Modelling of Heat Dispersion of Hot Water Discharge of the Cooling Plant of the Meghnaghat Power Plant

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Abstract Power plants normally use river water for cooling of condensers and discharge cooling water back to the river at a higher temperature. The cooling water will initially stay at the surface while it is being transported with the river flow, and gradually it will start mixing with the river water. The stratification will be weak because of small density difference. Therefore, a high vertical mixing can be expected, meaning that from the outlet the heated top layer and the river water below will have mixed into one homogeneous layer with respect to temperature. The heat dissipation rate is strongly related to the wind speed and air temperature and it also depends on the water depth. Modelling of hydraulic aspects of re-circulation of cooling water for the design and construction of Meghnaghat Combined Cycle Power Plant has recently been done using advance numerical modelling system MIKE 11, MIKE 21 and MIKE 3 developed by Danish Hydraulic Institute (DHI). While, one-dimensional modelling (MIKE 11) has provided flow information for the large complex river system of Bangladesh, two-dimensional modelling (MIKE 21) has provided the depth integrated flow description in more details and three dimensional modelling (MIKE 3) has taken into account the vertical variations. The processes, which have been taken into account in the modelling are advective transport, density driven flow, dispersion due to turbulence and diffusion due to temperature gradients. In the Meghna river, the dominant mode of transport of cooling water is found to be the advective transport. The horizontal and the vertical diffusion and dispersion is found to be secondary importance.

Keywords: Mathematical Modelling; Cooling water; Dispersion; Diffusion; Advective transport.

1. INTRODUCTION

A modelling study was carried out by Danish Hydraulic Institute (DHI) in association with Surface Water Modelling Centre (SWMC) in connection with designing the cooling water system of Meghnaghat Combined Cycle Power Plant (CCPP) [DHI in association with SWMC, 2000 and 2001]. The study approach has involved extensive use of advanced numerical modelling system for simulation of hydrodynamics and heat dispersion in 1D, 2D, as well as 3D models. The processes, which have been taken into account in the modelling are advective transport, density driven flow, dispersion due to turbulence and diffusion due to temperature gradients. In the Meghna river, the dominant mode of transport of cooling water is found to be the advective transport. The horizontal and the vertical diffusion and dispersion is found to be of secondary importance.

1.1 Study Area

The study area (Figure 1) encompassed by the present study is located at the border of the North Central and South East Region of Bangladesh.

Upstream, near Bhairab Bazar, the Old Brahmaputra tributes to the Upper Meghna and downstream, near Kalagachia, Dhaleswari joins the Meghna which is further joined by Lakhya river originating from the Old Brahmaputra. Behind the site of the power plant there is a channel with two connections to the Meghna, approximately 1.5 and 2.5 kilometers downstream of the site. Upstream of the site there is a minor channel which is connected to the Meghna river.

The local surface water hydraulics around the site are rather complex. The area is influenced by tidal action, which is significant during the dry season.

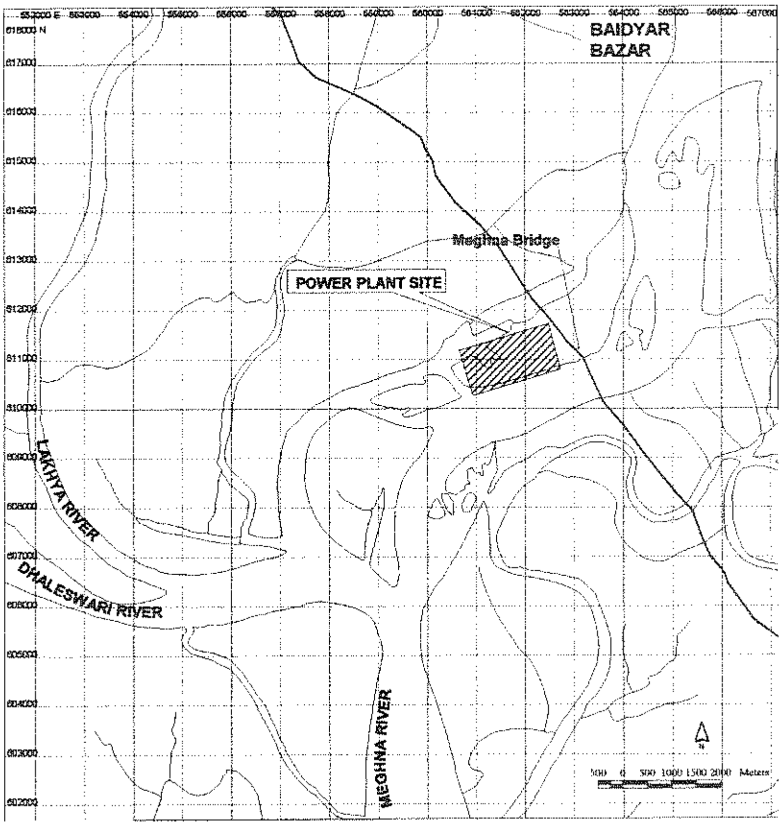

Figure 1. Study area with site location.

Wind conditions are generally light with wind speed around 1-2 m/s, and rarely exceeding 5 m/s. Wind directions are varying, though depending on the season with a north-westerly (NW) direction being typical for the dry season and a south to south-easterly (S, SE) directions being typical for the monsoon period.

Daily temperature varies typically between 15°C to 28 °C in the dry season and between 25 °C to 32 °C in the wet season.

1.2 Plant Operation and Cooling Water System

The plant is planned for operation in two different modes, viz. normal operation and bypass operation. Cooling water will be extracted from the Meghna River and discharge back to the Meghna River at a higher temperature.

The maximum cooling water demand has been estimated to range from approximately 15.8 m3/s to 17.4 m3/s, depending on the river state. Excess temperatures after passing the power plant condensers have been estimated to range between 5.3 °C to 5.7 °C at normal operation and between 7.3 °C and 8.4 °C at bypass operation.

The discharge of heat to the river water can be estimated at around 370 MW at normal operation and 530 MW at bypass operation.

The present design considers different alternatives for the cooling outlet, including:

- Outlet location approximately 1 km downstream of intake, established as a canal extending to the site embankment.
- Alternative discharge via a submerged pipeline (Ø 3000mm) penetrating the site embankment some 60 m downstream of the intake and extending 100 m towards the river from the site boundary.
- As above, but with the pipeline extending 150 m towards the river.

1.3 Principles of Combined Modelling

In the study MIKE11 (1D) has been applied for a large area of the river system, MIKE 21 (2D) for the study area extending from 605000 N (BTM) to 616000 N (BTM) and MIKE3 for a smaller area embedded in the MIKE21. The knowledge gained by MIKE 11 modelling has been applied to the

MIKE21 model as boundary conditions and in turn MIKE 21 has furnished boundary conditions to MIKE 3 (3D).

2. DATA

The hydrometric data required for the study was collected from different sources like, Bangladesh Water Development Board (BWDB), Surface Water Modelling Center (SWMC), Institute of Flood Control Drainage and Research (IFCDR)

The sources of bathymetry data are Bangladesh Inland Water Transport Authority (BIWTA), SWMC, and Survey 2000. The sources of meteorological data is Bangladesh Meteorological Department (BMD).

Indian Remote Sensing (IRS) image data for the Meghna and its surrounding rivers has also been used for schematization of the two dimensional model area including the power plant site.

3. TRANSPORT AND DISPERSION OF COOLING WATER

The cooling water after entering the river will be transported and diluted by several processes:

- Advection transport: the cooling water will be transported with the general flow in the river.
- Density driven flow: the cooling water has a lower density that the ambient water and hence, it will tend to rise to the surface.
- Dispersion and diffusion: the cooling water will disperse due to turbulance and diffuse due to temperature gradients.
- Heat exchange with the atmosphere: if the temperature of the cooling water is different from the air temperature the cooling water will exchange heat with the atmosphere. The dissipation rate is strongly related to the wind speed.

Re-circulation may occur as a result of flow reversal due to tidal action during dry season with low river net flow. In this case the cooling water may flow directly towards the intake, enter the power plant cooling system and flow back again to the power plant intake. In addition to the direct re-circulation, indirect re-circulation may occur when heated water from the far field is carried back towards the intake as a result of flow reversal.

4. MODEL SET-UP AND CALIBRATION

4.1 One-dimensional (MIKE 11) Modelling

The one-dimensional modelling includes application of an overall model, the existing General Model (GM) used for modelling of high flow conditions, and a sub-model of GM, specifically set up for application to dry season modelling.

The main purpose of the one-dimensional modelling is to provide boundary data for the two-dimensional modelling. This includes monsoon flow modelling for determining high flow conditions adjacent to the power plant site as well as dry season modelling for the study of the cooling water re-circulation.

The General Model of Bangladesh has been developed at Surface Water Modelling Centre (SWMC) under Surface Water Simulation Modelling Programme (SWSMP) using MIKE 11 modelling system. The purpose of the General Model is to provide the basic hydraulic information of the major rivers of the country. To serve that purpose, the model has been validated for the year 1997-98, at the latest.

4.1.1 One-dimensional sub-model

Based on the calibrated General Model, a sub-model for Meghna Power Plant has been developed. A schematic layout of this model is shown in Figure 2 in the next page.

The model was calibrated for dry period condition, as well as for wet period conditions. Given the river topography the basic parameter for calibration is the Manning number "M" (i.e. inverse of Manning's number, n), which is applied to describe the bed roughness of the river. The Manning number applied in the model varies from 10 to 50 for the rivers Meghna, Padma and Dhaleswari.

For calibration the comparison between observed and simulated water levels at Baidyar Bazar and Meghna Ferry Ghat on Meghna River for the month of January 1997 and the comparisons between observed and simulated water levels and discharges at Meghna Ferry Ghat on Meghna river for the wet period for the month of August 1996 have been done. The comparisons indicate reasonable agreement between observed and simulated water levels.

The model was finally validated using a different data set for dry season (January 1999) and wet season (August 1999) conditions.

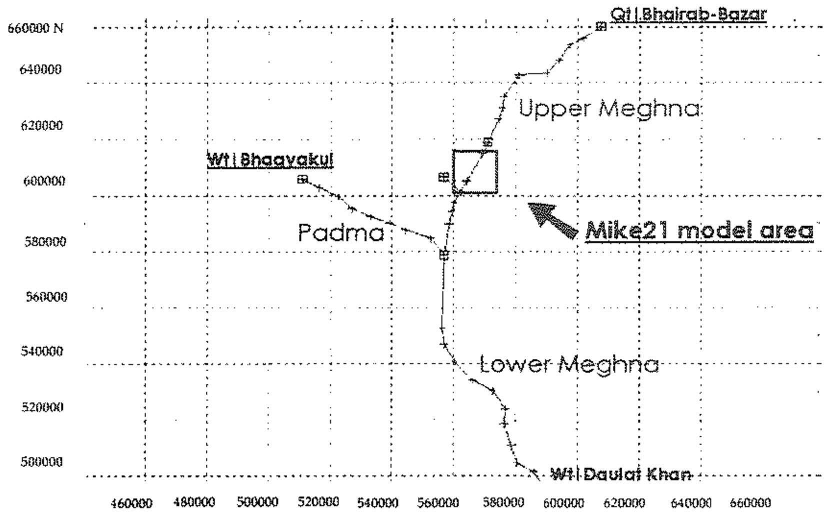

Figure 2. Schematic layout of 1D MIKE 11 model.

In summary it is concluded that the model is capable of simulating the characteristics of the generally prevailing hydraulic conditions in the river system considered.

4.2 Two-dimensional (MIKE 21) Modelling

The use of a 2D model implies that all prognostic variables (notably flow rates and excess temperature) are expressed as vertical average (depth-integrate) values.

The model is established in its own co-ordinate system, which was aligned with the BTM grid (co-ordinate transformation between the two grids is inherent in the setup). A horizontal resolution of 27 m was selected in order to provide for a detailed calculation of the excess temperature field and a reasonable approximation for representation of cooling water intake and outlet, while still keeping the computational time within manageable limits (Figure 3 in the next page).

The model considers the effect of flooding and drying of the shallow areas that dry up at low stages. This effect is important in the present application as a large portion of the power plant's thermal discharge will be directed into such areas via the natural flows of the Meghna River.

As detailed measurements of the current distribution in the area are not available, the 2D model was inter-calibrated with the 1D model to resemble the water level variation at Meghna Ferry Ghat before application to heat budget simulations.

There is no data basis available- such as current velocity distribution and dye tracer studies- for calibration of eddy coefficients and dispersion parameters. These coefficients were then specified based on experience from similar studies. The Smagorinsky formulation was applied as the turbulence model using an eddy coefficient of 0.5. The dispersion coefficient was assessed at 1 m2/s for both horizontal direction.

4.3 Three-dimensional (MIKE 3) Modelling

The primary objective of the MIKE 3 simulations concern the effects in the near field, i.e. to determine whether added recirculation results from the stratifying potential of the warm outlet water and therefore emphasis in the setup is on the area immediately surrounding the plant. To fully capture influences of tidal variations and to include hot water pools which re-enter the near field, a relatively large coarse grid was selected. The model setup is shown below, with 3 nested grids ranging from 81 to 9 meter horizontal resolution. The 81 m grid spans an area of 7 km by 4 km (Figure 4 in the next page).

The vertical grid size was set at 0.5 m, being a compromise between resolving the outflow characteristics while still keeping computational time down. The relatively small grid size requires a very small time step in order to ensure numerical stability, namely 3 seconds.

Although the helving time of the excess temperatures is some 50 hours, and therefore not important in the near field, heat exchange has been included in the model to allow for any excess temperatures re-entering the near field.

The 3-D Smagorinsky turbulence model was utilized, as the lack of strong density stratification does not justify a more complex eddy formulation. Eddy viscosity factors were estimated on the basis of experience from similar studies at 0.2 and 0.4 for horizontal and vertical directions, respectively.

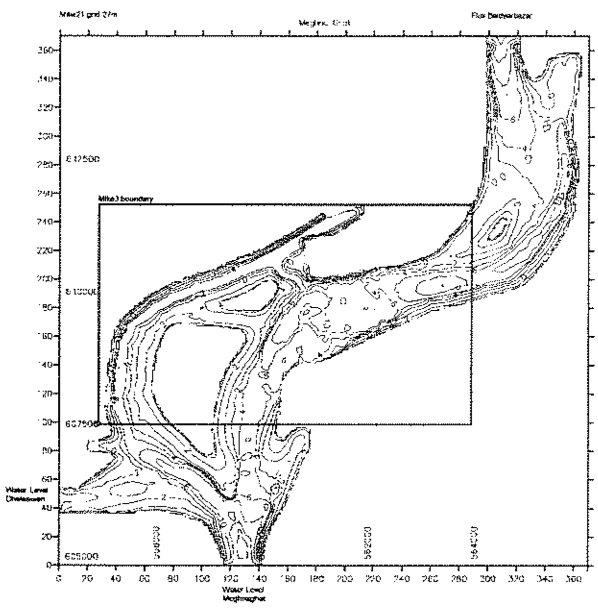

Figure 3. Model area and bathymetry for 2D simulations of excess temperature.

Conditions at the three open model boundaries were extracted from preceding runs with the 2D model (MIKE 21). The North Eastern boundary was specified as a velocity boundary, whereas to southern boundaries were specified as water level boundaries.

5. SIMULATION

The simulation periods as furnished for the re-circulation study were selected from preceding simulations with the 1D river model (MIKE 11) using a time window of 15 days to identify the best period reflecting water levels in the river as specified for each individual scenario. A simulation period of 15 days was selected to cover spring and neap tide conditions. Air temperatures were specified corresponding to river water temperature considering that as a reasonable choice reflecting typical conditions. Wind speeds were selected low –though still typical- tending a conservative assumption as regards heat dissipation to the atmosphere.

A summary of the ambient conditions as specified for the simulations of potential re-circulation of cooling water is provided in Table 1.

Table 1. Summary of ambient conditions.

Scenarios	Simulation period	Air temp. (°C)	Wind speed (m/s)
Wet period	15/07/96-30/07/96	28.5	2
Dry period	22/01/00-06/02/00	18	1
Transit period	15/22/99-30/12/99	32	2

The cooling water intake has been schematized in the model as a canal extending from the site embankment to the intake structure. The schematization in the model approximates a cross section with bottom level at –3 m PWD and a width of the canal of 12 m. The intake of water is modelled as a sink (or several sinks, MIKE 3) extracting water from the canal. The sink (sinks)

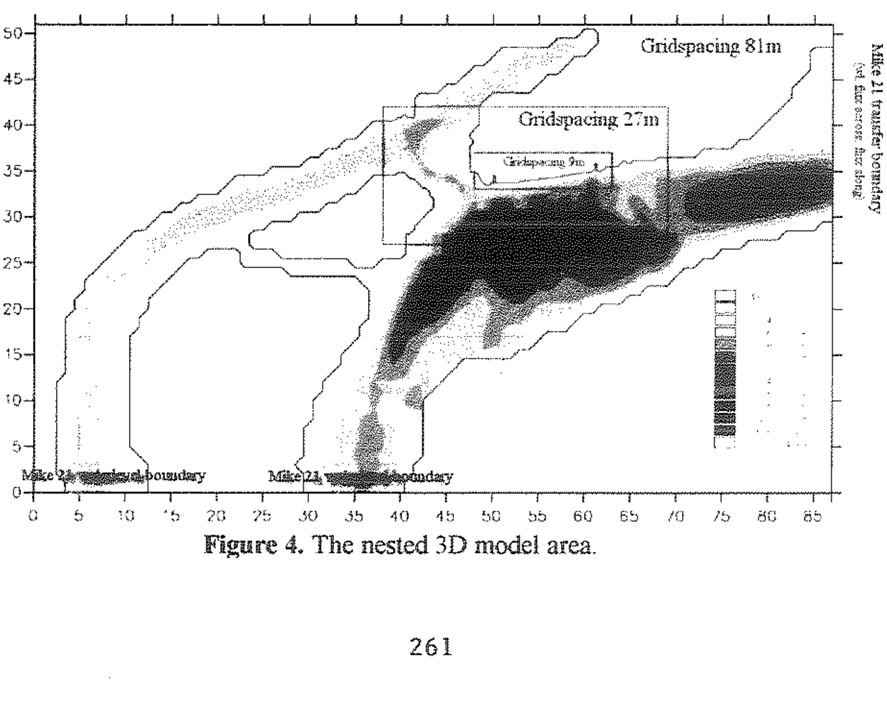

Figure 4. The nested 3D model area.

is connected to a source (sources) representing the cooling water discharge.

6. RESULTS

The results of the simulations of excess temperatures at the intake has been processed and presented in Table 2. One sample plot has been presented in Figures 5.

Table 2. Excess temperatures at the intake for different option scenarios.

Ambient cond.	Plant opertn.	Excess temp. (°C) Avg.	Excess temp. (°C) Max.	River temp. (°C)
Discharge via canal 1 km downstream of intake				
Wet	Normal	0.00	0.00	28.5
	Bypass	0.00	0.00	
Dry	Normal	0.34	1.32	18
	Bypass	0.49	1.93	
Transit	Normal	0.23	1.00	32
	Bypass	0.33	1.45	
Discharge via pipe 100 m towards the river				
Dry	Normal	2.13	5.31	18
	Bypass	3.12	7.77	
Transit	Normal	1.4	4.38	32
	Bypass	2.04	6.37	
Discharge via pipe 100 m towards the river				
Dry	Normal	0.80	2.79	18
	Bypass	1.17	4.08	
Transit	Normal	0.50	2.18	32
	Bypass	0.73	3.17	

It is noted that when river net flow is strong (typical wet season) the tidal action is too weak to carry the cooling water discharge to the upstream point of cooling water intake and consequently re-circulation is not present under such condition. A positive effect of extending the pipeline from 100 m to 150 m from the site borderline has been found.

7. CONCLUSION

The general conclusion for the cooling water schemes applying submerged discharge via a pipe of 100 m or 150 m from site boundary is that re-

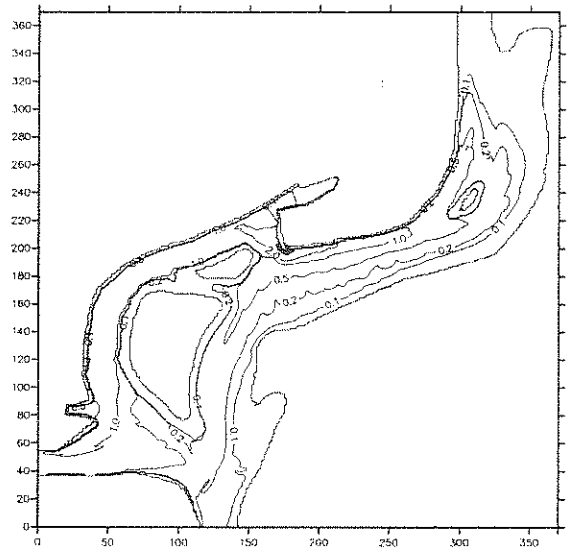

Figure 5. Maximum excess temperature field, Dry period, Outlet canal, Bypass operation.

circulation becomes more pronounced than for the alternative using a discharge canal with outlet1 km downstream of the intake. One reason is that the outlet is separated only approximately 120 m – 170 m from the intake. Also, the current pattern in the outlet area (5-6 m water depth, PWD) tends to obstruct a rapid transport of the heated water to the main river beyond safe distance from the intake. However, in this regard the outlet locations considered appear to approach the limit where the main river current becomes favourable for the transport of and dilution of the discharge.

Another conclusion is that an extension of the length of the pipeline from 100 m to 150 m appears to have a significant impact on the intake excess temperature.

8. REFERENCES

DHI in association with SWMC, AES Meghnaghat 450 MW Combined Cycle Power Plant, Final Report, Part A, May 2001.

DHI in association with SWMC, Thermal plume modelling of AES Meghnaghat Power Station, October 1999, revised August 2000.