Analysis Of Water Temperature Of Laguna Lake Using EFDC Model

Armi M. Cunanan, Jonathan W.L. Salvacion

Abstract: Laguna Lake is one of the widely used fresh water source in Metropolitan Manila. Numerous studies have been conducted for the water quality monitoring of the lake. Large amounts of pollutants are continuously received by the lake from domestic, industrial and others sources. The physical appearance of the lake alone needs attention. Physical characteristics of water include depth, flow velocity, flow rate, temperature, turbidity and transparency is very important. The lake’s water temperature not so much given attention but affects most of the chemical and biological characteristics of water, is given focus in this study. Hydrodynamic characteristics of the lake was considered in coming up with a graphical illustration of the temperature of the Laguna Lake using the Environmental Fluid Dynamics Code (EFDC). Laguna Lake is thermally unstratified with its average depth of 3.21 and mean temperature range from 25 ºC to 29 ºC. The EFDC model used in this study could be further used to model hydrodynamic transport and be linked with Water Quality Analysis Simulation Program (WASP).

Index Terms: hydrodynamics, Environmental Fluid Dynamics Code, Laguna Lake, lake temperature

1 INTRODUCTION

Laguna Lake is the biggest lake in the Philippines and is one of the most important inland bodies of water [1] located in the southeast of Manila [2]. It is being used for several purposes such as fisheries, transport route, flood water reservoir, power generation, recreation, irrigation, industrial cooling, waste sink, and potable water since July, 2009 [3]. It has three distinct bays namely West Bay, Central Bay and East Bay. The southernmost portion is called the South Bay. The Laguna Lake or Laguna de Bay is a large shallow freshwater body with an average depth of 2.5 meters with a surface area of 911 km2, a shoreline of 220 km and a holding capacity estimated at 2.19 x109m3 [1] [3]. During the months of December to February, the lowest air temperature and highest wind velocities occur in the Laguna Lake Basin resulting to water turbulence and high water turbidity. Although ample supply of free nutrients is present, low fish growth is experienced. On the months of November to April, dry season occurs. There are two climatic conditions in the Laguna Lake Basin, Type 1 and Type 4 of the Corona Climate System of Classification. There are two distinct seasons under Type 1, dry from November to April and wet from May to October; and Type 4 which is characterized by evenly distributed rainfall all throughout the year. [4] Lake temperature exerts a major influence on the biological activity of aquatic organisms since most aquatic organisms are cold-blooded or poikilothermic, and are unable to internally regulate their core body temperature [5]. A change in temperature of water bodies naturally occurs seasonally and daily. However, the fish’s ability to reproduce is affected by man made changes to the water temperature. Changes in temperature have an effect on other water quality parameters such as alkalinity, salinity, dissolved oxygen, electrical conductivity, and the chemical and biological reactions such as solubility in oxygen, carbon-dioxide-carbonate-bicarbonate equilibrium, increase in metabolic rate and physiological reactions of organisms are likewise affected. [6] In the present study, the thermal stratification of the Laguna Lake Basin was simulated using the Environmental Fluid Dynamics Code (EFDC) using a one-meter interval of the depths of the lake. This report presents a model which simulates specifically the temperatures in the Laguna de Bay by setting the boundary conditions for the hydrodynamic model including the depth and elevation, volume of inflow and outflow, wind, temperature and atmospheric forces. The data used in the model were collected from Laguna Lake Development Authority (LLDA) and Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). The model will then be used as a management tool to simulate the water quality of the Laguna Lake. The model showed that the water movement at the Manggahan is dynamic due to the 131.56 m3/sec flow of water in the area.

2. METHODS

EFDC Model

EFDC Explorer (EE) is a Windows-based Graphical User Interface (GUI) for pre- and post-processing of the Environmental Fluid Dynamics Code (EFDC). The program is developed and supported by the engineering company Dynamic Solutions-International (DS-Intl). EFDC Explorer is designed to support model set-up, Cartesian and curvilinear grid generation, testing, calibration and data visualization using 2 dimensional and 3 dimensional plots and animation of model results. [7] The EFDC comprises an advanced three-dimensional surface water modeling system for hydrodynamic and reactive transport simulations of rivers, lakes, reservoirs, wetland systems, estuaries, and the coastal ocean. The modeling system was originally developed at the Virginia Institute of Marine Science as part of a long-term research program to develop operational models for resource management applications in Virginia’s estuarine and coastal waters. The EFDC model is a public domain, with current users including universities, governmental agencies, and engineering consultants. [8]
Hydrodynamics
The EFDC model solves the three-dimensional, vertically hydrostatic, free surface, turbulent averaged equations of fluid with variable density. The model uses a stretched or sigma vertical coordinate and Cartesian or curvilinear, orthogonal horizontal coordinates. The hydrodynamic model also solves dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity, and temperature.\[9\] The vertically hydrostatic momentum and continuity equations of EFDC model for turbulent flow are solved in a coordinate system which may be curvilinear and orthogonal in the horizontal and stretched or topography-free surface in vertical direction.\[10\] [8] EFDC uses stretch or sigma vertical coordinates and cartesian or curvilinear, orthogonal horizontal coordinates to represent the physical characteristic of a water body.\[11\] The momentum and continuity equations in EFDC model using curvilinear grid generation, please refer to (1):\[12\]

\[
\frac{\partial (m \zeta)}{\partial t} + \frac{\partial (m_y H u)}{\partial x} + \frac{\partial (m_z H v)}{\partial y} + \frac{\partial (mw)}{\partial z} = 0
\]

If Cartesian grid generation would be used, \(m_x\) and \(m_y\) will be equivalent to 1 and (2) will be used.

\[
\frac{\partial (H u)}{\partial t} + \frac{\partial (Hu u)}{\partial x} + \frac{\partial (uw)}{\partial y} + \frac{\partial (w H)}{\partial z} - \frac{g}{\rho_0} \frac{\partial z + H}{\partial t} - \left( \frac{\partial (Hu)}{\partial x} + \frac{\partial (uw)}{\partial y} + \frac{\partial (w H)}{\partial z} \right) + Q_u = 0
\]

\(x\) and \(y\) = the curvilinear-orthogonal coordinates
\(z\) = vertical sigma coordinate
\(u\) and \(v\) = horizontal velocities in the curvilinear-orthogonal horizontal coordinates \((x, y)\)
\(m_x\) and \(m_y\) = the metric coefficients that would be calculated from \(dx\) and \(dy\) of the cells
\(w\) = vertical velocity in the stretched vertical and dimensionless coordinate \(z\).

\(z, \rho = \) kinematic excess pressure above the reference density
\(\rho_h = \) hydrostatic pressure
\(\rho_{atm} = \) kinematic atmospheric pressure
\(\varphi = \) the free surface potential
\(g = \) times \(z^* = \) free surface elevation
\(z_b^* = \) bottom bed or topography elevation
\(H(zs^* - zb^*) = \) total water column depth
\(f = \) Coriolis parameter
\(f_e = \) effective Coriolis parameter incorporating the curvature accelerations

In the EFDC model, governing equations for the flow hydraulics were derived from the vertically hydrostatic boundary layer form of the turbulent equations of motion for an incompressible, variable density fluid. Error! Reference source not found.. Error! Reference source not found.. Error! Reference source not found.. Error! Reference source not found.. Error! Reference source not found.. Error! Reference source not found.. Error! Reference source not found.. Error! Reference source not found.. Error! Reference source not found.

\[
\frac{\partial \rho}{\partial z} = \frac{-gH \rho - \rho_0}{\rho_0} = -gHb
\]

Boundary Conditions for the Hydrodynamic Model
Depth and Elevation. Laguna Lake Development Authority (LLDA) together with The University of the Philippines – National Institute of Geological Science (UP-NIGS) are currently updating the bathymetry data of Laguna Lake. Bathymetry data provided by LLDA was digitized in order to generate a Cartesian grid.

Volume of Inflow. Inflow boundaries and values were based on the water balance of Laguna Lake from LLDA. The inflow from the 23 river systems (excluding Marikina) were computed from the 2012 consolidated stream flow per station of Laguna Lake. (see Table 1

River Systems Stream Flow)
Wind, Temperature, Atmospheric Forces. Data for the Wind Velocity and Temperature were acquired from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). Record used was the average per month from 1977 to 2003 (see Table 2).

Wind, Temperature and Atmospheric Forces Average Values (1977-2003)). The switch in wind direction is the main indicator between the cool northeast wind (hanging amihan) and the southwest monsoon (hanging habagat) [13]. From the University of the Philippines-Los Baños, Laguna (UP-LB) monitoring station, wind in Laguna Lake is dominated by northeast wind direction averaging to 2 m/sec. Atmospheric forces utilized rainfall, relative humidity, and solar radiation. Meteorological data was used to model the surface heat exchange between the water surface and the atmosphere in the Laguna Lake EFDC model. The following are the meteorological parameters required for the EFDC model: atmospheric pressure in millibars (mb), solar radiation in watts per square meter (W/m²), evaporation in meters per day (m/day), relative humidity and cloud cover in fraction, dry bulb temperature in degrees Celsius (ºC), wind speed in meter per second (m/s), and wind direction.

### Table 2

**Wind, Temperature and Atmospheric Forces Average Values (1977-2003)**

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<td>84</td>
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3. **Modeling**

**Study Area**

Laguna Lake is shaped like a stylized “W” with two peninsulas jutting out from the northern shore. Between these peninsulas, the middle lobe fills the large volcanic Laguna Caldera. In the middle of the lake is the large island of Talim, which falls under the jurisdiction of the towns of Binangonan and Cordona in Rizal Province. The lake is one of the primary sources of freshwater fish in the country and its water drains to Manila Bay via the Pasig River. [14]
The total inflow in the lake is about $178.8 \text{m}^3/\text{s}$ ($6,265 \text{mm}$). The highest inflow contributor is the river discharge at $125 \text{m}^3/\text{s}$ ($4,380 \text{mm}$), direct rainfall at $38 \text{m}^3/\text{s}$ ($1,332 \text{mm}$) and groundwater influx at $15.8 \text{m}^3/\text{s}$ ($554 \text{mm}$). The total outflow from the lake is about $181.5 \text{m}^3/\text{s}$ ($6,630 \text{mm}$). The highest component of the outflow of the river is the Pasig River outflow at $150 \text{m}^3/\text{s}$ ($5,256 \text{mm}$), evaporation rate at $29 \text{m}^3/\text{s}$ ($1,016 \text{mm}$) and consumptive water users of some such as irrigation, water supply at $2.6 \text{m}^3/\text{s}$ ($88 \text{mm}$). The change in storage in the lake is quite insignificant since the reduction is only about $2.7 \text{m}^3/\text{s}$ ($88 \text{mm}$). It may increase or decrease in a yearly basis depending on the hydro-climactic condition of the basin. [15]

### Computational Domain and Mesh Generation

Topographic and bathymetric data from Laguna Lake Development Authority (LLDA) was used to develop an Environmental Fluid Dynamics Code (EFDC) model. Using the cartesian grid generation, resolution used for the computational domain (dx,dy) was $300 \text{m} \times 300 \text{m}$, the horizontal domain contains 137 cells in the i-direction and 158 cells in j-direction. Total active cells counted up to 9889. 23 river systems (excluding Marikina River), ground water, power generation, and irrigation were considered inflows. Pasig River is the major outflow contributor of the lake. The horizontal and vertical model grids developed for the Laguna Lake Model were based on the Universal Transverse Mercator (UTM) projection. In the simulation, typical water depths ranged from 0.2m to 19.8m as shown in Fig. 3.

### 4. RESULTS AND DISCUSSION

Data from the National Agromet Station, University of the Philippines, Los Baños (NAS UPLB), Laguna Station, was used in the wind data series of the simulation, average of the data used covered 1977-2003 prevailing wind. The wind average speed is 2 m/sec$^2$ for the entire 365-day run. Monthly prevailing wind direction is as follows. January – Easterly wind; February to May wind – North Easterly wind; June and July – Easterly wind; August – South Westerly wind; September and October - Easterly wind; November and December – North Easterly wind.
Fig. 4 shows the initial condition of the Laguna Lake Basin at day 1 from depths 1 to 9, while Fig. 5 shows the condition of LLB after 365 days also from depths 1 to 9. Many biological, physical and chemical processes are affected by temperature. With a slight increase in water temperature, the amount of biological activity and rate of chemical and metabolic reaction increase significantly, thus, it is very critical to both plants and animals. Most aquatic organisms have adapted to survive within a range of water temperatures but few can tolerate extremely hot or cold temperature. Temperature also affects aquatic life's sensitivity to toxic wastes, parasites and disease. Thermal pollution may cause fish to become vulnerable to disease, either because of stress due to rising temperatures or due to resulting decrease in dissolved oxygen [16].
Fig. 4: Initial condition of Laguna Lake Basin water temperature at 1 meter to 9 meter depth
Water movements at different scales and of different types significantly affect the distribution of temperature [17]. Oxygen tends to be less soluble as temperature increases. [6]. If the water temperature rises to high, the dissolved oxygen (DO) level decreases, directly threatening aquatic life and contributing to eutrophication [17]. Based on the Department of Environment and Natural Resources Administrative Order 34, 3 °C is the allowable temperature increase over the average ambient temperature for each month, where in this rise shall be based on the average of the maximum daily readings recorded at the site, but upstream of the mixing zone over a period of one month for water under Class A, B, C and D [18].

Fig. 6 represents the water temperature by depth of the Laguna Lake Basin. Depth of 3.00 meters was chosen since majority of the known depths ranges from 3.00 to 3.99 meters. Screen shots in 30 days interval is shown at a constant depth of 3.00 meters from Day 1 to Day 365 to represent a one year cycle of water. On the mean temperature data used from the NAS-UPLB station, lowest water temperature was recorded was on the month of January at 25.5°C, highest water temperature at 29.3°C, recorded on the month of May. Maximum temperature recorded was on the months of April and May at 34.2°C and 34.5°C, respectively, whereas, minimum temperature recorded was on the months of January and February with 21.3°C and 21.2°C respectively. Highest water discharge came from the Manggahan and Angono sub basin, constituting to 131.56 m³/sec and 124.88 m³/sec respectively based on the consolidated stream flow from LLDA.
Fig. 6: Water temperature at 3-meter depth from day 30 to day 365
5. CONCLUSION
The lake is shallow at an average depth of 3.21 meters and the temperature is high throughout the year therefore, it is thermally unstratified. On the 1-year simulation period done, water temperature of the Laguna Lake Basin varies only from 27ºC to 32 ºC. The major factor that affects the temperature of the lake are the inflow of the water from its tributary rivers. The wind direction is the major contributor for the direction of the flow of water. This model will be very useful to be used for modeling the water quality and hydrodynamic transport of Laguna Lake.

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REFERENCES