Three-Dimensional Hydrodynamic Modeling for a Developing Asian Country: A Case Study for Pasig River Estuary Linking Laguna Lake and Manila Bay, Philippines

Tokyo Metropolitan University Student Member ○Naoya Iwamoto
Tokyo Metropolitan University Student Member Maurice Duka
Tokyo Metropolitan University Regular Member Tetsuya Shintani
Tokyo Metropolitan University Regular Member Katsuhide Yokoyama

1. INTRODUCTION

Industrialization and urbanization have greatly exacerbated eutrophication and water quality problems in aquatic environments of lakes, rivers and estuaries. To address this concern, simulation studies for hydrodynamics and water quality can be made using three-dimensional modeling, of which is generally gaining popularity. Velocity and temperature distribution together with salinity intrusion and phytoplankton movement can be reasonably reproduced in the simulation. However, the lack of necessary information and limited data accessibility specifically in developing Asian countries pose a major impediment in carrying out these studies. Using intensive resource gathering techniques, this study proposes a 3D simulation of salinity intrusion in the Pasig River, which links the Laguna Lake and Manila Bay in the Philippines.

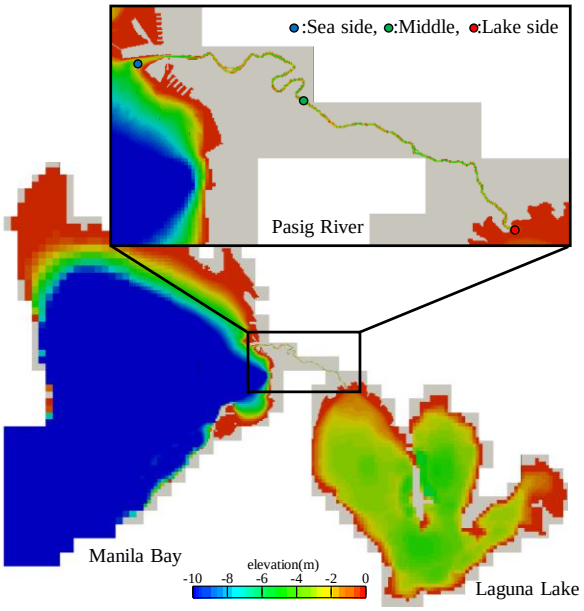

Figure 1. Relative location of Manila Bay, Pasig River and Laguna Lake

2. STUDY SITE

The study site is the interconnected water bodies of Pasig River, Laguna Lake and Manila Bay in the Luzon Island of the Philippines (Fig. 1). Pasig River has a total length of 27 km and an average width of 91 m. Meanwhile, Laguna Lake, which is utilized extensively for fishery purposes is a highly eutrophic, shallow lake with mean depth of 2.5 m, surface area of 900 km^2 and shoreline of 285 km. Tidal range in Manila Bay is 1.4 m during spring tide and 0.4 m during neap tide. The water level of Laguna Lake is smallest in April and May (dry season) and when the water level in Manila Bay exceeds the water level in Laguna Lake, the Pasig River flows landward.

Table 1. List of data and sources

Data Type	Reference
Shoreline	Google Map Website
Bathymetry of Manila Bay	Villanoy et al. (1997), SD
Bathymetry of Pasig River	Qian et al. (2000), JSCE
Bathymetry of Laguna Lake	Okino (1992), EsRec lecture & Yaota et al. (2015), JASS
Estimated Tidal Data of Manila Bay	Mobile Geographics Website
Boundary Condition Salinity	Pokavanich et al. (2006), EMECS
River Inflows to Laguna Lake	Catalogue of Rivers for Southeast Asia and the Pacific by UNESCO (2004)

3. NUMERICAL SIMULATION

The salinity intrusion was reproduced using a three-dimensional hydrodynamic model, *Fantom Refined*. The basic equations utilized in the model were those of continuity and three-dimensional Navier-Stokes with incompressible and

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Contact address: Minami-Osawa 1-1, Hachioji-shi, Tokyo, 192-0397, Japan, Tel:+81-42-677-2786 E-mail: k-yoko@tmu.ac.jp

Boussinesq approximations. The equations were discretized based on a collocated finite volume method. An unstructured Cartesian grid with Local Mesh Refinement (LMR) technique was used for the horizontal grid structure. In this study, the horizontal grid of topography size was 40 m in Pasig River, and gradually increased from 80 m to 1,280 m and 2,560 m near open ocean boundary to shorten the computation time. Vertical grid size was 0.25 m at surface and increased up to 20 m at bottom.

4. DATA ACQUISITION

Data for initial and boundary conditions necessary for simulation were acquired from journal articles, field survey reports and online websites as listed in Table 1. To estimate the bathymetry, the boundary between the water area and the land area was manually traced out using Google Map while the water depth was interpolated from the data presented in the published papers of Okino (1992), Villanoy et al. (1997), Qian et al. (2000) and Yaota et al. (2015). The salinity for the boundary condition was provided by Pokavanich et al. (2006). Input tidal data was prepared by interpolating the estimated tidal data of Manila Bay from Mobile Geographics website while pertinent weather data were likewise obtained online. River inflow data was sourced from a UNESCO (2004) catalogue upon which the discharge values of the six major rivers draining towards Laguna Lake were estimated by multiplying the average of the dry and rainy season flows of Pagsanjan River by watershed area ratio.

5. RESULTS OF SIMULATION

Several cases of salinity concentrations (freshwater, intermediate and saline) for Pasig River were first tested for sensitivity until a reasonable initial salinity condition is established for simulation. Results in Fig. 2 show a landward flow of river water during high tide. Additionally, a six-hour lag time was observed between peak high tide in the bay (22 h) and peak salinity in the lake (28 h). Fig. 3 shows well-mixed salinity distribution along the thalweg of the Pasig River while Fig. 4 provides the extent of maximum salinity intrusion on a horizontal viewpoint. It has to be emphasized that simulations were only made during spring tide in the dry season from April 28 to May 3, 2010. With limited information, rigorous data acquisition techniques allowed to successfully simulate salt water intrusion in the three interconnected water bodies of the Philippines. Verification can however be made in future field observations.

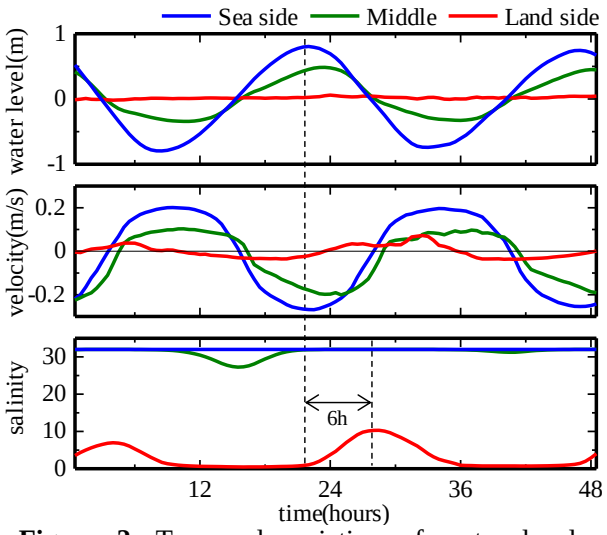

Figure 2. Temporal variation of water level, velocity and salinity during dry season along the Pasig River

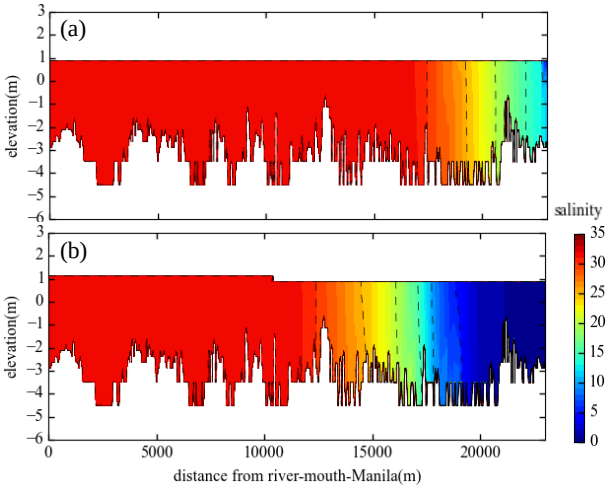

Figure 3. Longitudinal distribution of salinity during dry season spring tide at (a) maximum and (b) minimum salinity intrusion along Pasig River thalweg.

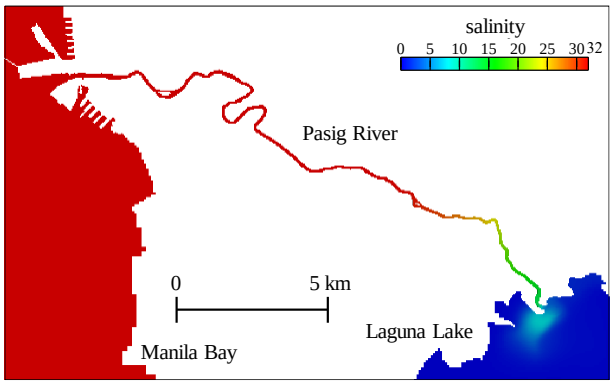

Figure 4. Horizontal salinity distribution during dry season spring tide at maximum intrusion