

Enhancing Water Circulation in a River Port

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Abstract

Chiang Saen Commercial Port, Thailand is located on the Mekong River. The port experienced poor water quality within its basin during dry season. The limited water circulation in the port originated from the ever-growing large sand dune at the port entrance and the shape of the port itself. A proposal to enhance the water flow was evaluated involving the excavation of the floodway, letting the water from the Sobkok River push the water out of the basin. A software package (MIKE21 HD) was utilized to investigate the floodway modification. The research began with detailed bathymetric mapping. The topography of the floodway was surveyed along with water level variations during normal and dry seasons. Water current characteristics were gathered for model calibration purposes. After acceptable model calibration was achieved, five scenarios were investigated. It was found that the floodway could significantly enhance the water circulation inside the basin if it was excavated deeper than 3 meters from the existing level. This paper considers the real-world problem and stresses the role of careful planning so that decisions can be made for the better environment.

Key Words: Water Circulation, Port, Mathematical Modelling, Environmental Management, Thailand

1. Introduction

The Chiang Saen Commercial Port is situated on the Mekong River. The port was constructed in 2009 to enhance commodity transportation with China, Myanmar, and Laos (Figure 1) [1]. During the feasibility study stage, the port was designed to locate behind a large sand dune since international considerations opposed the port being built along the Mekong River bank due to concerns that the opposite river bank might have been eroded. Engineering works included major inland excavation and navigational dredging. A floodway was also constructed to discharge excessive water into the Sobkok River during flood periods (Figure 1). From a navigational viewpoint, the port's function has been achieved since ships can load/unload commodities without having to anchor in the Mekong River, and the water current inside the port

is more stagnant. However, a problem emerged after a few years of operation.

Commodities passing through and ships visiting the port have been increasing. There were 2,175 ships loading/unloading at the port in 2012. The number of ships quadrupled in 2015 after being managed by the Port Authority of Thailand (PAT) (Table 1) [1]. However, unforeseen problems emerged. A lot of dams were constructed upstream, especially in China, with objectives to store water during drought periods and to generate hydropower [2]. The dams drastically reduced the quantity of the water reaching the port, which in turn decreased water circulation inside the port. Furthermore, inadequate toilets and waste reception facilities were provided in the port area. In addition, the behavior of ship crews was not environmentally friendly as they polluted the water in the port by throwing garbage and human excrement into the water. Moreover, the author found that the large sand dune at the entrance to the port had expanded (Figure 2). The bigger dune acted as a flow barricade, reducing the volume of water that flows

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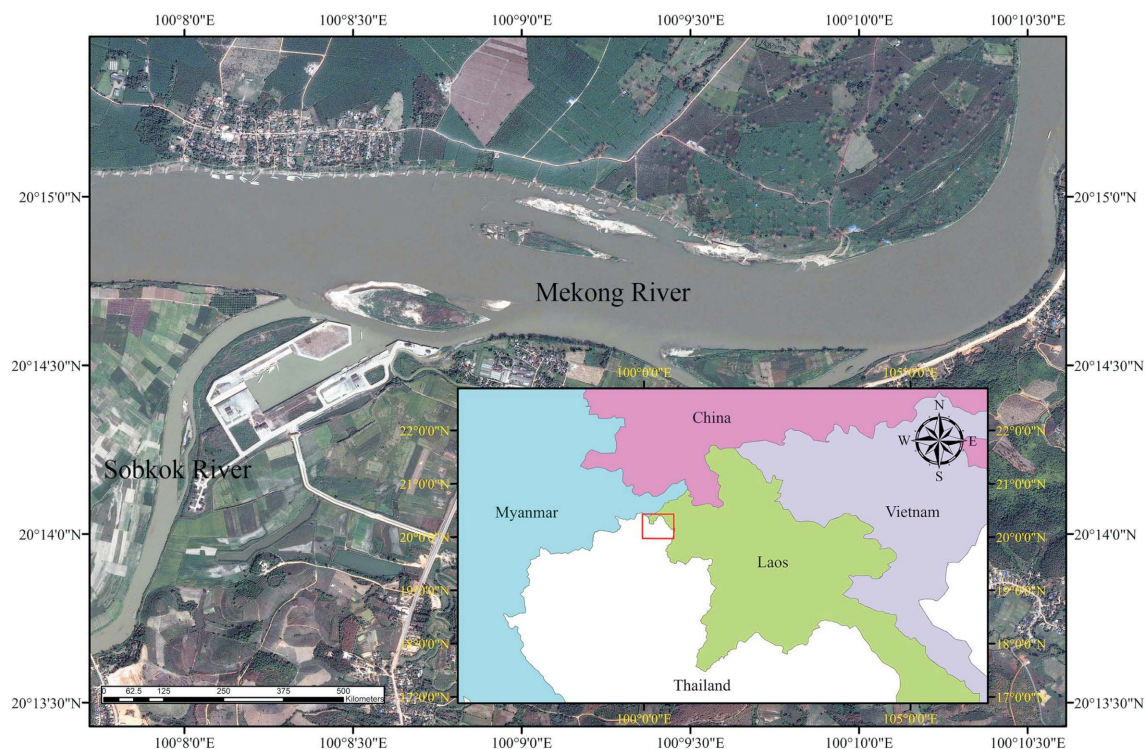


Figure 1. Study area.

Table 1. Number of ships visiting Chiang Saen Commercial Port

Year	Number of ships visiting the port
2012	2,175
2013	8,367
2014	8,144
2015	9,052

into and out of the port, resulting in less water exchange. These incidents collectively created unsatisfactory water quality inside the port during the dry season. On the other hand, there was no water quality problem during the normal season. Therefore, it was concluded that the water quality problem in the port was created by insufficient water circulation during the dry season.

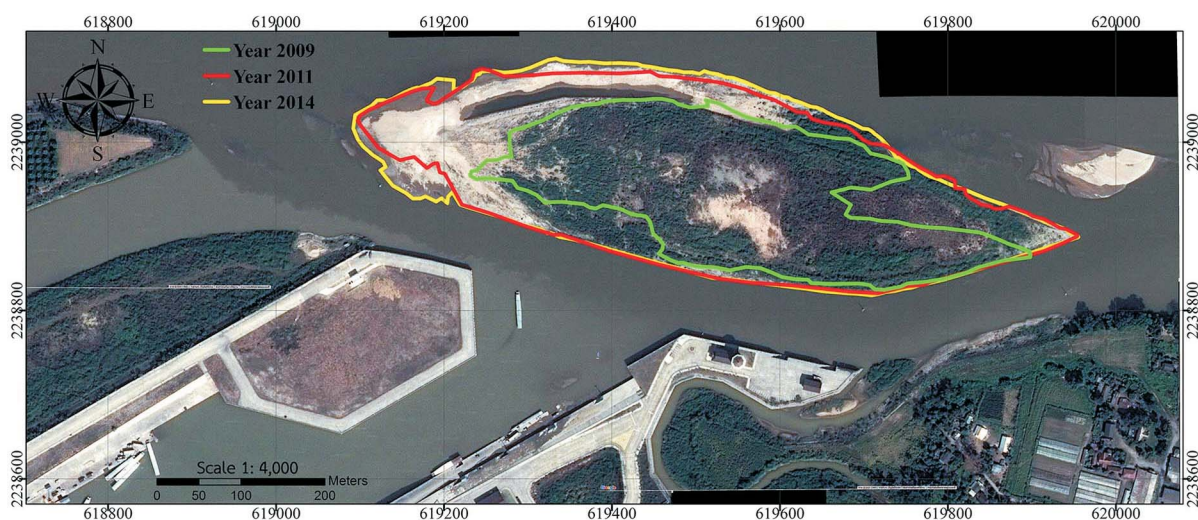


Figure 2. Sand dune at the entrance of the port.

One way to solve the water quality problem inside the port during the dry season was to excavate the floodway in order to let the water from the Sobkok River flow through the floodway and push the port water out to the Mekong River. A gigantic sluice gate was required. Such a measure involved a large construction cost but the PAT was not certain whether the action could correct the problem. Numerical simulations were applied for this real-world problem. A software package named MIKE21 HD was utilized to validate the proposed action. The novelty of this article is that it contains detailed data gathering and calibration processes as well as outputs that can actually be implemented. The problem of interest actually happened in reality. This article is the first published paper that deals with the water circulation enhancement in the river port. It provides a good demonstration and may be applicable to similar problems around the world.

2. Methodology

The study began with establishing an indicator to an-

swer the question of how much water circulation within the port was required. Field data was planned and collected accordingly. After the information gathering was completed, an evaluation of floodway modification was undertaken using MIKE21 HD.

2.1 Conceptual Solution

To assess whether the floodway excavation was effective, an indicator was needed. The water quality problem in the port occurred during the dry season (February and March) and not the normal season (the rest of the year), implying that the water circulation within the port during the normal season was sufficient to maintain the water quality at an acceptable level. The floodway excavation would allow more water from the Sobkok River into the port during the dry season but the sluice gate would be closed during the normal season (Figure 3). If the water quantity being discharged out of the port during the dry season ($Q_{out_{dry}}$) was equal or greater than the water volume flowing out of the port during the normal season ($Q_{out_{normal}}$) (Eq. 1), the floodway modification

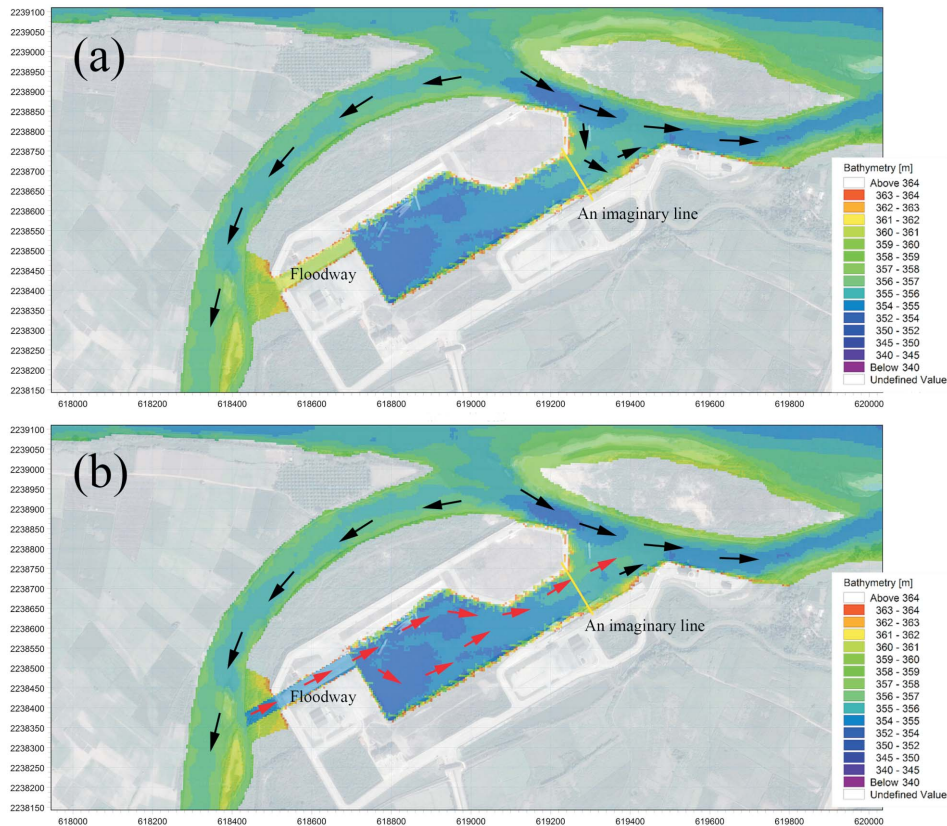


Figure 3. (a) Existing elevation of the floodway. (b) Conceptual solution (black arrows indicate natural flow characteristics and red arrows indicate additional flow due to floodway excavation).

would solve the problem.

$$Q_{out_{dry}} \geq Q_{out_{normal}} \quad (1)$$

2.2 Data Gathering

Since the investigation required estimations of $Q_{out_{normal}}$ and $Q_{out_{dry}}$, it was necessary to acquire information of water level variations during seasons. A bathymetric survey was carried out in November 2015, covering more than 13 km along the Mekong River, the Sobkok River, and within the port. The area was located in Universal Transverse Mercator zone 47. The depth and topographic elevation were recorded in meters above the national mean sea level (MSL). Three digital water gauges were installed to record water level variations for 2 months; one month during the normal season from 18 October 2015 to 22 November 2015, and the other month during the dry season from 18 February 2016 to 17 March 2016 when the amount of water in the river was expected to lowest (Figure 4). The speed and direction of the water current was measured hourly at 2 stations (Figure 5) from 21 November 2015 to 22 November 2015 for model calibration and verification purposes.

2.3 Modeling Procedures

MIKE21 HD is a general numerical modeling system for the simulation of water levels and flows in river and coastal areas [3]. It has been applied in many studies in rivers, estuaries, and coastal areas [4–9]. It is based on continuity and momentum equations (Eq. 2 to Eq. 4).

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t} \quad (2)$$

$$\begin{aligned} \frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left(\frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left(\frac{pq}{h} \right) + gh \left(\frac{\partial \zeta}{\partial x} \right) + \frac{pg\sqrt{p^2 + q^2}}{(Mh^{1/6})^2 h^2} \\ - \frac{1}{\rho_w} \left[\frac{\partial}{\partial x} (h\tau_{xx}) + \frac{\partial}{\partial y} (h\tau_{xy}) \right] - \Omega q - fVV_x \\ + \frac{h}{\rho_w} \frac{\partial}{\partial x} (p_a) = 0 \end{aligned} \quad (3)$$

$$\begin{aligned} \frac{\partial q}{\partial t} + \frac{\partial}{\partial y} \left(\frac{q^2}{h} \right) + \frac{\partial}{\partial x} \left(\frac{pq}{h} \right) + gh \left(\frac{\partial \zeta}{\partial y} \right) + \frac{pg\sqrt{p^2 + q^2}}{(Mh^{1/6})^2 h^2} \\ - \frac{1}{\rho_w} \left[\frac{\partial}{\partial y} (h\tau_{yy}) + \frac{\partial}{\partial x} (h\tau_{xy}) \right] - \Omega p - fVV_y \\ + \frac{h}{\rho_w} \frac{\partial}{\partial y} (p_a) = 0 \end{aligned} \quad (4)$$

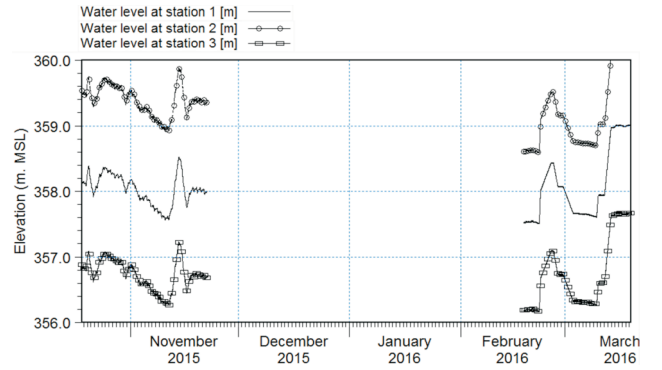


Figure 4. Measured water level variations.

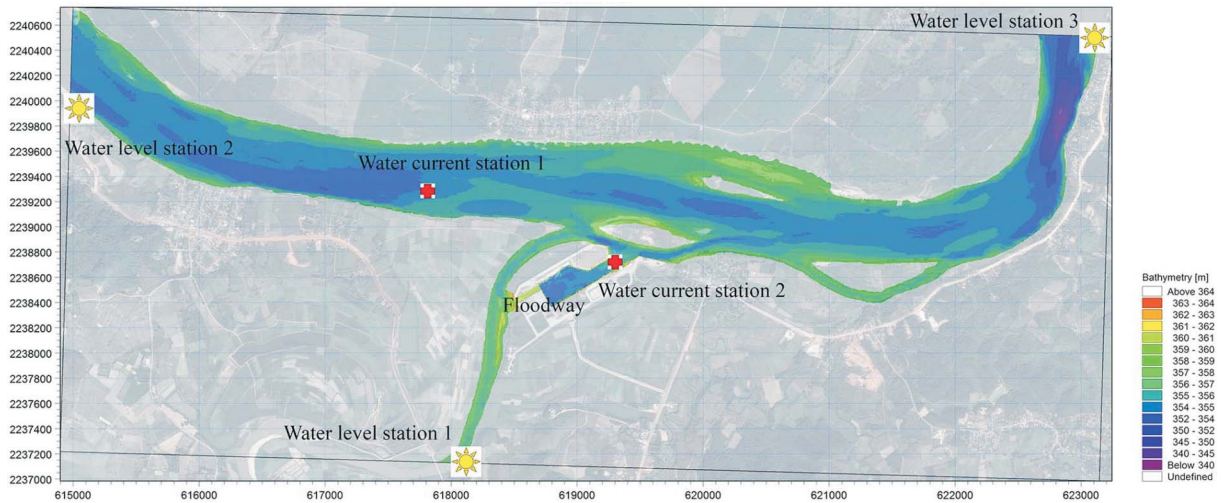


Figure 5. Bathymetry, water level, and water current stations.

where $h(x, y, t)$ is water depth (m), $d(x, y, t)$ is time-varying water depth (m), $\zeta(x, y, t)$ is surface elevation (m), $p(x, y, t)$ is flux density in x-direction ($\text{m}^3/\text{s}/\text{m}$), $q(x, y, t)$ is flux density in y direction ($\text{m}^3/\text{s}/\text{m}$), M is Manning's number ($\text{m}^{1/3}/\text{s}$), g is gravitational acceleration (m/s^2), $f(V)$ is wind friction factor, $V(x, y, t)$ is wind speed (m/s), $V_x(x, y, t)$ is a component of wind speed in x-direction (m/s), $V_y(x, y, t)$ is a component of wind speed in y-direction (m/s), $\Omega(x, y)$ is a Coriolis parameter which depends on latitude (s^{-1}), $p_a(x, y, t)$ is atmospheric pressure ($\text{kg}/\text{m}/\text{s}^2$), ρ_w is density of water (kg/m^3), t is time (s), and τ_{xx} , τ_{xy} , τ_{yy} are components of effective shear stress.

The analysis began with transforming field data into a format that conformed with MIKE21 HD. A bathymetric map having a 5×5 meter grid was constructed (Figure 5). Water level variations at 3 stations were used as boundary conditions (Figure 5). Differences among the water levels of the stations forced the water to flow. The domain's initial surface elevation was set to an average value of all water level stations at the first time step. At the beginning of the simulation, both $p(x, y, t)$ and $q(x, y, t)$ in the domain were zero. Therefore, an additional model-day was undertaken to warm up the simulation but ignored during the flow analysis. No wind data was incorporated into the model setup because the measured water levels already included wind stress acting on the water surface in themselves. Some modellers have used a single water level station or predicted water level data and then added external forces to drive the water [6,10,11], but the author chose to use the actual water level measurements at every open boundary for the simulations. Although the author's technique was more expensive, the method was robust and it could eliminate errors originating from data inconsistency that might result from different types of data being collected by different sources at different times.

To determine Q_{out_normal} , a simulation of how the water circulated in the study area during the normal season was undertaken. An imaginary line was drawn at the entrance to the port to measure the water volume flowing past the line (Figure 3), using the "discharge calculation" in the MIKE21 Toolbox. The same approach was taken for the simulation during the dry period, but the water level variations at the same 3 stations collected during the drought period were used as the boundary conditions

instead. Later, Q_{out_dry} was extracted at the port entrance and compared with Q_{out_normal} . Finally, the effectiveness of the floodway modification was simulated. Based on the topographic survey result, the elevation of the floodway was +360 m MSL, while in the vicinity of the back of the floodway in the Sobkok River, it was around +358 m MSL (Figure 3). Thus, the floodway was purposed to be excavated at least 2 m lower from the existing elevation to allow the water from the Sobkok River into the port. However, the deeper excavation would unnecessarily induce more expenses. If the simulations proved that Q_{out_dry} was larger than Q_{out_normal} after the floodway adjustment, the proposal to modify the floodway would be considered operational.

2.4 Model Calibration

MIKE21 HD was applied to simulate existing water current flow characteristics. A bathymetric map having a grid size of 5×5 m was prepared. Calibration parameters used in MIKE21 HD were Manning number and Eddy viscosity. For this study, the appropriate Manning number was $25 \text{ m}^{1/3}/\text{s}$ and the Eddy viscosity based on Smagorinsky constant was 0.20. An index applied to evaluate agreement between the measured and the calculated current characteristics was root mean square error (RMSE). The RMSE was selected as the indicator because of its advantages. It directly compares the differences between the measured and the calculated values. Moreover, the RMSE delivers the same unit as the parameter being compared, enabling a modeller to instantaneously understand its meanings [9,12,13]. Since the water current comprises time-varying information on speed and direction, applying the RMSE required some additional calculations. The current characteristics (speed and direction) had to be transformed into a horizontal velocity component (V_x) and a vertical velocity component (V_y). A positive V_x means that the current flows to the east, while a negative V_x implies that the current flows to the west. In the same manner, a positive V_y indicates that the current flows to the north, and a negative V_y indicates the current flows to the south. The criterion applied in this study was that the RMSE of any comparison (either the V_x or V_y component) should not exceed the absolute maximum velocity of the measured current in such a comparison [9,12,13]. As a result, the RMSE of V_x at the water current sta-

tion 1 was 0.110 m/s and the RMSE of V_y at the water current station 1 was 0.212 m/s. Moreover, the RMSE of V_x at the water current station 2 was 0.012 m/s and the RMSE of V_y at the water current station 2 was 0.011 m/s (Figure 6).

3. Results

After satisfactory calibration and verification were obtained, the simulations were undertaken for both normal and dry seasons. A specific period during 18 October 2015 to 22 November 2015 was chosen as a baseline flow magnitude that could maintain good water quality inside the port. The least river flow measured during 18 February 2016 to 17 March 2016 was selected as an incident when the floodway was required to increase the discharge out of the port.

3.1 Flow Characteristics During the Normal Season

The large sand dune at the entrance of the port and the shape of the port basin restricted the water flowing into and out of the port. The water at the entrance could not penetrate far enough into the basin's bottom (Figure 7), resulting in inadequate water circulation. The "discharge calculation" in the MIKE21 Toolbox was then utilized to compute flow rate and water quantity. During the normal season when the water quality in the port was satisfactory, the flow rate into and out of the port was less than 7 m³/s. The water volume that passed into and out of

the port during the normal season was approximately 122,414 m³/day. Such an amount of water was then set as the goal after the floodway was excavated since this volume could maintain acceptable water quality in the basin.

3.2 Flow Characteristics During the Dry Season and Floodway Excavation Effectiveness

During the dry season, less water exchange in the port occurred. Based on simulation results, it was found that the water flowing through the port entrance was about 43,338 m³/day, being three times less than that of the normal season. The discharge rate through the port reduced to less than 2 m³/s. Therefore, the goal of the floodway modification was to triple the flow during the dry season. Allowing water from the Sobkok River through the deepened floodway would push the water innermost in the basin out of the port (Figure 3).

Since the elevation of the floodway was +360 m MSL but in the vicinity of the back of the floodway in the Sobkok River was around +358 m MSL, it was expected that a minimum excavation of 2 m was required. Five scenarios, being 2-m, 3-m, 4-m, 5-m, and 6-m excavation, were simulated (Figure 8). The investigation found that the 2-m floodway deepening would not solve the problem since the water from the Sobkok River would not flow into the basin. The 3-m excavation would significantly enhance the circulation. The water from the Sobkok River would rush into the basin, increasing the discharge to 546,242

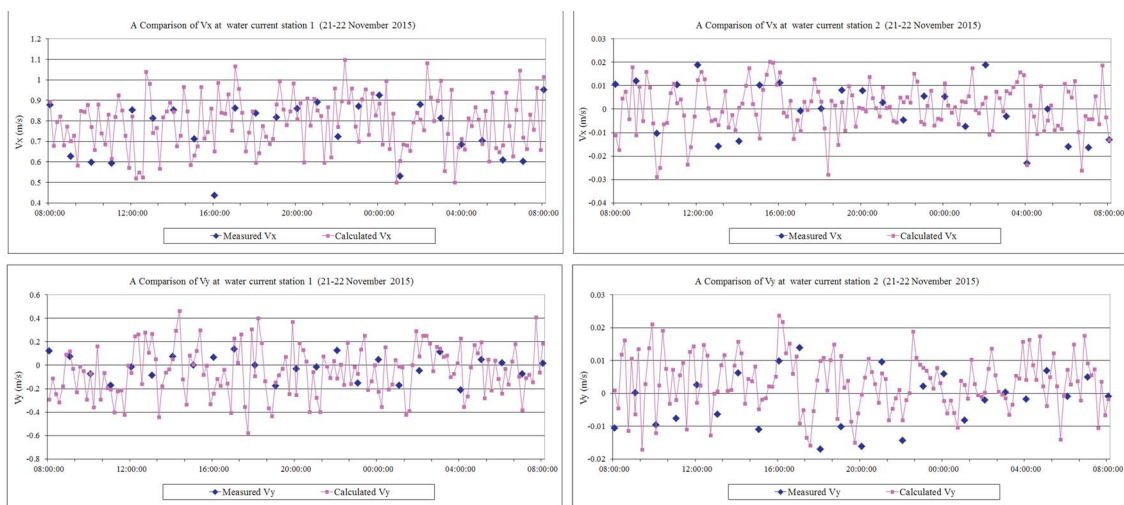


Figure 6. Calibration results.

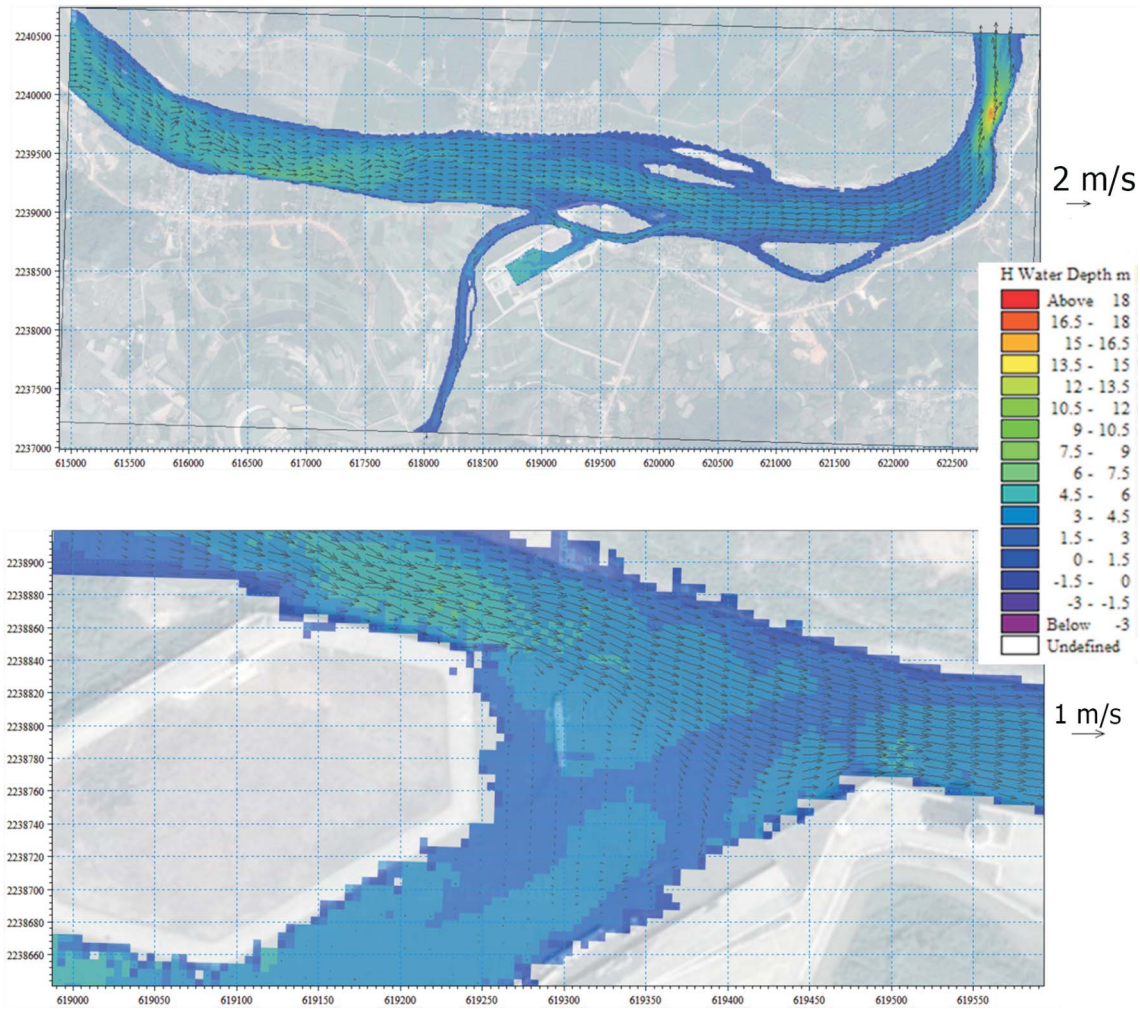


Figure 7. Flow characteristics during normal season.

m^3/day (more than 4 times greater than the pre-determined objective). Excavation deeper than 3 m would still increase the discharge but at a diminishing rate (Figure 9). The 4-m excavation would induce a discharge of $823,346 \text{ m}^3/\text{day}$ out of the port. Moreover, the 6-m floodway deepening would increase the discharge to $895,572 \text{ m}^3/\text{day}$. Therefore, the 3-m floodway excavation was suggested as an efficient solution that could solve the problem without excessive investment.

4. Discussion

Applied mathematical modelling is a crucial tool that helps decision makers select the right solution. Deciding without adequate information equates to guessing. Some decisions involve large investments and a change

in the wrong direction may incur unnecessary costs of money, time, manpower, and other resources.

This article demonstrates the application of mathematical modelling to solve a real-world problem. Chiang Saen Commercial Port experienced a water quality problem within its basin during dry seasons. The limited water circulation in the port originated from the ever-growing large sand dune at the port entrance and the shape of the port itself. The Port Authority of Thailand (PAT) who managed that port considered finding a solution as urgent and wanted to solve the problem by excavating the floodway to let water from the Sobkok River flow into the port basin and push the water out to the Mekong River. However, the floodway modification would cost millions of dollars, and the PAT was not certain that this proposal would succeed. Therefore, important questions that

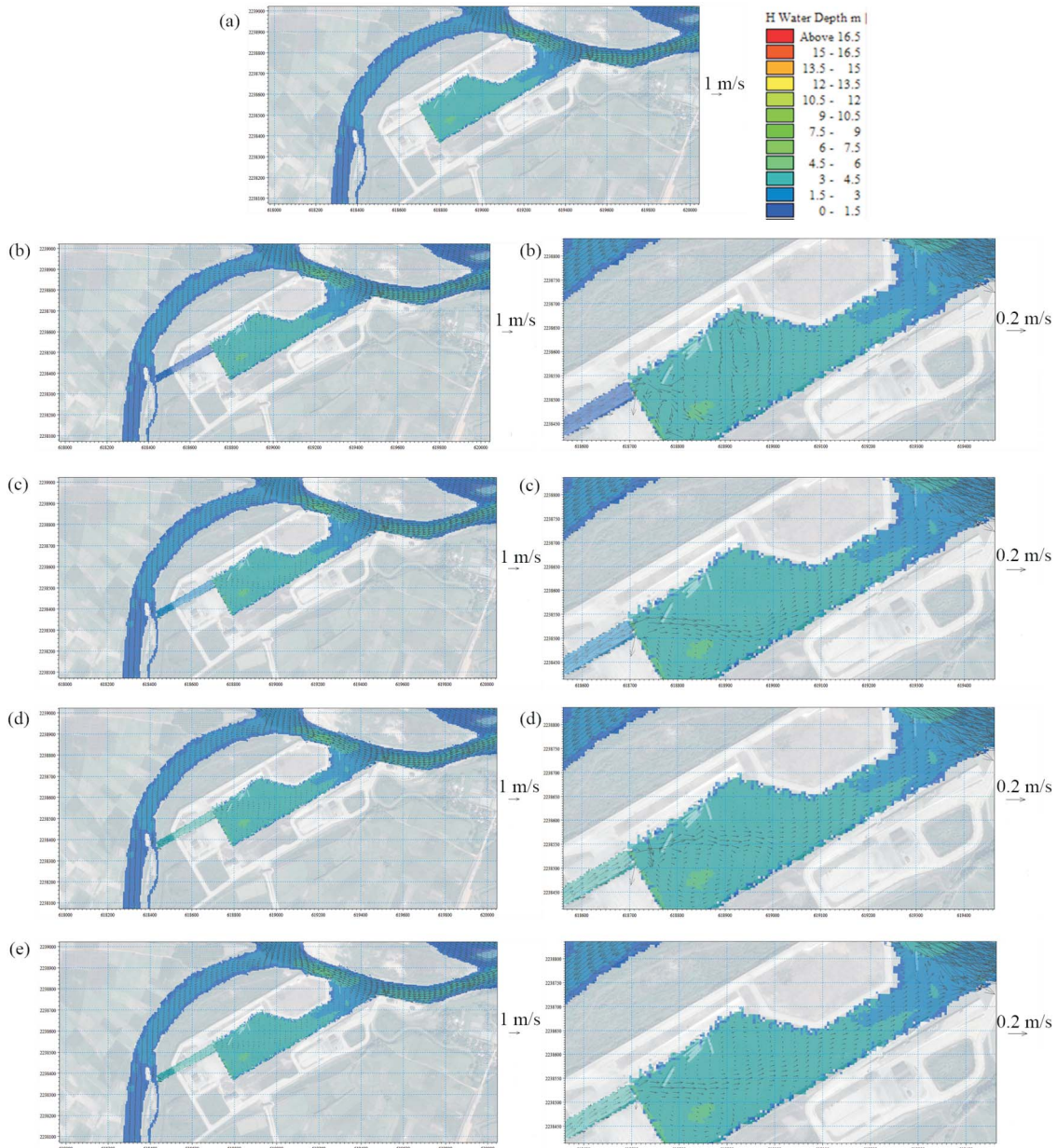


Figure 8. Simulation results for (a) 2-m, (b) 3-m, (c) 4-m, (d) 5-m, and (e) 6-m floodway excavation.

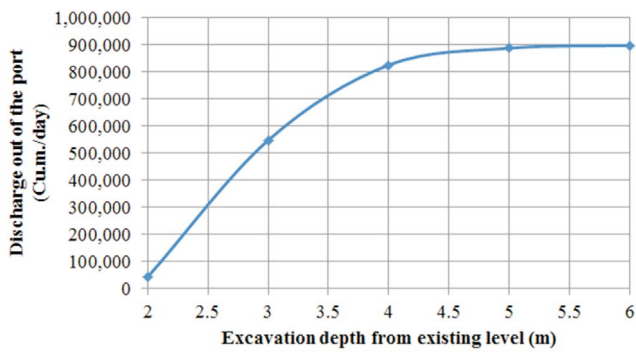


Figure 9. Results of floodway deepening.

required robust answers were: (a) whether the floodway deepening would increase the basin circulation, and (b) how deep the excavation should be.

Carrying out accurate mathematical modelling was not cheap, but definitely cheaper than constructing the floodway and then having to demolish it if it could not solve the water quality problem inside the basin. The process of mathematical modelling began with collecting field information including bathymetric data, water levels during normal and dry seasons, water current

characteristics, as well as other geographical information in the port and its surrounds. Calibration and verification were then undertaken to make sure that the simulation could represent a real-world scenario. Several scenarios were investigated. It was found that the floodway modification could significantly enhance the water circulation inside the basin if the excavation was deeper than 3 m from the existing level. The overall study process took 8 months to complete and the money spent to find out the answers was less than US\$ 70,000. Thus the study provided greater confidence for the PAT if it decided to invest millions of dollars with the actual floodway construction.

The real-world problem presented in this study is one of the very few publications that deal with enhancement of water circulation inside a port. Thus, it can be a good example for other similar cases around the world. However, the study process in this article involved careful planning, using experienced modellers, and sophisticated survey instruments. If simulations are required in a country where these components are not readily available, the decision makers there should utilize other decision-supporting tools before selecting a solution.

5. Conclusion

This research applied a hydrodynamic model (MIKE 21 HD) to solve a real-world problem occurring in the Chiang Saen Commercial Port where the water quality in the port basin was poor during dry seasons. Enhancing water circulation could be achieved by deepening the floodway but it involved a huge investment. Mathematical modelling was utilized to investigate whether the proposed measure was effective. Several scenarios were simulated with little expense, but the simulated results could grant paramount confidence to decision makers. If no mathematical modelling were applied, the port might take a blind action and might unnecessarily lose millions of dollars if the proposed solution was neither effective nor efficient.

Acknowledgement

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References

- [1] Information on <http://www.csp.port.co.th> (accessed 4 December 2017).
- [2] Mekong River Commission Secretariat (2010) Strategic environmental assessment of hydropower on the Mekong mainstream: Final report, Vietnam.
- [3] Information on <https://www.mikepoweredbydhi.com/products/mike-21/hydrodynamics> (accessed 23 Sep 2017).
- [4] Babu, M. T., P. Vethamony, and E. Desa (2005) Modeling tide-driven currents and residual eddies in the Gulf of Kachchh and their seasonal variability: a marine environmental planning perspective, *Ecological Modelling* 184(2–4), 299–312. doi: 10.1016/j.ecolmodel.2004.10.013
- [5] Hakim, B. A., M. Wibowo, W. Kongko, M. Irfani, W. Hendriyono, and G. Gumbira (2015) Hydrodynamics modeling of giant seawall in Semarang bay, *Procedia Earth and Planetary Science* 14, 200–207. doi: 10.1016/j.proeps.2015.07.102
- [6] Lumborga, U., and A. Windelin (2003) Hydrography and cohesive sediment modelling: Application to the Rømø Dyb Tidal Area, *Journal of Marine Systems* 38, 287–303. doi: 10.1016/S0924-7963(02)00247-6
- [7] Saengsupavanich, C. (2011) Impact of a proposed pier on Tidal currents: Koa Kood Island, Thailand, *World Academy of Science, Engineering and Technology* 81, 103–106.
- [8] Saengsupavanich, C. (2010) A current environmental impact assessment of a port in Thailand: Marine physical aspects, *Ocean & Coastal Management* 54, 101–109. doi: 10.1016/j.ocecoaman.2010.11.001
- [9] Saengsupavanich, C. (2014) Impacts of a barge accident on river bank stability, Proc. of the 2014 Asia-Pacific Management and Engineering Conference (APME 2014), China.
- [10] Panda, U. S., M. M. Mahanty, V. Ranga Rao, S. Patra, and P. Mishra (2015) Hydrodynamics and water quality in Chilika Lagoon-A modelling approach, *Procedia Engineering* 116, 639–646. doi: 10.1016/j.proeng.2015.08.337
- [11] Vethamony, P., K. Sudheesh, M. T. Babu, S. Jayakumar, R. Manimurali, A. K. Saran, L. H. Sharma, B. Rajan, and M. Srivastava (2007) Trajectory of an oil spill off

- Goa, Eastern Arabian Sea: Field observations and simulations, *Environmental Pollution* 148(2), 438– 444. doi: 10.1016/j.envpol.2006.12.017
- [12] Saengsupavanich, C. (2012) Predicting and mitigating dredging dispersion impact: a case of Phuket Port, Thailand, *World Academy of Science, Engineering and Technology* 72, 1639–1644.
- [13] Saengsupavanich, C. (2013) Marine physical impacts of bridge foundations in Tammalung Estuary, Thailand, Proc. of the ECSA 53: Estuaries and Coastal Area in Times of Intense Change, Shanghai, China.

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