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Determination of Thermal Pollution Effect on End Part of Stream

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***Abstract:** The present study was conducted to evaluate the environmental impact of thermal effluent sources on the main water quality parameters at the low flow conditions. The low flow causes the flow velocity to be low which causes accumulation of any pollutant source. The study was performed by creating a 2-d model of the last reach of Rosetta branch at winter closure. Delft 3d software is used to create a hydro-dynamic model to simulate the flow pattern within a 5 km of the branch upstream Edfina regulator. Water quality model is coupled afterwards to simulate the water quality parameters. A base case scenario of the current state at the low flow condition is set up and calibrated. Another scenario is performed after adding a thermal pollutant source. Thermal power plant is used as an application of thermal pollutant source. Cooling water is with drawled from an intake and discharged back to the water source with a relatively higher temperature downstream the intake. A case study of Dairut thermal power plant which is planned to be constructed at this area is used. Hydrographic survey is performed to collect essential hydraulic data for the model. Field measurements are performed to collect water quality along the area. A numerical model was set up and the area was simulated. Results showed accumulation of thermal plume. The higher temperatures lowered the dissolved oxygen in the thermal plume area. On the other hand, BOD and NO_3 values increased with different rates. Ammonium was positively affected and was lowered.*

***Keywords:** Rosetta Branch, Water Quality, Delft 3d, Thermal Pollution.*

I. INTRODUCTION:

With the rise of the industrial revolution back in the eighteen's century, transition to new manufacturing processes occurred, improving the efficiency of water power. The development of machine tools and the rise of the factory system increased the standard of living. Then industrialization has spread throughout much of the world, technological and economic progress continued widespread of suburban sprawl and the expansion of human populations. Increased water diversion is associated with human population growth and development[1].

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In view of these developments, a variety of new energy infrastructures to meet the demands for population growth that lead the decision makers to redirect the rudder towards the power plants. That was in order to provide a continuous source of electricity as a clean and renewable source of energy. Contrariwise, Power plants might cause Intensive damages on the environment. If these damages were not studied and carefully planned before construction and operation, therefore impact assessment of power plants is nesses. Egypt also faced same challenges in consuming the massive amount of energy in the past few years, can be represented in Figure (1):

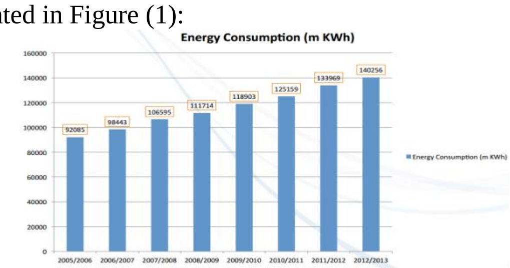

Figure (1): Energy consumption according to ministry of electricity and renewable energy statistics

Power plants release large volumes of water at higher than ambient temperatures, and the area surrounding the discharge pipes may not support a healthy, productive water because of physical and chemical alterations of the habitat [2]. This can lead to reductions in the biological productivity of the habitat at the discharge site for some aquatic resources as their prey species and important habitat types, such as aquatic vegetation, are no longer present.

As a result of high temperature, these discharges to rivers may endues higher than usual levels of organic matter, fecal bacteria and toxic substances. The resultant increases in biochemical oxygen demand (BOD) can lead to fish kills, and the high concentrations of fecal bacteria may restrict water use. Reduced dissolved oxygen (DO) can cause direct mortality of aquatic organisms or result in sub-acute effects such as reduced growth and reproductive success.

Understanding the occurrence of emerging contaminants is an essential part of water safety management. Many monitoring studies of the occurrence and distribution of emerging organic contaminants in water have been launched in Rosetta branch[3], [4] and [5]. With rapidly increasing capabilities of the computer, the numerical model combined with field detection is an effective approach to identify important processes and simulate the change of water quality in a water environment[6].

Water quality model combined with hydrodynamic model has made great progress not only for two dimensional analysis in the past few decades but also towards adding more complex interactions between physical, chemical and biological processes[7].

Most numerical models of water quality were established for regular monitoring indicators such as BOD, DO and nutrients [8]because of their limited monitoring data [9]and their crucial influence on the water quality[10] and [7]. Several studies showed that water quality models were applied to continuous organic pollutants in which adsorption was considered to be an important process. Therefore, there is a growing need for integrated emerging contaminant model, especially the model at wide temporal and spatial scales[11].

As a fully integrated multidimensional numerical modeling software suite for the aquatic environment, Delft3D was selected for this study. This modeling suite was developed by Deltares can perform a simulation of both hydrodynamic and water quality and also solve the coupling situation related to different time and spatial scales used in both compartments. In particular, the mathematical model Delft-FLOW is used for hydro-dynamic simulation [10]and Delft-WAQ for water quality simulation [12]since there are many studies that show this modeling suite has a good performance for hydrodynamic and water quality modeling [13] and [14]. In this study, Delft software model is applied to simulate emerging contaminants in the last reach of Rosetta branch from a thermal source of cooling water from a power plant.

1. Methodology

This study aims to investigate the emerging effect from thermal pollutants on the main water quality parameters. Hydrographic survey team from Hydraulics Research Institute (HRI) will collect the study area's bathymetry. The data will cover a 4.5 km of Rosetta branch. Figure2 shows the study area relative to the Nile Delta.

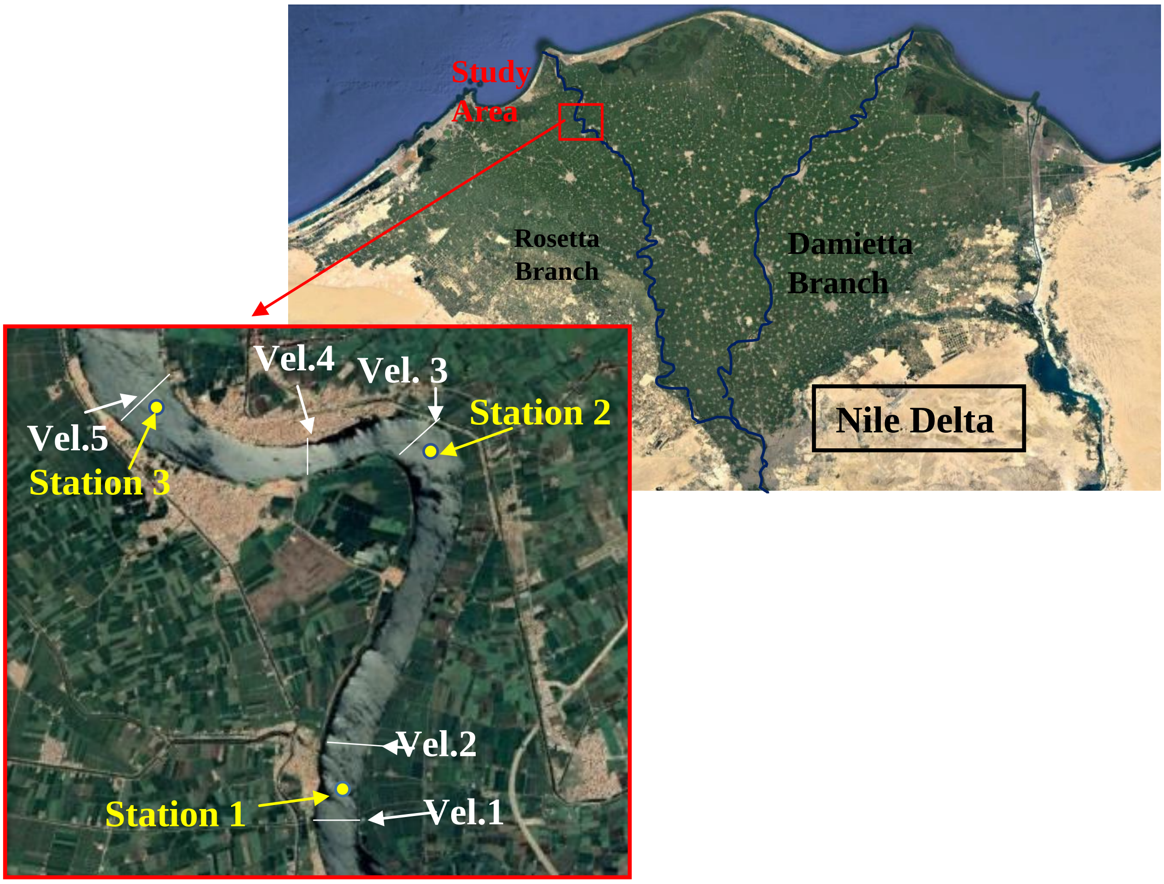

Figure 2: Location map showing the study area and the investigated sites

Data collected is added to numerical software. A mathematical model Delft-3d is used. Model schematization was initiated by a grid generation tool called RGFGRID creating a grid of 5m resolution and projecting the surveyed point bed levels on the grid by a pre-processing tool QUICK-IN then by triangular interpolation, a map of bed level variations on all points of the grid indices is produced. Model requirements were achieved (ex.: orthogonality of grid cells were set to be less than 0.05, aspect ratio in was less than 1.5 and courant number was less than 10). Fish cages located in the area of simulation that were surveyed by GPS unit were also simulated by thin dams. The roughness was changed along the area by creating a roughness map and using it as an input to the model. The roughness values ranged between 0.02 for most of area and 0.05 for vegetated areas and fish cages areas. The next step was to input boundary conditions which were discharge and water level in this case. Time step was set to 3 seconds in hydro-dynamic and 1 minute in water quality and simulation period was 2 months to ensure stability in flow pattern for achieving steady flow condition Delft- FLOW module is used to create a hydro-dynamic simulation. Some statistical models will be applied to the model to judge its suitability for simulating the study area. After the model success, it will be ready to simulate the environmental conditions of the area. The thermal power plant will be added. Cooling water suction and discharge locations will then added to the model as point sources.

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The cooling system mentioned withdrawals water from the source and discharges it back to the water. This cooling water is discharged after using in cooling operation to the water source with a relative excess temperature at a distance downstream the intake which will be considered as a continuous thermal pollutant source. This effluent water is then added with its temperature. Thermal plume will follow the stream hydro-dynamics and is ready to be studied in the water quality module.

Another team from HRI with co-operation with Central Laboratories for Environmental Quality Monitoring (CLEQM) make a visit to study area for collecting water quality parameters along winter season as a the low flow season. The environmental data is then sent to CLEQM to be studied. Archival data from Egyptian Environmental Affairs Agency (EEAA) is collected to study water quality parameters during high flow season in summer. Both data are then added to the model as a two different scenarios before constructing the plant. Then after thermal plume is added, the change in these water quality parameters is studied.

II. RESULT ANALYSIS

Bed level variations were plotted as a map in Figure (3). Resulted depth averaged velocity from the 2d model in the FLOW module is shown in Figure (4). Data are collected from study area shown in figure (2). Water quality parameters are collected from 3 different stations along the study area. Some data were available to be measured in field, these data are collected in table (1). Other data were measured in the lab, these data are shown in table (2).

Table 1 Field Measurements at different locations

Sample No.	Code	Velocity Location	Location relative to Vel. Cross section	depth at location	Depth of sample	Temp.	PH	D.O.	EC
				m	m	^{0}c	unit	mg/l	µs/cm
1	A1	C.S.1	Middle	7	1.4	19	7.59	5.9	2371
2	A2	C.S.1	Middle		3.5	18.4	7.76	5.7	850
3	A3	C.S.1	Middle		6	18.5	7.74	5.4	831
4	B1	C.S.3	Third width from Right Bank	10.2	3	16.5	7.71	5.9	1792
5	B2	C.S.3	Third width from Right Bank		5.1	17	7.75	4.9	851
6	B3	C.S.3	Third width from Right Bank		8.6	18	7.76	4.6	829
7	C1	C.S.3	Third width from Left Bank	4	0.8	17.1	7.74	4.9	828
8	C2	C.S.3	Third width from Left Bank		2	18	7.72	4.8	828
9	C3	C.S.3	Third width from Left Bank		3.4	18	7.74	4.7	828
10	D1	C.S.5	Middle	7	1.4	16.8	7.73	4.9	832
11	D2	C.S.5	Middle		3.5	17.5	7.79	4.8	832

Table 2 Lab measurements of collected water samples

Sample No.	Code	Velocity Location	Location relative to Vel. Cross section	depth at location	Depth of sample	BOD	NH_3	NO_3
				m	m	mg/l	mg/l	mg/l
1	A1	C.S.1	Middle	7	1.4	17	0.38	2.515
2	A2	C.S.1	Middle		3.5	16	0.18	2.615
3	A3	C.S.1	Middle		6	18	0.05	2.537
4	B1	C.S.3	Third width from Right Bank	10.2	3	13	0.23	2.394

5	B2	C.S.3	Third width from Right Bank		5.1	16	0.15	2.5
6	B3	C.S.3	Third width from Right Bank		8.6	13	0.05	2.449
7	C1	C.S.3	Third width from Left Bank	4	0.8	13	0.2	2.589
8	C2	C.S.3	Third width from Left Bank		2	11	0.11	2.576
9	C3	C.S.3	Third width from Left Bank		3.4	11	0.05	2.659
10	D1	C.S.5	Middle		1.4	13	0.26	2.576
11	D2	C.S.5	Middle	7	3.5	12	0.14	2.579
12	D3	C.S.5	Middle		6	17	0.05	2.138

To ensure an accepted range of deviation between model and field velocity, some statistical tests were applied. We use three statistical models to ensure the simulating of the model to the existing situation in the study site[15]. Based on previous studies, specific analysis are applied to be used in model evaluation. With these values, model performance can be judged based on general performance ratings. The statistical model are as follows:

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim})^2}\right]}{\left[\sqrt{\sum_{i=1}^{n} (Y_i^{obs} - Y^{mean})^2}\right]}$$

$$PBIAS = \left[\frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim}) * (100)}{\sum_{i=1}^{n} (Y_i^{obs})}\right]$$

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n} (Y_i^{obs} - Y^{mean})^2}\right]$$

The guidance of these statistical tests was applied based on the next table standards.

Table (3) General performance ratings for recommended statistics[15]

Performance Rating	RSR	NSE	PBIAS (%) Streamflow	PBIAS (%) Sediment	PBIAS (%) N, P
Very good	$0.00 \le RSR \le 0.50$	$0.75 < NSE \le 1.00$	$PBIAS < \pm10$	$PBIAS < \pm15$	$PBIAS < \pm25$
Good	$0.50 < RSR \le 0.60$	$0.65 < NSE \le 0.75$	$\pm10 \le PBIAS < \pm15$	$\pm15 \le PBIAS < \pm30$	$\pm25 \le PBIAS < \pm40$
Satisfactory	$0.60 < RSR \le 0.70$	$0.50 < NSE \le 0.65$	$\pm15 \le PBIAS < \pm25$	$\pm30 \le PBIAS < \pm55$	$\pm40 \le PBIAS < \pm70$
Unsatisfactory	$RSR > 0.70$	$NSE \le 0.50$	$PBIAS \ge \pm25$	$PBIAS \ge \pm55$	$PBIAS \ge \pm70$

From field results, statistical calculations based on previous mentioned techniques. The results of essential variables were as follows in Table(4):

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Table (4) Model Performance when applying Statistical tests

	RSR	PBIAS	NSE
station 1	0.12868162	2.623612975	0.9997258
	V.GOOD	V.GOOD	V.GOOD
station 2	0.18208699	7.456103212	0.9989007
	V.GOOD	V.GOOD	V.GOOD
station 3	0.17358053	-3.1477839	0.99909217
	V.GOOD	V.GOOD	V.GOOD
station 4	0.31448705	-20.99243826	0.99021837
	V.GOOD	SATISFACTORY	V.GOOD
station 5	0.51508993	-9.523421795	0.92960655
	V.GOOD	V.GOOD	V.GOOD

Comparing the model results in the calibration phase to these values the results were highly satisfactory. And shows that the model is applicable to be used as an appropriate guideline for hydraulic simulations.

The results of hydro-dynamic module was coupled with the water quality module. WAQ module uses the results of FLOW module like the flow pattern, bed shear stress, thermal plume dispersion and salinity as inputs. This module simulates the water quality parameters and processes. Table () illustrates the parameters that were used in the WAQ model to achieve measured parameters with reasonable accuracy after a number of runs.

Table (4) Calibration process parameters for water quality model

Measurement	Value	Unit
Decay rate BOD	0.08	(d^{-1})
Temp. coefficient decay rate BOD	1.04	-
Vertical Dispersion	1	(m^2/s)
Horizontal Dispersion in both directions	0.5	(m^2/s)
First Order Nitrification Rate	0.1	(d^{-1})
First Order Denitrification Rate	0.1	(d^{-1})
First Order Mineralization Rate	0.1	(d^{-1})
Temp. coefficient For Nitrification	1.07	-
Optimum Oxygen concentration for Denitrification	1	(gm $O^2/m^{3)}$
Critical Temperature for mineralization	3	^0C

The base case of WAQ model was run with the HRI measured parameters and calibrated according to the above mentioned process parameters. The water quality parameters were calibrated by changing in the process parameters several times and comparing the model values with the obtained field data. Grid aggregation was performed by grid aggregation tool DIDO to minimize performing excessive operations at all the grid points and to reduce run time and size.The next four maps show both the hydro-dynamic and water quality results at the low flow season for current situation. It appears from the hydro-dynamic results, the very low velocity at that time of the year which value does not exceed 0.02 m/s. These values of small velocity had a significant rule in accumulating the temperature within the domain which highly affects water quality parameters as will be illustrated later.

An Other scenario was set up after adding the effluent thermal source. The change of the main water quality parameters appears gradually. After 12 hours only of simulation, a plume of low oxygen concentration at the effluent appeared parallel to the thermal plume. After 1 day, the accumulation increased upstream the outlet source lowering the dissolved oxygen. After 1 month is passed, oxygen decreased at most of simulation area Figure (10).

Figure (11)shows the Bed level and Temperature distribution of plant outfall cross section. It also appears on Figure (12), the high rise of oxygen concentration at the intake of the plant due to the high velocity at suction which increases the circulation at this area which affects the reaeration causing a local high increase at the intake. This have a significant effect on controlling the dispersion of the plume in the upstream direction. On the other hand,BOD is increasing continuously from the boundary due to the continuous polluted flow with a higher BOD values. After 1 month, this polluted incoming flow accumulates upstream the intake of the plant that controls the thermal plume. This continuous operation causes the BOD values to be highly increased around the plume since this flow is not allowed to pass the thermal plume area due to its high velocity relative to the incoming small velocity of the branch which is very obvious at Figure (13)Nitrates values are significant for simulation as it's a nutrient to most of algal species and phytoplankton.

Also it's an indirect nutrient for fish as it consume algae. Fishing and raising fish in cages are very widespread in this area. Temperature increased nitrates but not in a very high rate as much as of those in BOD Figure (13). After 1 month, in Figure (14) the continuous incoming flow with higher NO_3 value reaches the intake and causes the plant to withdraw water with higher values of nitrates and consequently discharges the cooling water with higher values of nitrates (exceeds the limits of NO_3 in standards and regulations) which negatively affect the eco-system and the environment. Ammonium solubility responses mainly to changes in PH. For the same PH value, ammonium solubility decreases with increasing temperature. Range of PH in this area is 7.7 from field measurements. Unlike negative thermal impacts on DO and BOD, temperature had a positive effect on ammonium. NH4 values were decreased in the plume area Figure (15).

III. CONCLUSION

The environmental impact of low flow period of the year was investigated at the last reach of Rosetta Branch. Field measurements were found to be exceeding the limits of Egyptian legislation standards. Thermal impact on the main water quality parameters was studied by setting up a numerical model for the current state and after adding a thermal pollutant source. The results showed a severe negative impact on dissolved oxygen. Values were decreased from 5.6 to 3.5 mg/l as the temperature increases from 18.5 to 27 ^{0}c since solubility of oxygen decreases as the temperature increases. Reversely, BOD values increased from 12 to 15 mg/l with the same increase of temperature. Higher temperature had a positive effect on NH4 values as in decreased from 0.15 to 0.12 mg/l in one month. NO3 values increased with a small rate from 20 to 22.5 mg/l. these results indicate a certain probability of change in stream aquatic life. A change in types of aquatic algae and fish is probable due to the change in temperature and stream water quality.

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