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Thermal pollution modelling of cooling water discharge into a closed creek system

S. Buvaneshwari[1]*, Vijaya Ravichandran[2] & B. V. Mudgal[3]
[1]Indian Institute of Science, Department of Civil Engineering, Bangalore, India
[2]Coastal and Environmental Engineering Division, National Institute of Ocean Technology, Chennai, India
[3]Centre for water resources, Anna University, Chennai, India
*[E-mail: buvanasriramulu@gmail.com]

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This paper is focused on the behaviour of the heated effluent discharged at an elevated temperature into the Ennore creek by North Chennai Thermal Power Station (NCTPS). Functioning of thermal power plants near tidal creeks and estuaries, due to the feasibility of intake and discharge of water for cooling poses serious environmental concern from heated water discharge due to the flow characteristics of the creek. Discharge of the heated effluent and its dispersion is a function of ebb and flood flow into the Ennore creek as the creek mouth remains closed for most part of the year. This study aims to investigate the dispersion characteristics of the heated effluent in the near-field and far-field under various discharge and dynamic conditions of the creek using calibrated hydrodynamic models and comparison with the field data measured during varying tidal conditions.

[**Keywords:** Thermal Pollution, Hydrodynamics, CORMIX, MIKE21]

Introduction

Urban sprawl, industrialization and development, fuel the insatiable demand for energy. Thermal power contributes to the major portion of the power demand. It uses the fossil fuel to generate power. The heat that is generated by the power plants needs to be taken out of the system and is generally done through cooling waters. If the cooling water is recycled, then cooling towers are adopted, else in a once through cooling systems the heated water is safely discharged back into the water bodies adhering to the norms. Here heated water becomes the pollutant.

Tamil Nadu Electricity board operates a thermal power station of 600 MW capacity at Ennore, North Chennai Thermal Power Station (NCTPS). The power plant uses sea water to meet its cooling water requirement and the condenser reject heated water which is about 8°C higher than the intake waters is let into the Ennore creek. The heated water discharge is about 27.5 m^3/s. Ennore creek is a dynamic and ecologically sensitive water body receiving waste water from numerous sources including industrial and municipal effluents.

In open coastal waters effluent discharged from outfalls undergoes rapid initial dilution, typically within a few hundred meters of the outfall, before reaching either a level of neutral buoyancy or the ocean surface. It undergoes a number of physical, chemical and biological processes in the water column before being transported out of the region or settling down into the sediments or being accumulated by biota. Mixing and dilution of the effluent occur due to turbulence that causes entrainment and diffusion. The source of this turbulence changes with distance from the discharge point. Near the diffuser, the primary source of turbulence is shear, induced by the discharge momentum and buoyancy. Local currents and local boundaries may modify this "self induced" turbulence. This region is often called near field or initial mixing region. Farther from the diffuser, this self-induced turbulence decays, and mixing is primarily due to turbulence naturally present in the ocean. This region is called far field[1,2].

A prerequisite for estimating the changes to the water environment is the understanding of the movement of the water mass as defined by the waves and tides, otherwise called wave and tidal hydrodynamics and current circulation patterns. Behaviour of plumes from ocean outfalls can be predicted using numerical models and assessment needs to be made of the three different stages, viz., initial dilution (near field modeling), transport (advection and dispersion modeling) and decay (fate) of pollutants (water quality modeling).

The mixing and transport process in the creek is highly dependent on the tidal ebbing and flooding conditions[3,4]. Shoreline changes along the Ennore coast and closure of the creek mouth due to sand bar formation results in low circulation of flow in the creek. This study aims at modeling the fate and transport of thermal discharges into the Ennore Creek in the near field and far field. The model results are validated against real time measurements observed in the field during various seasons of a year and different times of the day given the influence of ambient temperature on the advection-dispersion characteristics of the creek.

Materials and Methods

Study area

Ennore Creek

The southeast coast of India is an important stretch of coastline, where many major rivers drain into the Bay of Bengal and they are also richer in marine fauna than the western coast of India. Ennore creek (13°13'54.48" N, 80°19' 26.60" E) is located in the northeast coast of metropolitan Chennai city, Thiruvallur district, Tamil Nadu, India as shown in Fig. 1.

Most of the area consists of alluvial tracts and beach dunes, tidal flats and creek in the eastern part. Ennore comprises of lagoons, with salt marshes and backwaters, which are submerged under water during high tide and form an arm of the sea opening in to the Bay of Bengal. The total area of the creek is 4 km^2 and is nearly 400 m wide. Creek channels connect to the Pulicat Lake in the north and to the Kortalaiyarriver in the south.

Ennore creek was once a place with rich flora and fauna. It was not only the nature's gift but also a predominant source for supporting the traditional fishermen community settled in this Creek. The creek once filled with rich biodiversity contributed an excellent green belt which is now totally taken out by the untreated sewage from Royapuram sewage outfall, untreated and treated industrial effluents from Manali Industrial Belt, which houses huge number of chemical industries. The natural wealth of the creek is given place to sewage channel and the biological productivity of the coast has come down. The northern section of the creek is the Kosasthalaiyar backwater which is connected to the Pulicat Lake, with North Chennai Thermal Power Plant and the satellite port of Ennore. Wastewater enters the creek through the Buckingham canal in the north and south of creek, Kortalaiyarriver and Amullavoyal canal in the south. Ennore Thermal Power Station ETPS withdraws cooling water from the creek and disposes warm water into sea through marine outfall.

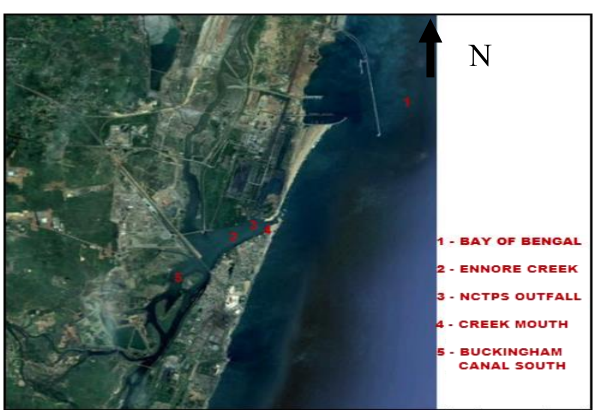

Fig. 1—Ennore Creek-Environs

North Chennai Thermal Power Station (NCTPS) unit discharges the cooling water into Buckingham canal which joins with Ennore Creek. It has a open pre cooling channel having width up to 130 m for about 2.5 km, after flowing through the existing warm water channel for about 2 km, the warm water travels a distance of 4.5 km to reach the Ennore creek and thereby mixing with the creek water. The objective of such an arrangement was to bring down the thermal pollution.

The frequent closure of the Ennore mouth has resulted in insufficient tidal inflow and thus reduced cooling waters for the thermal power plants. Hence NCTPS has 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, it has stopped withdrawing water from creek and now intake water for cooling is taken inside Ennore port.

Ennore Creek Mouth

The currents in the coastal waters are influenced by the seasonal circulation in the Bay of Bengal. Currents move along the coast towards the North from March to October and move towards south from November to February. The flood and ebb tide is a significant component of the discharge characteristics in the Ennore creek.

The dynamic Ennore creek mouth influences the current and tide pattern inside the creek, the currents are generally tidally influenced depending on the mouth condition. As a part of the study the width of the creek mouth was measured in the month of April and it was found that it was 72 m wide.

Field Investigation

The temperature observation of NCTPS plant effluent is divided into two parts as shown in the Fig. 2.

In Fig. 2 I indicates the observations inside the NCTPS plant of about 2 km stretch channel and the measurements with respect to discharge, velocity profiles, depth, temperature are taken using Q-Liner instrument which works under acoustic Doppler principle.

The region II (Fig. 2) indicates the observations of the temperature inside the creek for spring tide and neap tide and it is covered for both flood and ebb tide conditions using the YSI probe.

NCTPS Effluent Dispersion- Choice of model

Dispersion and mixing of pollutant concentrations in receiving waters is dependent on the ambient conditions of the receiving environment and discharge characteristics of the effluent. The ambient conditions are defined by the water body's geometry, currents, as well as its dynamic characteristics. The discharge conditions are a function of outfall geometry (diameter, height above bed, orientation) and flux characteristics (discharge rate, density, momentum and buoyancy)[5, 6].

Immediately after the effluent exits the diffuser into the ambient waters, the initial jet characteristics of momentum flux, buoyancy flux, and outfall geometry influences the jet trajectory and mixing. This region will be referred to as the "near-field", where outfall design can control the initial mixing characteristics through adjustment of design variables. In this region, the effluent jets are turbulent fluid zones in which vigorous mixing takes place. The USEPA length scale rule based empirical CORMIX model is particularly useful in the near field as turbulence modeling using deterministic hydrodynamic approaches is very complex[7].

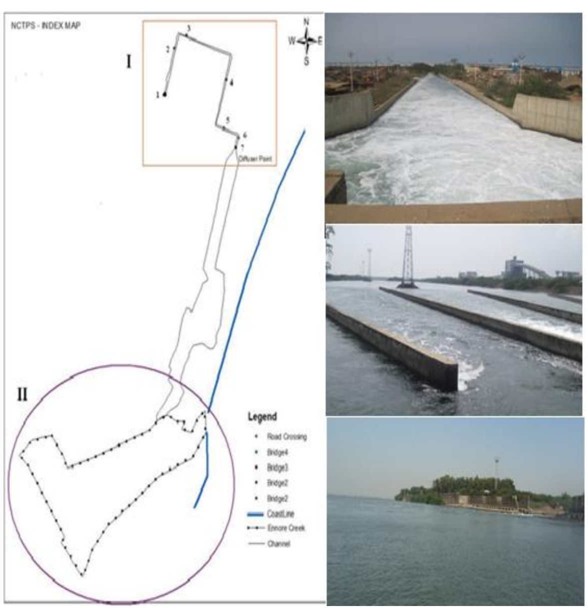

Fig. 2—Layout of NCTPS Thermal Discharge

Beyond the near field, ambient currents and density stratification gradually deflect and mix the plume into the predominant flow. As the turbulent plume travels further away from the source, the source characteristics become less important. The ambient environmental conditions will control trajectory and dilution of the turbulent plume through buoyant spreading motions and passive diffusion due to ambient turbulence. This region will be referred to here as the "far-field"[8]. Thus, the designer must keep in mind that minor geometric changes in the diffuser block may alter plume characteristics in the near field, while changes in the far field may need alterations in the significant geometric changes such as wider spacing between risers/ports[9].

CORMIX predictions in the near field are often benchmarked by some modellers, yet the model is limited in its ability to predict far field plume characteristics. Another model used for diffuser design is USEPA's PLUMES (DOS version) or Visual Plumes (Windows version). For far field predictions, deterministic 2-D and 3-D hydrodynamic models like USEPA's HSCTM2D and EFDC, Danish Hydraulic Institute's MIKE21 and MIKE3 are considered to be more suitable. In nearshore coastal waters, where ambient conditions can be turbulent due to waves, currents and winds, CORMIX's far field formulations are likely to be conservative. Thus, for large discharges, models such as MIKE21 should also be considered. For cooling water effluents from power plants and brine effluents from desalination plants, buoyancy flux is important[10]. As the effect of the relative density difference between the effluent discharge and ambient conditions in combination with the gravitational acceleration determines the tendency for the effluent flow to rise (i.e. positive buoyancy) or to fall (i.e. negative buoyancy). This study uses CORMIX3 as well as MIKE21.

The modeling of NCTPS effluent dispersion into Ennore creek is done for the present discharge rate 27.5 m^3/sec by varying the creek mouth conditions. Indicates the present plant capacity (600MW) discharge that is let into the creek after travelling a distance of about 4.5 km inside the NCTPS plant and the hydrodynamic conditions comprise flooding and ebbing of spring and neap tides under creek mouth open and closed condition. The hydrodynamic dispersion characteristics of the thermal effluent discharge by NCTPS at Ennore creek is modelled using CORMIX3 for near-field dispersion characteristics and MIKE21for the far-field dispersion characteristics. Model results are compared with the field observations to ensure the applicability of the hydrodynamic model to this problem. The temperature observations in the Ennore creek for the spring and neap tide are generated as temperature plots for the flood and ebb tide using the software surfer.

Further the MIKE21 hydrodynamic model is used to predict the dispersion characteristics for the excessive discharge. The scenarios simulated for the heated effluent dispersion are given in the Table 1.

Results

Field Observation inside NCTPS

North Chennai thermal power station a 600MW capacity plant discharges 27.5 m^3/sec of condenser reject water at about 5°C to 8°C above the ambient, travelling a distance of about 2 km in a lined channel and then into a very shallow water body of about 2.5 km distance inside the NCTPS plant and reaches the Ennore creek.

The first set of measurements started from the NCTPS condenser reject into the channel. Since the channel sides were covered by bushes taking temperature measurements with the Q-Liner was difficult hence seven bridge sections as given in table 2 were selected to deploy the instrument to measure the discharge, depth, surface temperature and velocity profiles. The temperature was also measured with respect to depth using YSI probe and it was observed there is no thermal stratification along the depth of 2 m. The results also indicated that the temperature drop was negligible over a distance of 4.5 km.

Q-liner output

i. Flow rate = 27.13 m^3/sec
ii. Velocity = 1.2 to 0.9 m/sec
iii. Depth = 2.33 m
iv. Temperature = 36°C

The condenser reject temperature depends on the intake sea surface temperature. These measurements were taken in February 2011.

Field Observation inside the Creek-Flood Tide

In order to measure the extent of dispersion in the creek, temperatures were observed using YSI probe and the locations are noted using hand held GPS. The observations were made on spring and neap tide days during the month of April and May in each day temperature was measured in the creek starting from creek mouth up to Buckingham canal during flood tide and ebb tide.

The temperature dispersion plots for the present discharge condition is generated using surfer for the tidal flow condition in the creek.

The temperature observation in the Ennore creek is covered for 3 hours before the start of ebb tide, when

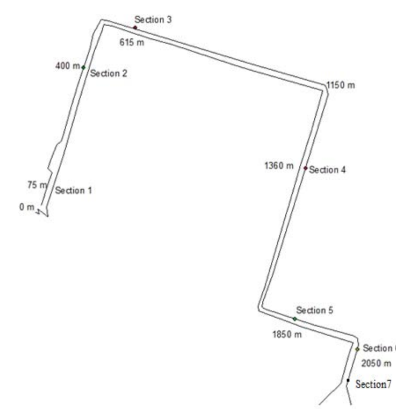

Fig. 3—Measurements in the NCTPS Channel Bridges

Table 1—Simulation Scenarios of MIKE21

Scenarios	Width of the Mouth (m)	Discharge rate (m^3/sec)
Creek Mouth Open	210	27.5
Creek Mouth Close	72	27.5

Table 2—Temperature Measurement Section Location

Location	Latitude	Longitude	Remarks
Location 1	80° 19' 40"	13° 15' 38"	starting point
Location 2	80° 19' 43"	13° 15' 47"	Bridge 1
Location 3	80° 19' 48 "	13° 15' 50"	Bridge 2
Location 4	80° 20' 03 "	13° 15' 39"	Bridge 3
Location 5	80° 20' 02 "	13° 15' 25 "	Bridge 4
Location 6	80° 20' 07"	13° 15' 24"	Bridge 5
Location 7	80° 20' 06"	13° 15' 19"	Diffuser point

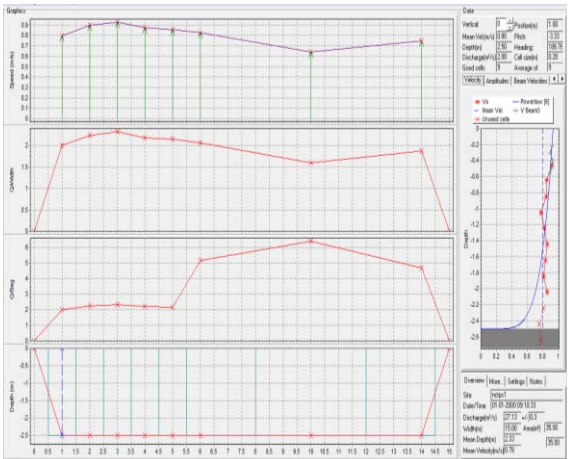

Fig. 4—Q-Liner Output

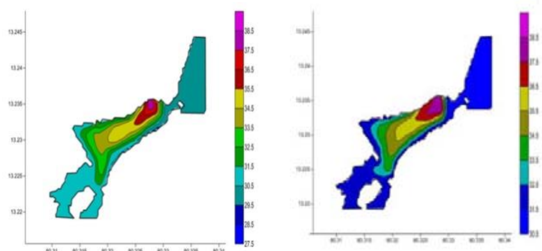

Fig. 5—Flood Tide Temperature Plots-April 2011 Spring and Neap

almost the whole creek is filled with the seawater as the maximum flood tide condition is reached. It was observed that the temperature of the NCTPS effluent entering the creek varied 8°C to 9°C above the ambient in April which is the most critical period as the ambient temperature is high in summer when compared to other seasons and the thermal plume travels the entire creek distance of about 1 km before dispersing to the ambient conditions. This is observed for the spring tide of April and May flood condition as shown in Fig. 6 and Fig. 7. The temperature plot of neap tide indicates likely, rise in temperature of about 0.5°C to 1°C which may be due to the solar radiation and the time of the day during summer when the measurement was made. It needs to be noted that daytime of summer is the most critical period for temperature rise in the ambient as well as in the effluent water.

The temperature observation in the Ennore creek is covered for duration of 3hours before the start of flood tide. The thermal effluent dispersed in the creek is travelling a distance of about 500 m from the discharge point to the creek mouth, as it is pushed by the creek water to the open sea as shown in the Fig. 7.

The thermal plume movement towards the sea at a high temperature of about to 5°C above the ambient

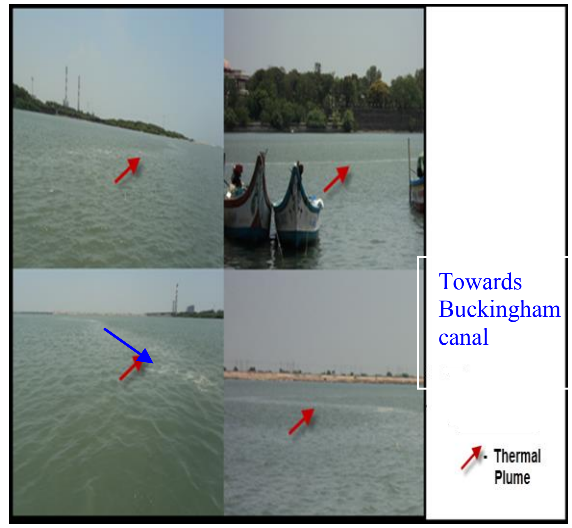

Fig. 6—Thermal Plume Trace during Flood Tide

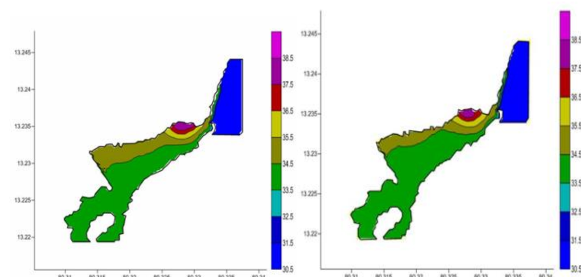

Fig. 7—Ebb Tide Temperature Plots- April 2011Spring and Neap

Fig. 8—Thermal Plume Trace during Ebb Tide

and this phenomenon is predominant during April. The solar radiation is observed to play a vital role in raising the temperature of about 0.5°C to 1°C during noon which is spread over the entire creek causing negligible variation in the temperature profile.

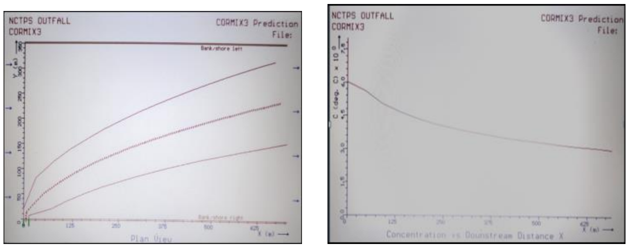

Fig. 9—Plots of Present Discharge during Flood Tide

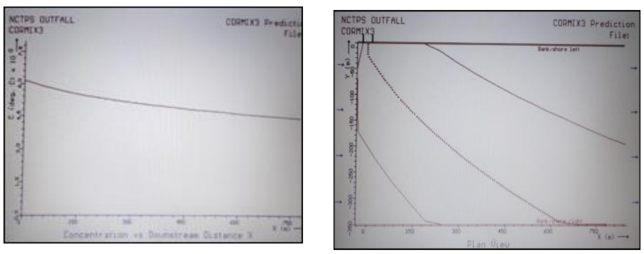

Fig. 10—Plots of Present Discharge during Ebb Tide

It indicates the thermal plume being pushed by the creek water from Buckingham canal and Kortalaiyar River, thereby the plume gets deflected towards the sea. The observations were also made along the trajectory to trace out the temperature variation along the thermal plume trajectory.

Thermal Dispersion (27.5 m^3/s) of NCPTS Effluent during Flood Tide using Cormix3

It is found that the temperature at the end of near-field is 4°C above the ambient and it is not completely dispersed even after a distance travel of about 625 m towards the Buckingham canal.

It is found that the temperature at the end of near-field is 5°C above the ambient and it is not completely dispersed even after a travel of about 750 m towards sea as the thermal plume gets deflected by the creek water.

Thermal Dispersion (27.5 m^3/s) for Creek Mouth Open Condition using Mike21

Indicate the thermal plume being pushed towards sea and travelling towards port and the effect is felt to a distance of 500 m at 5°C above the ambient and enters the Buckingham canal at 4°C above the ambient and thermal plume width of both tide is less when compare to mouth close condition.

Comparison of Model Results with Field Data

The Thermal plume simulated by the CORMIX3 and MIKE21for the present discharge under creek mouth closed condition is compared with the surfer plots generated by the field data for various tides. The model results and surfer plots are compared at the

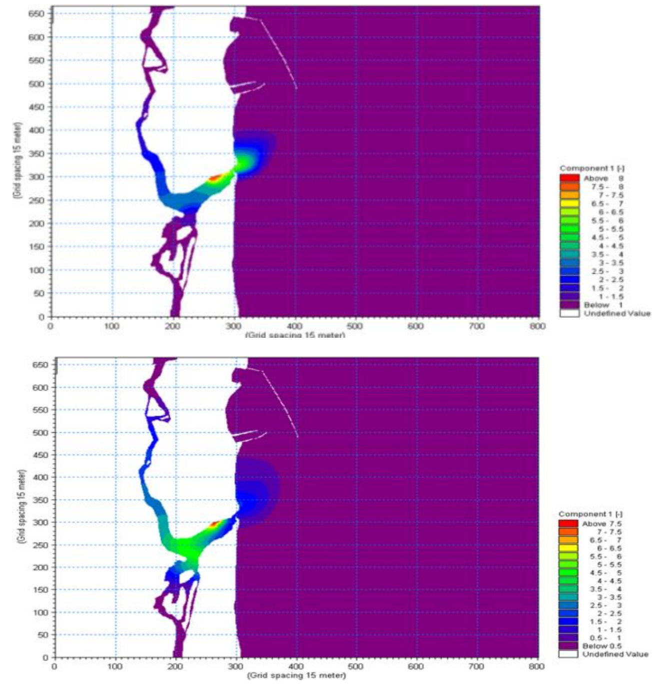

Fig. 11—Thermal Dispersion from Low Tide to High Tide

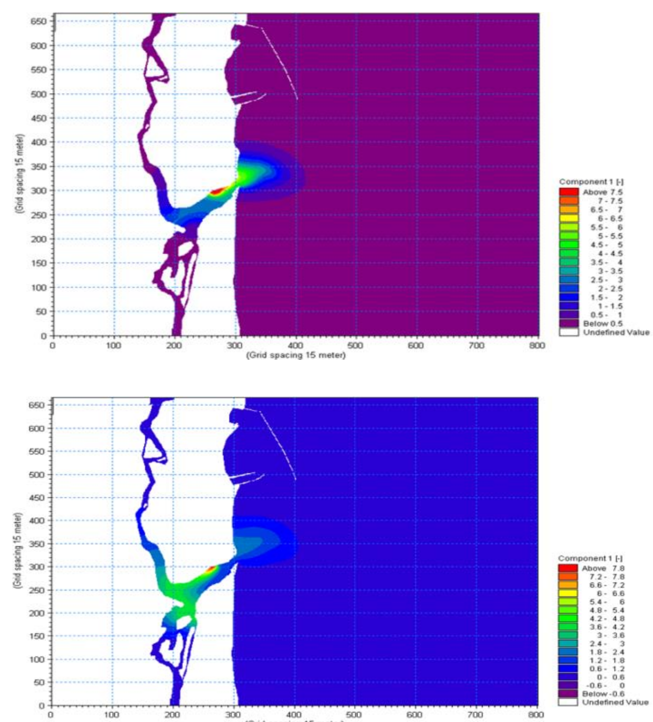

Fig. 12—Thermal Dispersion from Low Tide to High tide

entrance of Buckingham canal and at the creek mouth point opening to sea. As MIKE21 gives a time series data the average temperature of flood and ebb tide is taken for comparison. In CORMIX3 the temperature at the downstream coinciding with the points of comparison is taken into account. The temperature at the Buckingham canal during flood tide is 4°C above the ambient and at the creek mouth 5°C above the ambient during ebb tide, are matching with the model results and the temperature plots. Thus the results showed a good argument with the field data emphasizing the proper simulation of the model.

Conclusions

The near-field dispersion characteristics of the NCTPS heated effluent discharge during flood tide simulated using CORMIX3 surface buoyant discharge of about 27.5 m^3/sec indicates a plume travel distance of about 625 m towards Buckingham canal and the temperature at the near field region end is 4°C above the ambient. This indicates the temperature is not dispersed in the Ennore creek of 2 km stretch. Further the plume enters the Buckingham canal at a temperature rise of about 3°C above the ambient and during ebb tide condition plume travels a distance of about 750 m towards sea and the temperature at the near field region end is 5.5°C above the ambient. As the NCTPS outfall is close to the creek mouth, the flow getting reversed during ebb tide condition deflects the plume at a shorter distance and reaches open sea at an elevated temperature.

The far-field dispersion behaviour of the heated effluent is simulated using MIKE21 Advection Dispersion Model for the creek mouth closed and open condition for a discharge rate of 27.5m^3/sec. The results showed a good variation of temperature with respect to time, a clear picture of the thermal plume movement with respect to flood and ebb condition and it is found that the effect of thermal plume is felt to a distance of 500 m towards Ennore port during ebb and the thermal plume travels a distance of 1.5 km and reaches the Buckingham canal at 4°C above the ambient.

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