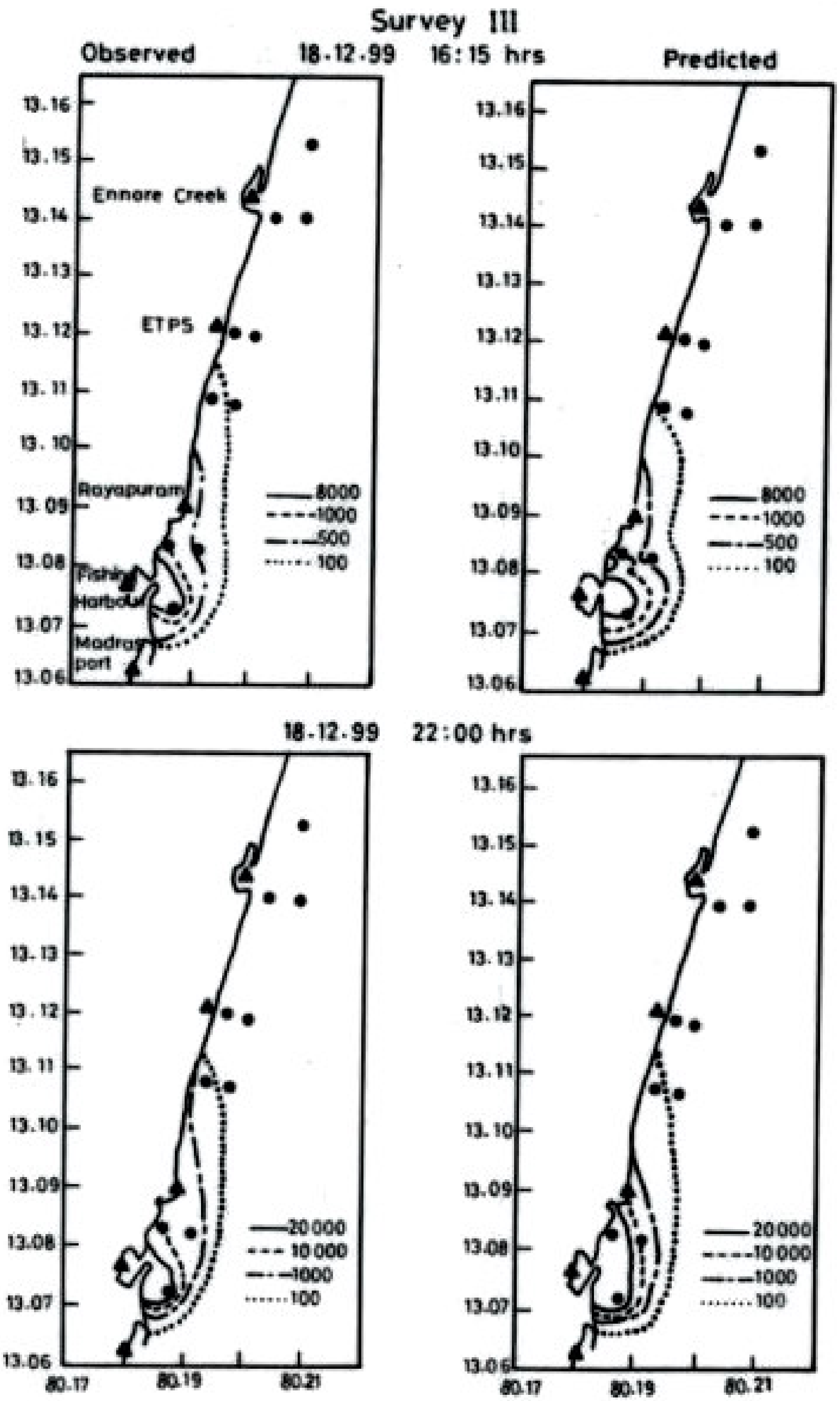


Fig 8.12 Comparison of Fecal coliform concentration December 1999 (Runs 3&4)

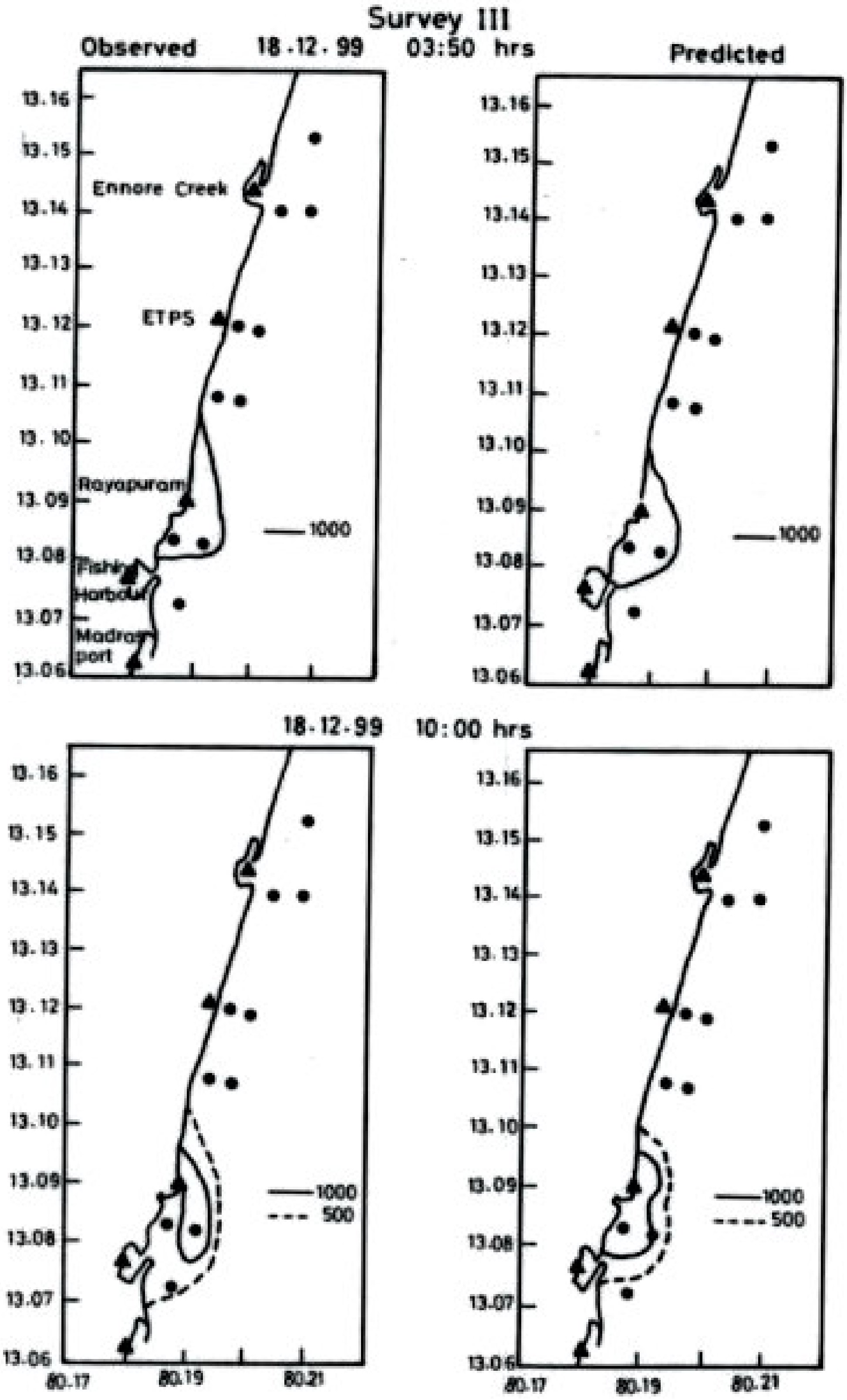


Fig 8.13 Comparison of Streptococcus Fecalis concentration Dec' 1999 (Runs1&2)

9 PROJECTIONS FOR FUTURE

9.0 COASTAL AND CREEK WATER QUALITY

9.1 ESTIMATION OF FUTURE LOADS

9.1.1 Introduction

Discharges into Adyar river, the Cooum river, the Buckingham canal Otteri Nullah and open sea are from about 708 outfalls from industries, commercial institutions, sewage treatment plants, pumping stations, sewers, strom water drains and slums (TNPCB). In order to reduce the pollution from direct untreated discharge, six Sewerage Treatment Plants have been constructed at Kodungaiyur-1, Kodungaiyur-2, Koyambedu, Nesappakam, Perungudi and Villivakam in Chennai.

While total estimated sewage flow is 440 million liters per day (MLD), the existing treatment capacity is 223 MLD with the remaining 217 MLD of untreated municipal and industrial effluents being discharged (12,330 kilo litres/day) into Chennai Rivers and Canals. BOD loads of about 300 mg/l at Cooum have been reported by several authors (1998-1999). TNPCB reports state that the quality of water in Cooum and Adyar rivers do not satisfy any of the criteria prescribed by the Central Pollution Control Board. Although TNPCB reports do not explicitly state the conditions at Ennore Creek, a significant portion of the North Chennai wastewaters enters the Ennore Creek through the Buckingham Canal (approximately 30%) and other nullahs.

9.1.2 Background data

Past data on BOD loads have been obtained from data provided by Severn Trent water report in the years 1989 and 2001. Table 9.1 gives the BOD loading data for the discharging points with receiving waters indicated in brackets. According to the data

- The highest BOD load of 7786 Kg/day was recorded at Koyambedu plant discharges into Cooum.
- The second and third highest BOD loads of around 6000 Kg/Day have been recorded at Nesappakam plant (Adyar river) and Kodungaiyur 1(Buckingham Canal).
- The BOD load at Perungudi (Buckingham Canal) was 3100 Kg/Day
- Amongst the discharging points lowest BOD loads were recorded at, Kodungaiyur2 and Villivakkam (Otteri Nullah)

Evaluation of the observed BOD loadings at the discharge points reveals that:

- The BOD loads are higher at all discharge points (6000- 8000 Kg/Day) except Villivakkam (300 Kg/Day). However, the BOD load at Villivakkam – Otteri Nullah discharges point has doubled over the study period
- The BOD loads at the pumping stations of Koyambedu, Nesappakam and Kodungaiyur-1 are similar to 1990 levels due to increased sewage treatment capacity (Table 9.1), while increased BOD loads are observed at Kodungaiyur 2 and Perungudi plants inspite of the increased treatment capacity
- The BOD load at Kasimode discharge point (into the Sea) is 1760 Kg/day

9.1.3 Estimates for future

The future BOD loads are estimated by considering the predicted growth rate of 13.14% and 11.61% respectively for 2010 and 2020 as shown in Table 9.2. The BOD load at Kasimode discharge at Sea is estimated at 1991 Kg/day in 2010 and 2222 Kg/day in 2020.

Table 9.1 Predicted BOD load for Chennai drains (Kg/day) -1991- 2020

Area	BOD load (Kg/day)		Predicted BOD load* (Kg/day)	
	1990	2001	2010	2020
Kodungaiyur 1 (Buckingham Canal)	6000	6000	6788	7577
Kodungaiyur 2 (Buckingham Canal)	975	6000	6788	7577
Koyambedu- (Cooum)	7786	7786	8809	9832
Nesappakam- (Adayar)	6030	7705	8717	9730
Perungudi - (Buckingham Canal)	3100	6975	7892	8808
Villivakkam – (Otteri Nullah)	150	300	339	379

*Estimated BOD loads are obtained by multiplying existing values with projected population growth rate of Chennai @ 13.14% for 2010 and @11.91% for 2020

Table 9.2 Estimated mass BOD load in study area

(North Buckingham Canal -Chennai Royapuram)

Period	Measured Flow m^3/day	Observed BOD/ mg/l	Observed BOD load 1999	Estimated BOD load (Kg/day)	
				2010	2020
Feb-99	13000	150	1950	2200	2460
May-99	11300	150	1700	1910	2140
Dec-99	11000	150	1650	1860	2080
Kasimode discharge point	11700	150	1760	1990	2220

9.2 PROJECTIONS

The issues of immediate concern in the creek with respect pollution are BOD and Fecal coliform concentrations. The goal of projection for the creek is to assess whether secondary wastewater treatment facility would improve the creek water quality. A wastewater plant would require reducing the BOD of the creek water to 30mg/l. Modeling was carried out using MIKE11 with the reduced BOD loads (30mg/l) and results examined for all the phases of tides that existed during the different seasons.

As discussed in the previous chapters, modeling results indicate that secondary treatment with disinfections will not reduce the BOD and fecal coliform levels in the creek to meet SW-III standards. The salient feature of this modeling is that the predictions are without the unauthorized discharges.

This emphasizes that meeting WQ standards through treatment will not be adequate. Discharges would have to be relocated to outside the Ennore Creek, as the creek does not have the sufficient assimilative capacity. The discharge through a marine outfall is recommended for existing discharges. Discharge with disinfections and without treatment can be done at 15m water depths to meet standards in the coastal waters. A preliminary modeling using USEPA's model CORMIX has been carried out to evaluate the near field behavior and extent of dilution achievable.

9.3 MODELING USING CORMIX FOR MARINE OUTFALL

The Cornell Mixing Zone Expert system (CORMIX) has been used to carry out dispersion analysis for the present study. CORMIX is a software system for the analysis, prediction and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. The system's major emphasis is on predicting the geometry and dilution characteristics of the initial mixing zone so that compliance with water quality regulatory constraints may be judged. The system also has reasonable capabilities to predict the behavior of the discharge plume at larger distances.

The CORMIX system is implemented on IBM compatible and utilizes a rule-based systems approach to data input and processing and consists of three sub-systems. They are:

- CORMIX1 – for analysis of submerged single port discharges
- CORMIX2 – for submerged multi-port diffuser discharges
- CORMIX3 – for buoyant surface discharges

The user can make detailed predictions of mixing zone conditions and readily investigate the performance of alternative outfall designs. For further information on CORMIX, the reader may reference Jirka and Doneker (1991).

The first step in the modeling using CORMIX is to maximize the dilution and to establish that well-mixed conditions are attainable for the given ambient discharge conditions in the "nearfield" (vicinity) of the outfall. Also the diffuser configuration is determined on the basis of CORMIX modeling results. CORMIX 1 permits simulation of one port only, while CORMIX 2 permits 3 or more ports.

A wastewater discharge of 13 MLD into the North Buckingham Canal (Table 9.2) as measured during the study was considered as the baseline. The design flow was based on the projections of growth @ 13.14% and 11.61% respectively for 2010 and 2020) and calculated as 16.50 MLD for the analysis. The projected discharge was therefore calculated as 16500 m^3/day i.e., 0.19 m^3/sec for a design case. Two conditions i.e., discharges without treatment were considered in the analysis at (a) 10m and (b) 15m water depths and the locations of the Near Field Region (NFR) and pollutant concentrations at the edge of NFR were determined from the analysis.

Similarly, the unsewered areas draining the Buckingham Canal and Otteri Nullah will need to be collected using an interceptor and discharged to the ocean. Thus multiple ocean outfalls are suggested along the North Chennai coast from Royapuram. The analysis has been carried out for one such outfall.

9.3.1 Diffuser Design Criteria

Hydraulic requirements

The diffuser is checked for both single port diffuser and multipoint diffuser with slightly reduced nozzle diameter than the outfall transport pipeline. The outfall pipeline is assumed to 250 mm HDPE / carbon steel / other structurally effective pipes (ID), such that velocities in the pipe are above 3m/s for the design discharge of 0.19 m^3/sec.

While using CORMIX the following hydraulic conditions are to be satisfied:

- Sea water intrusion into the outfall pipe must be prevented. This requires the densimetric Froude number to be greater than unity. This condition was met. The prevention of saline instrusion also requires the total port area to be less than the area of outfall pipe although, in practice, optimum outfall performance has been found to occur for total port areas less than two thirds of the original pipe area.
- Jet velocities should be greater than 3m/s, in order to inhibit marine biofouling (US Environmental Protection Agency recommendation).
- The total port area should be more than one third of the actual outfall pipe, in order to avoid an excessive total head loss. This is confirmed in condition 1 above.

The diffuser needs to be located beyond the breaker zone, as inspection maintenance and replacement of the nozzles/pipe may be required from time to time, especially if biofouling is difficult to prevent.

9.3.2 Diffuser Configurations

Single Port Diffuser

For a single port diffuser, and a velocity of 3.0 m/s in the discharge line, the outfall pipe diameter was estimated to be 250 mm (ID). This pipe was reduced to 200mm at the port (nozzle) to ensure that the nozzle area is less that 2/3 of the discharge line C/S area, and that the densimetric Fronde number is greater than 1. The jet velocities at the port are calculated to be 6.0 m/s, which meets the requirement for biofouling prevention. While the ratio between nozzle cross sectional area and outfall pipe is above 1:3, the high velocity of 6.0 m/s will result in significant head loss.

Multiport Diffuser

The other choice is to use a multiport diffuser that is multiple ports/nozzles on the outfall pipe. This option is considered only if the single port is not suitable from an environmental perspective, requiring distribution of the reject water discharge over greater area to meet the hydraulic/dilution requirements. Amongst the various options tested, one case of a multiport system is presented as shown below. In all cases, the riser depth is considered to be 1 m above sea bed (6m below chart datum):

Five ports with five risers, i.e. 1 nozzle per riser. The risers are considered to be 6.25m apart, for a total diffuser length of 25m. The nozzle diameter is 11 cm, meeting the design requirements for biofouling and headloss.

9.3.3 Model setup

The density of the effluent is lower than the ambient seawater density resulting in the effluent plume being buoyant and thus moving towards the surface. Increase of salinity values by 1 ppt at the bottom if limited to vicinity of the outfall are unlikely to cause an environmental impact of concern.

Ambient Conditions

The following ambient conditions were used for model setup

Seawater density : 1025 kg/m^3
Current : 0.1 m/s

Ambient Temperature : 30^oC
Stratification : well mixed (No stratification)
Distance to Diffuser :Distance at which 10m & 15m water depths are available, approximately 1000 & 1500m respectively
Depth at diffuser site : As digitized from survey map

Port Characteristics

The following discharge conditions were used in simulation runs using above ambient conditions

Single Port

Discharge : 0.19 m^3/sec
Pipeline Diameter : 250mm ID
Diffuser Diameter : 200 mm ID
Diffuser Height : 1m from Seabed
Diffuser issue angle : 45^o Vertical

Multiport

Discharge : 0.19 m^3/sec
Pipeline Diameter : 250mm ID
Nozzles : 5 nos.
No. of risers : 5 nos.
Port Diameter : 11cm
No. of Nozzle/riser : 1, pointing away from the shore along pipeline alignment
Diffuser issue angle : 45 ° to vertical, Horizontal
Diffuser height : 1 m above seabed

9.3.4 CORMIX simulations

The aim of these simulations is to identify a range of configurations, which satisfy the environmental requirement. Results of the simulations for various conditions are discussed in the followed paragraphs and tabulated in Table.

Table 9.3 Results of simulation

Case	Location of Outfall	Diffuser Configuration	NFR Location	Pollutant concentration at the edge of NFR
Single Port Diffuser				
Untreated waters (BOD = 150 mg/L)	10m Water depths 1000 m from the shoreline	Diameter of nozzle 0.2m Diffuser length = 25m Position = 1.0 m above	86.7 m	1.66 mg /L
Untreated waters (BOD = 150	15m Water depths 1500 m from the	Diameter of nozzle 0.2m Diffuser length = 25m	86.4 m	1.66 mg /L

Case	Location of Outfall	Diffuser Configuration	NFR Location	Pollutant concentration at the edge of NFR
(BOD = 150 mg/L)	shoreline	Position = 1.0 m above		
Multiport Diffuser				
Untreated waters (BOD = 150 mg/L)	10m Water depths 1000 m from the shoreline	Diameter of ports 0.11m No of diffusers = 5 Diffuser length = 25m Position = 1.0 m above seabed	69 m	2.92 mg /L
Untreated waters (BOD = 150 mg/L)	10m Water depths 1000 m from the shoreline	Diameter of ports 0.11m No of diffusers = 5 Diffuser length = 25m Position = 1.0 m above seabed	22m	0.8 mg/L

In each of the simulated runs, the distance for various dilutions is determined and tabulated. The estimation assumes the pollutant to be a non-conservative constituent that with a decay/loss 3 x 10^{-3}/sec of the material due to physical, biological, or chemical process. This is an environmentally conservative assumption, as losses due to decay and/or volatilization, if any, would reduce water column pollutant concentrations of BOD, fecal coliform in ambient environment still further.

9.3.5 Single Port – Case 1

The simulations were carried out for outfalls 1000 and 1500m from the shore. The average ambient velocity at the discharge location is not likely to exceed 0.4 m/s and in general will be around 0.1 m/s. Since high currents may dilute the concentration further, the behavior of the plume and the dilutions were evaluated for critical ambient currents of 0.1 m/s only measured during the survey. The low current velocity of 0.1m/s will be critical as also dilution will be minimal. Vertical angle of 45^o was considered.

In almost all of the cases, the plume configuration was a positively buoyant plume, such that the vertical angled discharge would result in an initial movement upwards and full mixing in the water column, followed by significant dilution as the plume is advected by the ambient currents. For the critical condition of low ambient flows, the 30 times dilution occurred within 25 m. The BOD concentrations would return to background values (i.e. within the range of measurement error where the difference between background values and the plume will not be discernible) within 50m.

Figure 9.1 shows the effluent plume plan view with distance from the diffuser. The side view of the plume shows that the plume will be positively buoyant, tending to move towards surface. The resultant BOD concentrations (Figure 9.1) indicate that dilution is significant within the 25m, with the receiving waters (ambient concentrations) reaching background levels. However, the momentum of the discharge jet may result in local scouring and may impede the flow of ambient waters locally, also resulting in sedimentation of suspended sediments. Thus the option of increasing the numbers of ports must be considered. Thus, the single port diffuser may not be suitable, although it may meet the water quality requirements.

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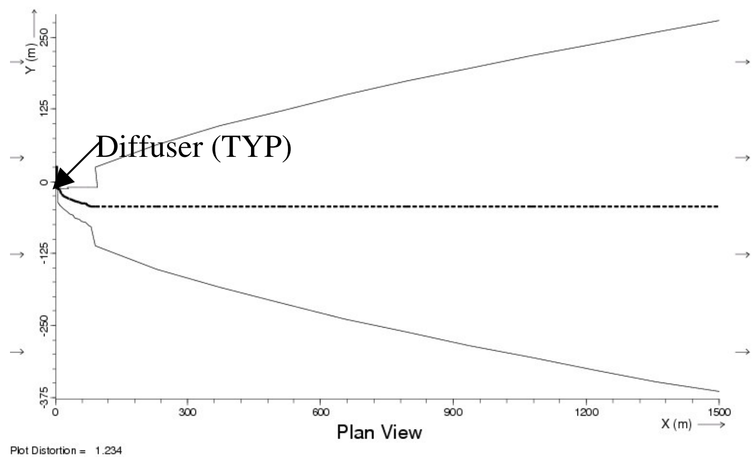
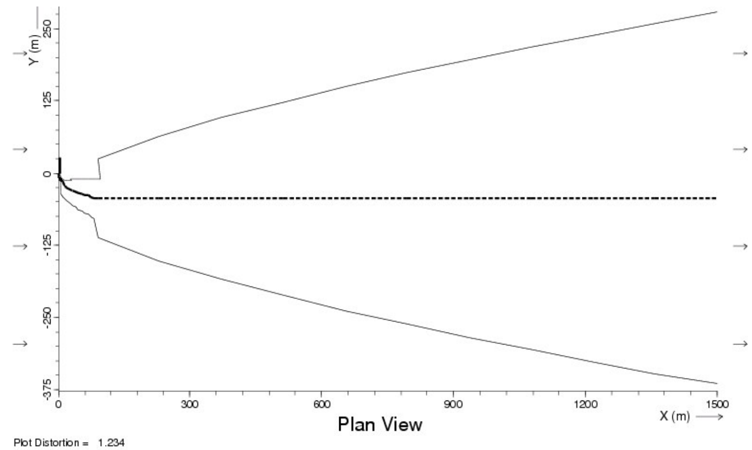
<tr><td>
</td><td>
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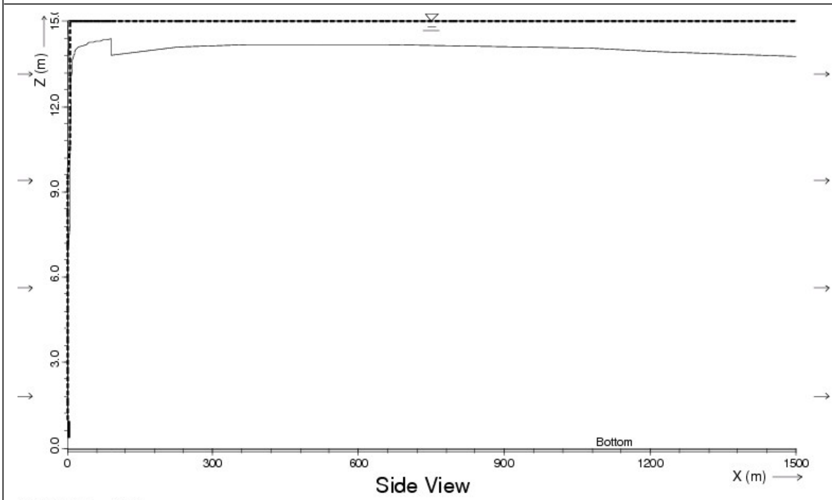
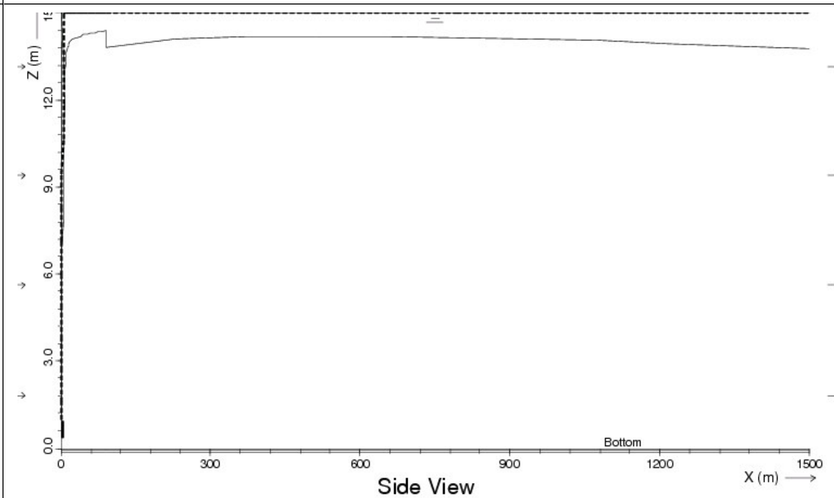
<tr><td>
</td><td>
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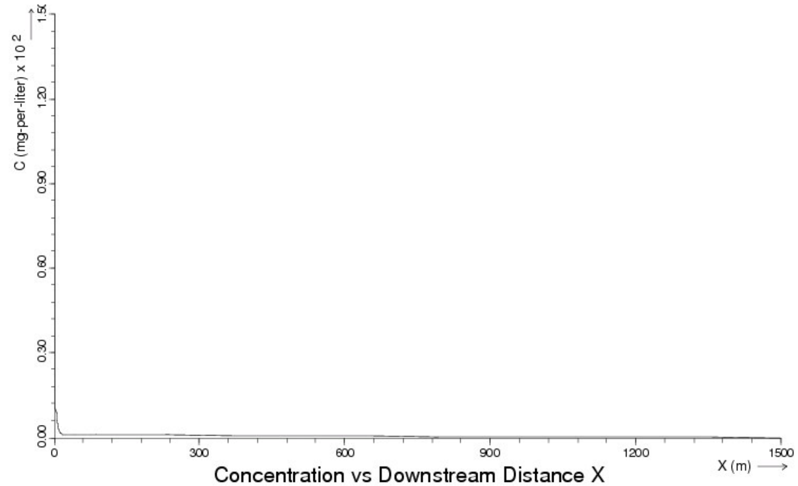
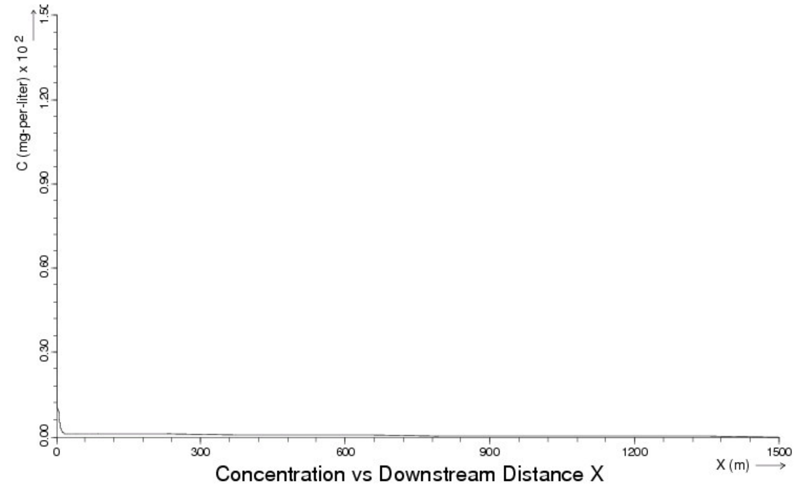
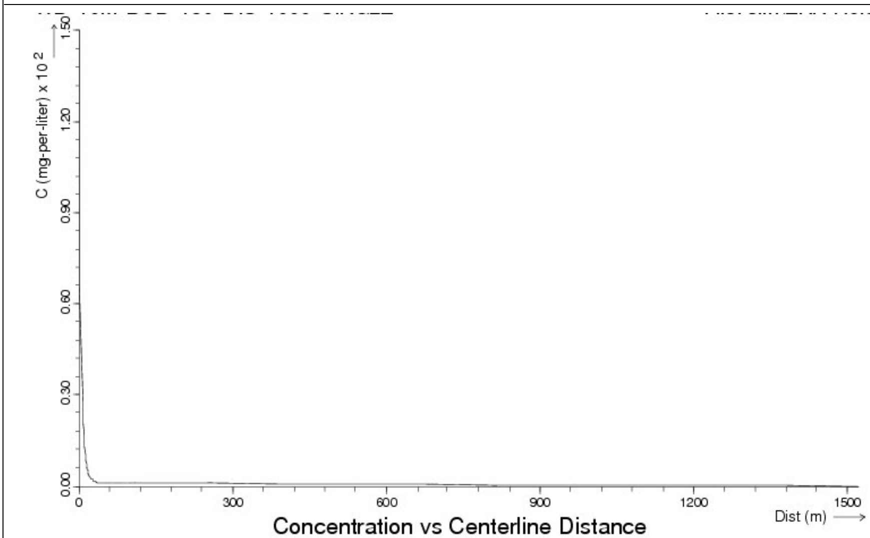
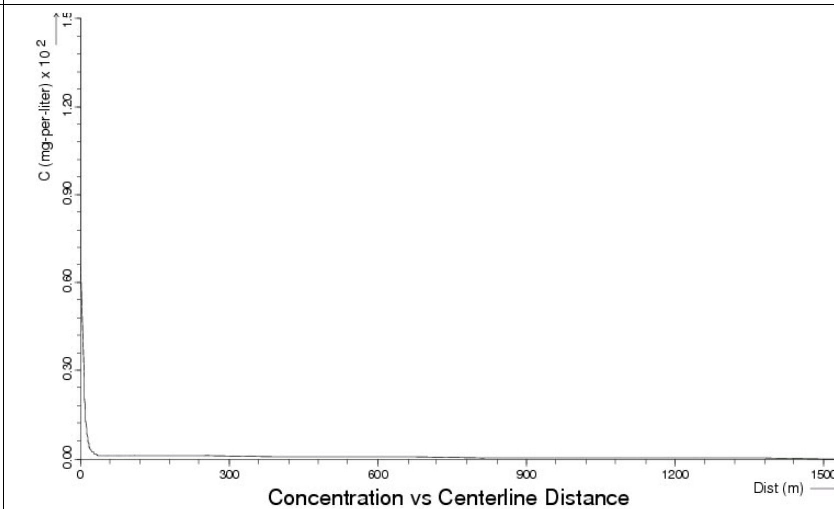
Discharge in 15 m water depth (Arrows indicate ambient flow direction)	Discharge in 10m water depth (Arrows indicate ambient flow direction)
	
	

Fig 9.1 Results of CORMIX for Single Port diffuser

9.3.6 Case 2 - Multiport Diffuser

Five risers with one nozzle each at 6.25m centers were used to distribute the effluent in the receiving waters. The risers are 11cm diameter, with a vertical issue angle of 45 degrees as shown in Fig. 9.2 and Fig.9.3. Plan view and buoyant tendency are shown (Fig. 9.4), which as mentioned in Case 1, is a conservative estimate. For the critical condition of low ambient flows, the 30 times dilution (to meet SW-IV standards) occurred within 25 m. The dilution of BOD is greater due to the higher local mixing (Fig. 9.4), showing an increase of less than 1 mg/L from ambient within 50 m. Since the momentum of the jet is lower, the local scouring will be decreased, while the discharge is less likely to influence local ambient flow. This design is preferred to that of the single port design.

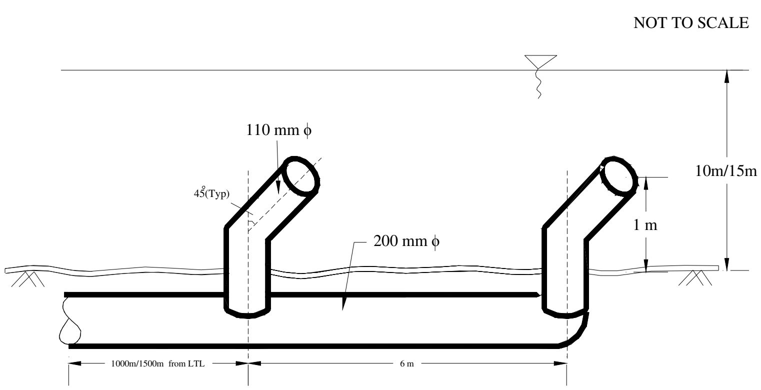


Fig 9.2 Diagram of Diffuser Block

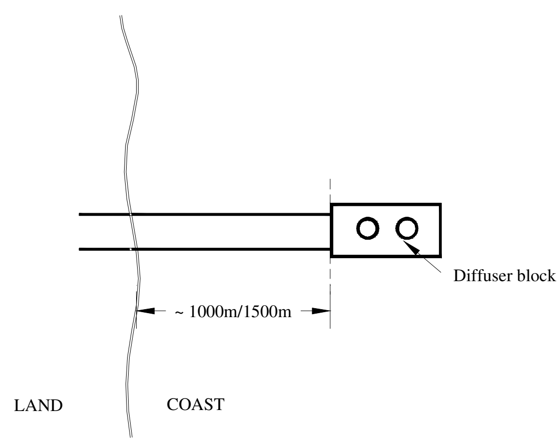
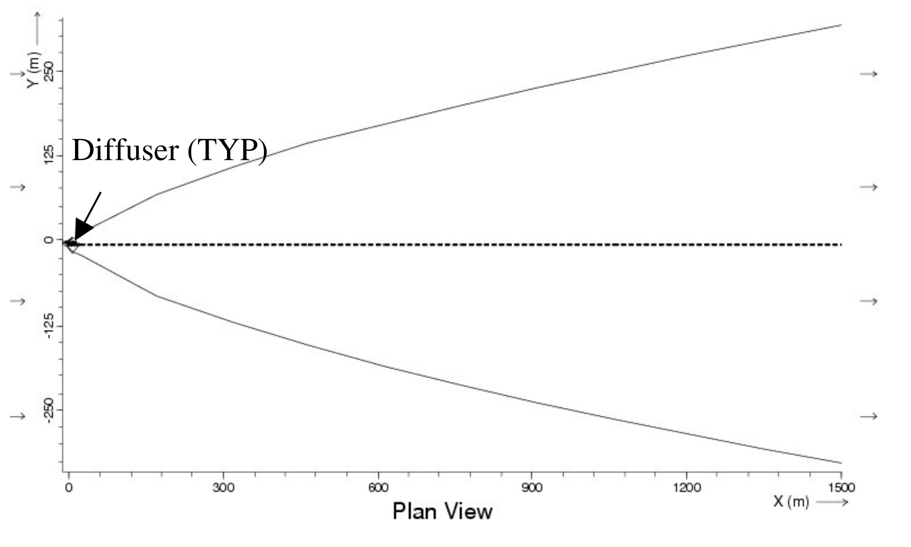
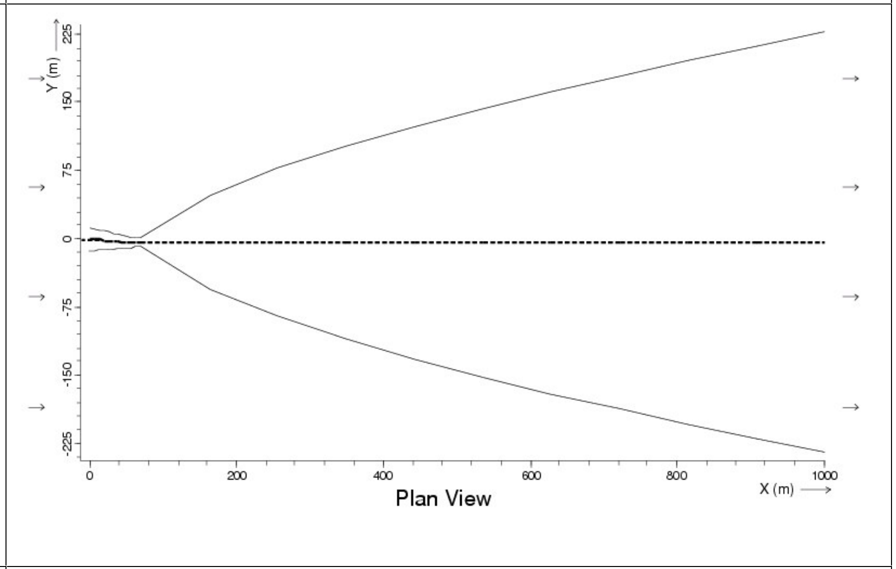
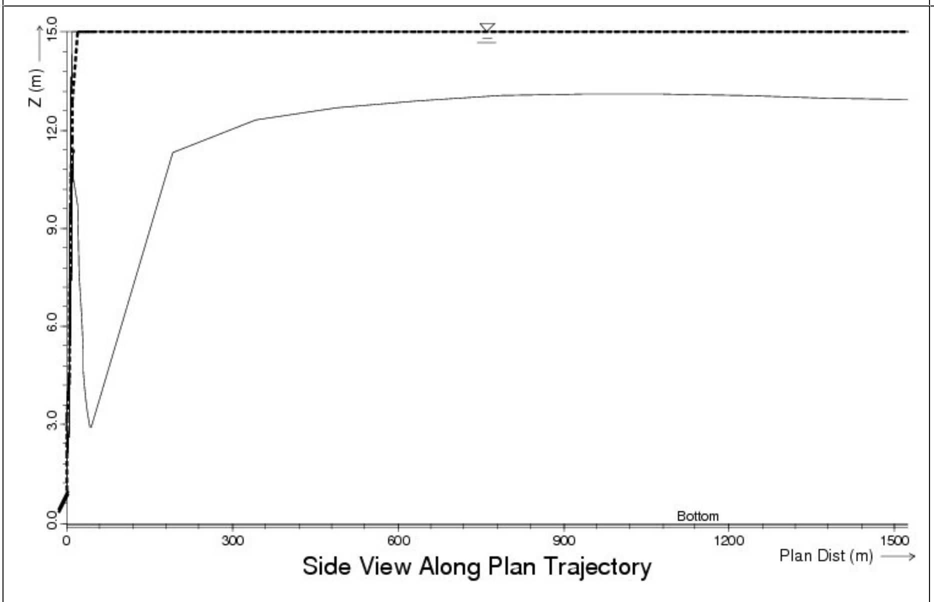
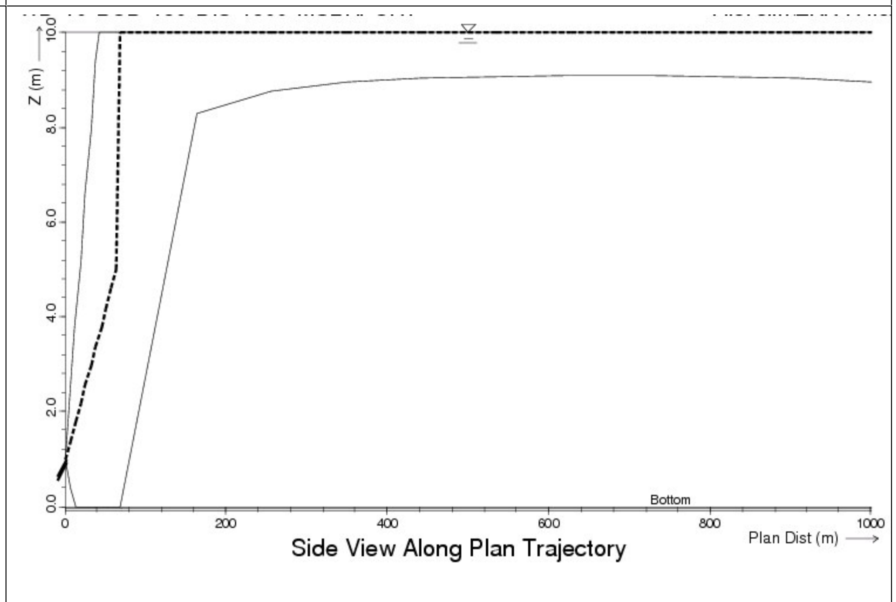


Fig 9.3 Schematic plan view of Outfall Pipe & Diffuser Block

Discharge in 15 m water depth (Arrows indicate ambient flow direction)	Discharge in 10m water depth (Arrows indicate ambient flow direction)
	
	

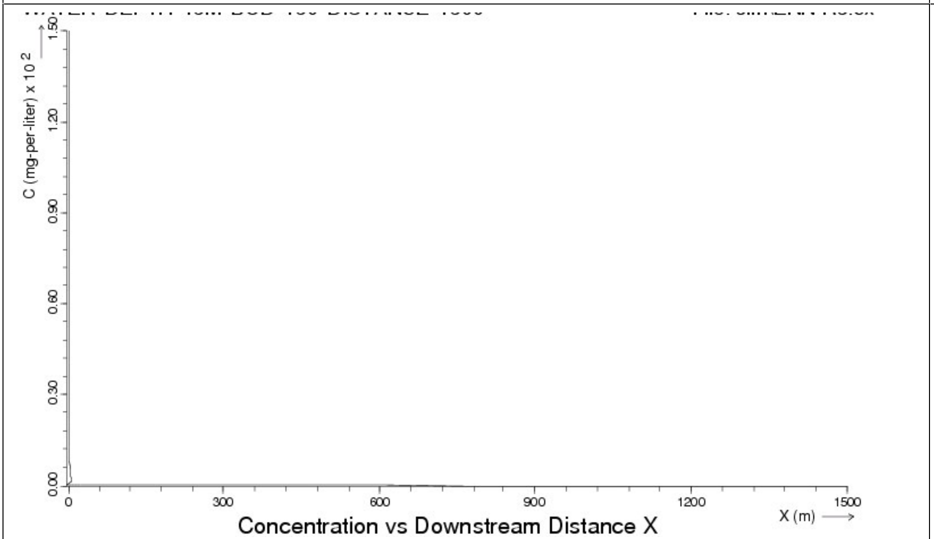
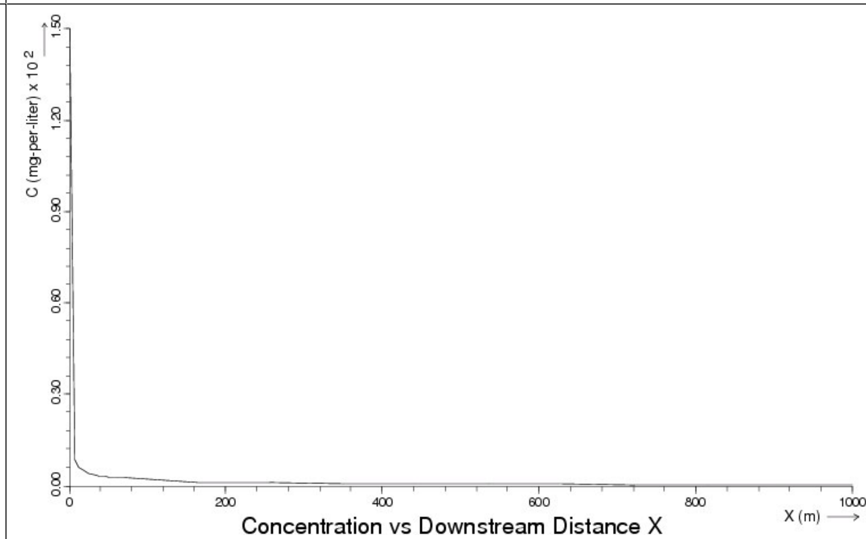
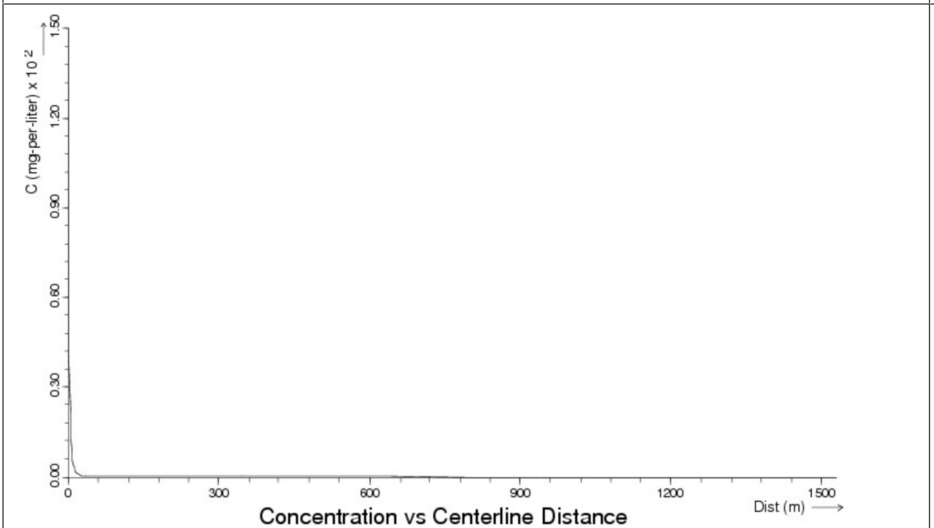
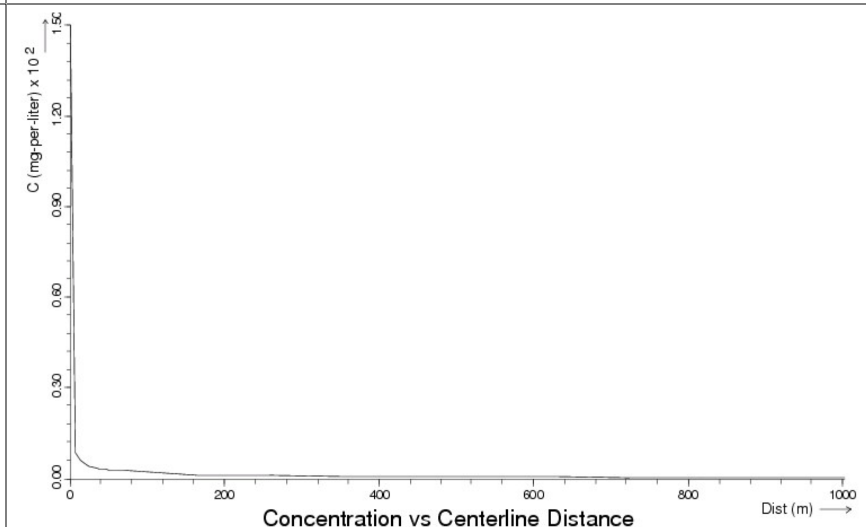
Discharge in 15 m water depth (Arrows indicate ambient flow direction)	Discharge in 10m water depth (Arrows indicate ambient flow direction)
	
	

Fig 9.4 Results of CORMIX for Multiport diffuser

10.0 CONCLUSIONS

The waterways of Chennai such as Adayar, and Cooum Rivers and the Ennore Creek have their negligible dilution / assimilative capacity. This is due to the large volumes of municipal and industrial effluents from several non point sources and unauthorized discharges and the low hydrodynamic capacities (low dilution and negligible exchange with the ocean waters) from frequent mouth closures. From the WLA study conducted for the Ennore creek, it is evident that the water quality issues in the Ennore Creek are DO/BOD, pathogen and Eutrophication related. The coastal water issues are pathogen related from alongshore transport of untreated sewage outfalls at Royapuram. Modeling conducted for the Ennore Creek waters with reduced BOD and pathogens (after secondary treatment) do not result in substantial improvement in the water quality. Secondary treatment will also maintain nutrient levels at status quo without reduction and thus Eutrophication in the creek will continue.

With the projected increase of 13.14% and 11.61% in 2010 and 2020 respectively, the severe Eutrophication issues would warrant tertiary treatment notwithstanding the proposed 6 treatment plants proposed by the Chennai Metropolitan Water and Sewerage Board. Wastewater plant capacity must be designed for critical scenarios when the water temperatures are the highest, freshwater/dilution flow is lowest and during neap tides. Removal of nutrients through tertiary treatment may result in reduced Eutrophication, albeit at significant costs.

However, it needs to be noted that in the absence of contact sports and fishing in the North Chennai coastal waters and the Ennore Creek, the uses of these waters do not warrant such high investments. It is therefore critical to evaluate the efficacy of these schemes that target discharge of treated effluent into inland waters like the Adyar, Cooum and Ennore Creek. Failure to remove the excessive nutrient loads will result in Eutrophication, eventually leading to DO, biomass and odor problems. Perceptible improvement in water quality may be marginal. Therefore the most viable long-term alternative would be to discharge the effluents in deep ocean waters through marine outfalls.

Similar water quality assessments made by NIOT in the Vishakhapatnam harbor area between 1999 and 2001 for the COMAPS program of the DOD indicate that the inner harbor is heavily polluted with violation of SW-IV standards for DO and BOD in these locations, which are indicative of high municipal loads leading to Eutrophication of the water bodies. An ocean outfall outside the outer harbor was suggested by NIOT for Vishakhapatnam also.

Therefore for coastal cities with high population growth, the option to dispose treated effluents to open coastal waters would be the most appropriate. This approach was followed in the case of Mumbai where the assimilative capacities of the Thane and Mahim creeks are low, warranting ocean disposal systems.

Thus multiple ocean outfalls in deeper depths are recommended for disposal of wastewaters draining to the Chennai waterways and into the North Chennai coastal waters.

In addition to this long-term solution, the following concerns shall need to be addressed for effective water quality management,

- Monitoring of untreated municipal wastewater discharges into the water bodies in addition to monitoring of industrial effluent discharges
- Monitoring of receiving water quality in addition to monitoring of industrial outfalls in order to determine the discharge limits
- Insistence of life-cycle assessment by the industries of its goods and services. For e.g., oil tanker washings and treatment of the wastewaters may be carried out inside the refinery premises
- Focus of receiving water quality monitoring programs such as COMAPS on site-specific issues / discharge, water uses so as to capture comprehensive information and local problems and set itself the goal of management of water quality to conform to use standards..

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