Hydrodynamic and Salinity Intrusion Model in Selangor River Estuary

N F Haron¹ and W Tahir¹
¹Flood Control Research Centre, Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA

E-mail: neemzay@yahoo.com

Abstract: A multi-dimensional hydrodynamic and transport model has been used to develop the hydrodynamic and salinity intrusion model for Selangor River Estuary. Delft3D-FLOW was applied to the study area using a curvilinear, boundary fitted grid. External boundary forces included ocean water level, salinity, and stream flow. The hydrodynamic and salinity transport used for the simulation was calibrated and confirmed using data on November 2005 and from May to June 2014. A 13-day period for November 2005 data and a 6-day period of May to June 2014 data were chosen as the calibration and confirmation period because of the availability of data from the field-monitoring program conducted. From the calibration results, it shows that the model was well suited to predict the hydrodynamic and salinity intrusion characteristics of the study area.

Keywords: Delft3D-FLOW, hydrodynamic model, salinity intrusion, calibration, estuary.

1. Introduction

Estuaries are semi-enclosed coastal bodies of water where fresh water and salt water meet and mixed [1]. Based on mixing characteristics, estuaries can be classified as vertically-mixed, slightly-stratified, highly-stratified or saline-wedge. The fresh water from river lighter than salt water, thus it had a tendency to remain on top of the salt water. In order to study on salinity behaviour, there are several research focus on salinity intrusion in estuary [2][3][4][5][6][7] using various methods including hydrodynamic model.

The application of a three-dimensional hydrodynamic and salinity transport model is required to identify environmental impacts related to management alternatives. The motivation for the application of a 3D hydrodynamic model and associated data acquisition and analysis is to better understand how salinity distributions respond to changing freshwater and pollutant loading over varying time scales.

Numerical models are often resorted to the study of water movement, or circulation, in estuaries and tidal rivers. Because of that, computer-modelling works was chosen to assist in predicting the hydrodynamic and salinity transport in Selangor River Estuary. Delft3D-FLOW was applied to the study area to simulate the hydrodynamics and salinity intrusion. Delft3D-FLOW has been extensively used to carry out simulations of flows, sediment transports, waves, water quality, morphological developments and ecology in coastal, estuary and river.

The main objective of this research is to develop a proper numerical modelling that projected the salinity intrusion of Selangor River Estuary. The purposes of this investigation are to develop a comprehensive hydrodynamic and salinity intrusion model for Selangor River Estuary by using Delft3D-FLOW and to evaluate hydrodynamic and salinity transport model for different sets of data.

A hydrodynamic model is set up and developed in this study on the behaviour of the saline intrusion and movement in the estuarine system. The model is calibrated and validated by using a Delft3D-FLOW. The model covers from river mouth up to Kg. Asahan (34 km from river mouth) in order to observed the maximum salinity intrusion length in the estuary. It is because Ishak et al. determined that the maximum limit of salt water intrusion reached some 16 km from the river mouth which was recorded during a low river discharges (6.0 m3/s) on a medium tide (tidal range 3.2 m), but this was reduced to about half the distance...
during high river discharges [8]. During this maximum intrusion, the salt water did not reach Kg. Kuantan, the attraction centre for the fireflies display which dwells on mangrove species Sonneratia Caseolaris (Berembang trees).

2. Methodology

2.1 Study Area
This study is focus on construct a hydrodynamic model and salinity intrusion in Selangor River Estuary (Figure 1). This research is emphasizing on the trend of the salinity transport in the estuary, determine the factors contributed to the trend observed and extrapolate the data collection based on the effects of those continuing factors imposed to the river. Selangor river has interacted many researchers to investigate about the river and the surrounding area along the river basin such as siltation modelling [9], flooding issues [10][11], case study of fireflies [12], land use changes [13], analytical salt intrusion model [14], and many more.

The Selangor River Estuary is located in Selangor river basin, situated in the upper part of the Selangor state. Selangor River starts from Fraser's Hill and stretches for 110 km to the coast of Kuala Selangor. The basin covers an area of 2,200 km2 contains nine sub-basins, which are Ulu Selangor, Kerling, Kuala Kubu, Sg. Tinggi, Rantau Panjang, Batang Kali, Tanjung Karang, Rawang and Kuala Selangor. It is the third largest river basin in Selangor after Sg. Langat and Sg. Bernam basins. The main uses of the river were listed in the Sg. Selangor Basin Management Plan 2007-2012 as water supply, ecosystem, tourism and recreation, sand mining, aquaculture, and inland navigation. The river is also famous for tourist attractions such as the firefly sanctuary at Kg. Kuantan.

To ensure that these uses can be sustained, the plan unveiled four main policies, which comprised ensuring water supply, ensuring clean water, protection against floods, and conservation of the fireflies as being observed in many research of Selangor river.

Salinity in the study area is influenced by the mixing of fresh water discharges from the Selangor river with salt water from the Malacca Strait. The quantity of fresh water discharged at any particular time is influenced by past and present precipitation, amount of surface water storage, evaporation and other hydrologic factors. The quantity of available salt water in the study area is primarily dependent on transport of ocean water through Selangor River Estuary inlet by tidal and low frequency coastal sea level forced currents.

Figure 1. Study Area. [15]

2.2 Field Data Collection Program
Field data are required to specify initial conditions, boundary conditions, and forcing function distributions in time and space for the calibration, validation and application of a three-dimensional hydrodynamic and salinity intrusion model of the study area. The objectives of the field program are to obtain calibration and verification data sets which include significant high freshwater inflow events as well as to provide information on representative mean seasonal conditions for the construction of hypothetical event scenarios. Sequences of scenarios will be used to predict and quantify the spatial and temporal extent of physical
processes that directly contribute to biological impacts within the study area. However, due to some problem regarding measurement equipment constraints, and time constraints, the data collection for validation purposes only have been done. Meanwhile, data for calibration have been provided from a consultant, Mr. Abdul Jalil Hassan measured water level at Kg. Asahan from 15 November to 27 November 2005 since the station in the region of the study area.

A survey was conducted from 31 May to 5 June 2014 for Selangor River Estuary to collect data needed to validate the Selangor River Estuary hydrodynamic and salinity intrusion model as presented in Figure-2.

2.3 Selangor River Estuary Model Calibration
A common technique in flow modelling is to start the calibration process with a 2-dimensional model. Therefore, in this study, water level calibration was carried using data obtained from a consultant, Mr. Abdul Jalil Hassan who was measured water level at Kg. Asahan from 15 November to 27 November 2005 since the station in the region of the study area. The most suitable Manning’s coefficient n value used in the calibration is 0.02. Besides, Figure-3 presents the comparison between observed and simulated water level not much difference and have the same pattern. Thus, the calibration of water level is acceptable.

![Figure 2](image2.png)

**Figure 2.** Location of salinity and water level for Selangor River Estuary model.

![Figure 3](image3.png)

**Figure 3.** Water level comparison between observed and simulated for $n = 0.02$ at Kg. Asahan station on November 2005.
2.4 Selangor River Estuary Model Validation
Due to the limited availability of data the model is only validated for salinity. Salinity levels are controlled by flow velocities and water levels, so a validation of only salinity is assumed to be sufficient.

In Table-1 indicates salinity comparison between observed and simulated salinity in May until June 2014 at station Kg. Bukit Belimbing and Jetty LKIM, Kuala Selangor. Meanwhile, in Figure-4 and Figure-5 show the graph simulated salinity versus observed salinity from May 2014 until June 2014 at Kg. Bukit Belimbing station and Jetty LKIM Kuala Selangor station for validation purpose respectively. In both figures, the observed salinity lower than simulated salinity for several times due to the heavy local rain in Kuala Selangor during the measurement. As a result, the discharge from the river and rainfall have deviated the reading of salinity. However, from the conditions it is shown that the high freshwater discharge will dilute the concentration of salinity. Thus, salinity level will reduce.

3. Preliminary Simulation
Preliminary simulation was done for different flow (low streamflow and high streamflow) as shown in Figure-6 to Figure-9). All the figures show the salinity level and water level at Jetty LKIM, Kg. Bukit Belimbing, Kg. Kuantan and Kg. Asahan varies with different flow conditions where salinity increases while the water level decreases during low river discharge and vice versa during high river discharge. Besides, the salinity level becomes zero at river upstream (Kg. Asahan, 34 km from river mouth) as the maximum limit of salt water intrusion reached about 16 km from the river mouth which was recorded during a low river discharges as stated by Ishak et al. (2002). As a result, the model was able to predict the values and the extent of the salinity intrusion along the Selangor River Estuary.

Table 1. Salinity comparison between observed salinity and simulated salinity in May 2014 and June 2014 at station Kg. Bukit Belimbing and Jetty LKIM, Kuala Selangor.

| Station         | Date and Time | Observed Salinity (ppt) | Simulated Salinity (ppt) |
|-----------------|---------------|--------------------------|---------------------------|
| Jetty LKIM      | 31/5/2014     | 2.7                      | 2.6                       |
|                 | 10:11         |                          |                           |
| Jetty LKIM      | 1/6/2014      | 0.1                      | 0.3                       |
|                 | 14:34         |                          |                           |
| Jetty LKIM      | 2/6/2014      | 0.1                      | 0.7                       |
|                 | 14:31         |                          |                           |
| Jetty LKIM      | 3/6/2014      | 0.3                      | 1.1                       |
|                 | 14:32         |                          |                           |
| Kg. Bukit Belimbing | 4/6/2014   | 0.1                      | 0.9                       |
|                 | 9:38          |                          |                           |
| Jetty LKIM      | 4/6/2014      | 19.4                     | 21.8                      |
|                 | 9:51          |                          |                           |
| Jetty LKIM      | 4/6/2014      | 4.2                      | 6.0                       |
|                 | 13:37         |                          |                           |
| Jetty LKIM      | 5/6/2014      | 10.3                     | 19.6                      |
|                 | 9:43          |                          |                           |
| Kg. Bukit Belimbing | 5/6/2014  | 0.1                      | 0.1                       |
|                 | 9:57          |                          |                           |
| Jetty LKIM      | 5/6/2014      | 2.6                      | 4.8                       |
|                 | 14:16         |                          |                           |
Figure 4. Simulated salinity versus observed salinity from May 2014 until June 2014 at Kg. Bukit Belimbing station for validation.

Figure 5. Simulated salinity versus observed salinity from May 2014 until June 2014 at Jetty LKIM Kuala Selangor station for validation.

Figure 6. Comparison of salinity and water level during low streamflow and high streamflow at Jetty LKIM.
Figure 7. Comparison of salinity and water level during low streamflow and high streamflow at Kg. Bukit Belimbing.

Figure 8. Comparison of salinity and water level during low streamflow and high streamflow at Kg. Kuantan.
4. Conclusions
The Selangor River Estuary model was calibrated using data on November 2005 and validated using data from May to June 2014. The hydrodynamic and salinity intrusion model was applied for preliminary simulations for different flow scenarios at different locations along the Selangor River Estuary. From the simulations, it can be indicated that the water level will increase as the freshwater inflow increase, consequently the salinity level will decrease in the estuarine system. It is anticipated that the calibrated and validated model will be useful as a resource management tool for addressing alternate strategies to mitigate adverse impacts of high freshwater inflow events specifically in Selangor River Estuary.

References
[1] Cao, J., Li, R. & Zhu, Y., 2008. Study on Saltwater Intrusion in the Yangtze River Estuary by 3D Numerical Model. In Education Technology and Training, 2008, and 2008 International Workshop on Geoscience and Remote Sensing, ETT and GRS 2008. pp. 81–84.
[2] Nuryazmeen, F.H., Tahir, W. & Koon, L.W., 2013. Extreme estuarine flooding leading to estuary transverse flow salinity intrusion. International Journal of Civil & Environmental Engineering IJCEE-IJENS, 13(02), pp.54–58.
[3] Nuryazmeen, F.H., Tahir, W. & Mohamad, I.N., 2014. Potential of Estuary Transverse Flow Salinity Intrusion Due to Extreme Estuarine Flooding. In R. Yusoff et al., eds. InCIEC 2013. Springer Singapore, pp. 343–352. Available at: http://dx.doi.org/10.1007/978-981-4585-02-6_30.
[4] Nuryazmeen, F.H. & Tahir, W., 2014a. Laboratory investigations on estuary salinity mixing : preliminary analysis. International Journal of Sciences: Basic and Applied Research (IJSBAR), 13(1), pp.36–41.
[5] Nuryazmeen, F.H. & Tahir, W., 2014b. Physical model of estuarine salinity intrusion into rivers: A review. Advanced Materials Research, 905(2014), pp.348–352. Available at: http://www.scientific.net/AMR.905.348.
[6] Nuryazmeen, F.H. et al., 2015. Salinity Velocity Pattern in Estuary Using PIV. In S. H. A. Bakar et al., eds. Proceedings of the International Symposium on Flood Research and Management (ISFRAM 2014). Springer Singapore, pp. 221–243.
[7] Nuryazmeen, F.H. & Tahir, W., 2016. Simulation of Estuary Transverse Flow Salinity Intrusion During Flood Event : Case Study of Selangor River Estuary. In Wardah Tahir et al., eds. ISFRAM 2015 (Proceedings of the International Symposium on Flood Research and Management 2015). p. Chapter 12
[8] Ishak, A.K. et al., 2002. Salinity intrusions into the Selangor river estuary and its effect on the mangrove species sonneratia caseolaris. In Proceedings of the Seminar R and D MINT 2002: Strengthening R and D Culture for Technology Generation. pp. 123–130.
[9] Ariffin, J. & Abdul Talib, S., 2006. Siltation modeling for Selangor dam in Hulu Selangor (Report), Selangor, Malaysia, pp.1-24.
[10] Hassan, A.J., 2006. Pemodelan sungai dan dataran banjir untuk penjanaana peta risiko banjir : Kajian kes Sg. Selangor. Universiti Sains Malaysia, pp.1-249
[11] Hassan, A.J., Ab. Ghani, A. & Abdullah, R., 2006. Development of flood risk map using GIS for Sg. Selangor Basin. Proceeding 6th International Conf. on ASIA GIS, 9-10 Mac, UTM, pp.1–11.
[12] Kirton, L.G. et al., 2012. Monitoring populations of bioluminescent organisms using digital night photography and image analysis: A case study of the fireflies of the Selangor River, Malaysia. Insect Conservation and Diversity, 5(3), pp.244–250.
[13] Sulaiman, N. & Mohamad, J., 2014. Landuse conflicts in the Sungai Selangor watershed. In UM-KU, ed. Newsletter: JSPS Asian Core Program (IWM). Universiti Malaya, pp. 4–6.
[14] Gisen, J.I.A., 2015. Prediction in ungauged estuaries (Thesis). Delft University of Technology, pp.1-142.