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Predicting and Mitigating Dredging Dispersion Impact: A Case of Phuket Port, Thailand

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***Abstract*—**Dredging activities inevitably cause sediment dispersion. In certain locations, where there are important ecological areas such as mangroves or coral reefs, carefully planning the dredging can significantly reduce negative impacts. This article utilizes the dredging at Phuket port, Thailand, as a case study to demonstrate how computer simulations can be helpful to protect existing coral reefs. A software package named MIKE21 was applied. Necessary information required by the simulations was gathered. After calibrating and verifying the model, various dredging scenario were simulated to predict spoil movement. The simulation results were used as guidance to setting up an environmental measure. Finally, the recommendation to dredge during flood tide with silt curtains installed was made.

***Keywords*—**Coastal simulation, Dredging, Environmental protection, Port. Coastal engineering, Thailand

I. Introduction

DREDGING is one of the most important activities for ports. It involves removing sediment from seabed. The deepening mostly has an objective to accommodate largest ships expected to arrive at the port. Environmental impacts associated with the dredging include turbidity and sediment dispersion, destruction of benthic habitats as well as adjustment of benthic communities, removal of seagrasses and coral reefs, underwater shockwave that disturbs marine animals, smoke and noise from dredging machines, alteration of wave pattern, and obstruction of maritime activities among others [1-4].

Sediment dispersion, which is the focus of this study, may be harmful to coral reefs because of its impacts to block light penetration and suffocate the corals [5]. Mitigation measures are thus required to protect such valuable ecology. There are a lot of suggestions to reduce the sediment dispersion such as silt curtain installation, scheduled dredging during neap tide, as well as a proper selection of dredger type. However, such recommendations are too general. There is a great need to specifically establish the mitigation measures to suit a local context.

This article uses a case study of Phuket port, Thailand to illustrate how to lessen impacts of the dredging. It applies computer simulations to determine appropriate time of the dredging operation as well as assessing suspended solid concentration to reach existing nearby coral reefs.

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A. Study Site

Phuket port is one of the most important deep-water ports in Thailand. The port was reclaimed in 1986 and is located in a bay protected by headlands (Fig. 1). It accommodates cruiser ships and container ships as large as 20,000 DWT. Its current berthing length is approximately 360 m. The navigational channel depth is approximately -12.29 m from National Mean Sea Level (MSL). Currently the port is planning to expand its navigational channel. Approximately 8,000 m^3 of bottom sediment will be removed by a cutter suction dredger.

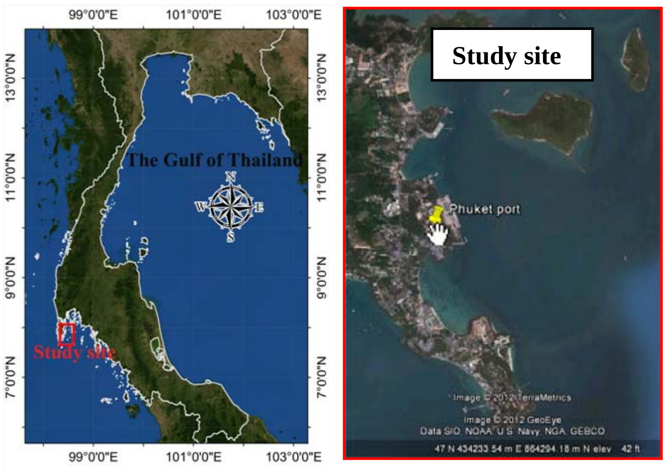

Fig. 1 Study site and a Google Earth image

Coral reefs exist in a vicinity of Phuket port. Phuket Marine Biological Center reported that the coral reefs at the north of the port were healthy but damaged in some locations [6]. The reefs at the south of the port were in moderate condition, having a live coral to dead coral ratio of 1.1:1 [6] (Fig. 2). One of the construction criteria is that the expansion dredging must not destroy the coral reefs. Moreover, the dredging should disturb the reefs as least as possible. Therefore, careful planning is required.

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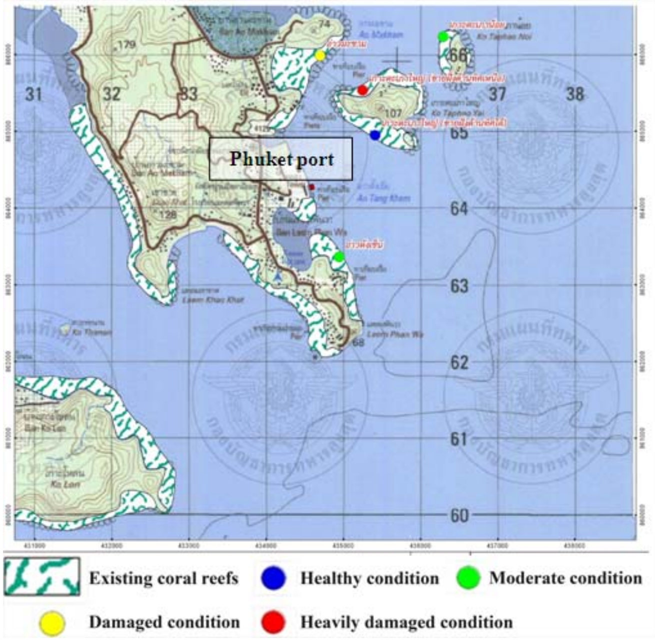

Fig. 2 Existing coral reefs around Phuket port (Courtesy: STS Engineering consultant Co. Ltd., Thailand)

II. Methodology

A. Data Collection

The study began with collecting related information important for computer simulations. Bathymetric as well as topographic surveys were carried out. They covered not only the port area but also nearby bays. After the surveys were completed, a bathymetry map having a grid size of 5 x 5 m was prepared for the computer simulations (Fig. 3).

Major driving forces influencing water current circulation include tide, wind, and wave. However, individually putting them in the simulations was difficult since it would require a lot of calibration efforts. Errors from each component would add up, resulting in excessive inaccuracy. Alternatively, the author selected to directly measure water level variations at two stations simultaneously (Fig. 3). They could be directly used as boundary conditions. The author's approach had many advantages. Firstly, an individual impact of the factors influencing the water circulation could be ignored. Only the summation of such forces was considered. Secondly, the boundary conditions were very accurate, leading to reliable simulation outputs. Thirdly, model calibration and verification processes were easier since they involved less calibration parameters. The water level measurements expanded for one month, covering spring and neap tides. From the measurement results, it could be clearly seen that the water level variations at the stations expressed different amplitude and phase (Fig. 4). Such differences controlled ocean current circulation around the port.

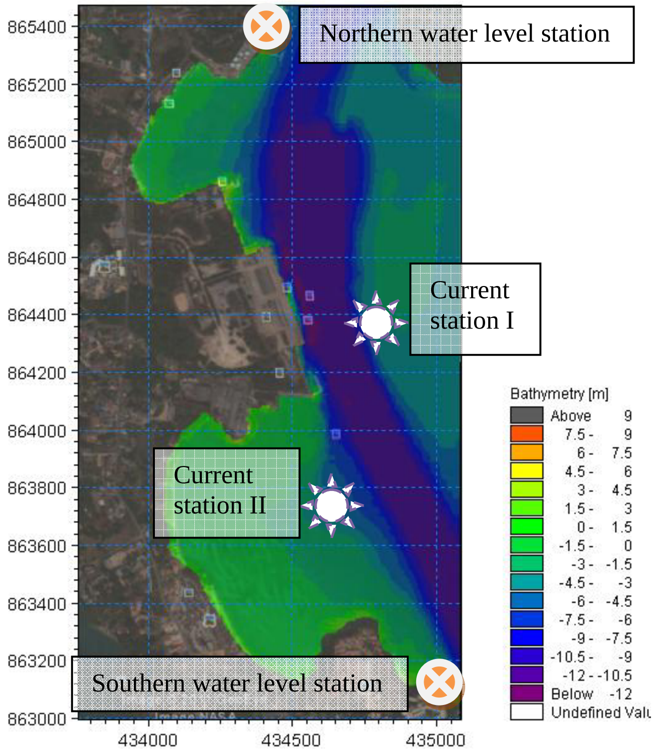

Fig. 3 Bathymetry map (m MSL, UTM Zone 47), locations of tidal, and current stations

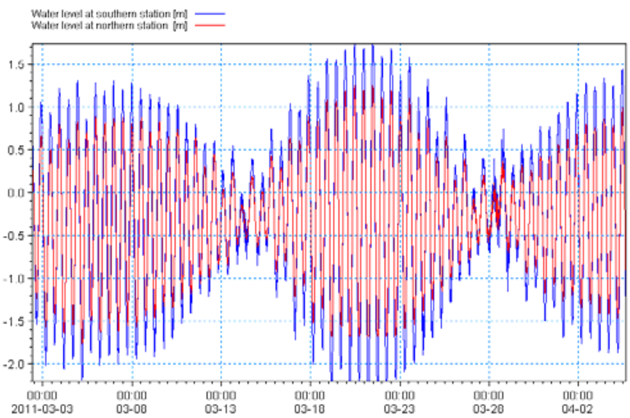

Fig. 4 Water level variations at different stations

Current speed and direction were hourly measured at 2 stations during spring and neap tides by a current meter (Fig. 3). Maximum current speed during the measurement was approximately 0.51 m/s. Information on the water current pattern was then used in model calibration and verification processes.

Sediment at the dredging site was sampled and analyzed for its size and grading. It was found that the sediment was silty sand with a median diameter of 0.4 mm (Fig. 5).

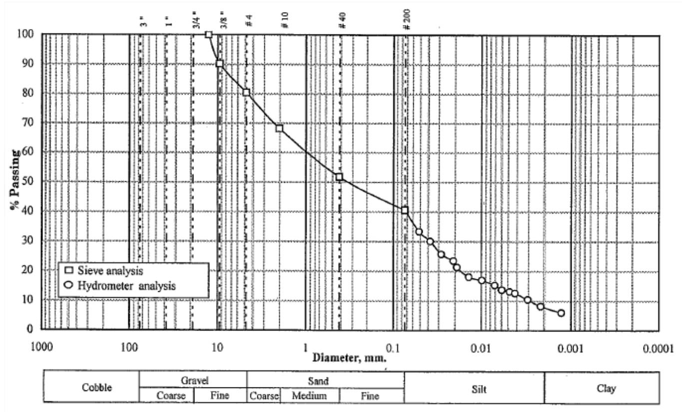

Fig. 5 Bottom sediment characteristics at the dredging site

B. A Simulation Procedure, Model Calibration and Verification Processes

A software package applied in this study was MIKE21. It was developed by Danish Hydraulics Institute [7]. It was capable of simulating water current circulation and dispersion of substances. A modeling procedure could be summarized in Fig. 6.

Calibration parameters used in MIKE21 were Manning number and Eddy viscosity. For this study, the appropriate Manning number was 12 $m^{1/3}$/s and the Eddy viscosity based on Smagorinsky constant was 0.25. An index applied to evaluate agreements 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 the meanings.

Since the water current comprised 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 horizontal velocity component (Vx) and vertical velocity component (Vy). Positive Vx means that the current flows to the east, while negative Vx implies that the current flows to the west. In the same manner, positive Vy indicates that the current flows to the north, and negative Vy indicates the current flows to the south. A criteria applied in this study was that the RMSE of any comparison (either Vx or Vy component) should not exceed the absolute maximum velocity of the measured current in such comparison.

Calibration and verification results of the study are presented in Fig. 7 to Fig. 10.

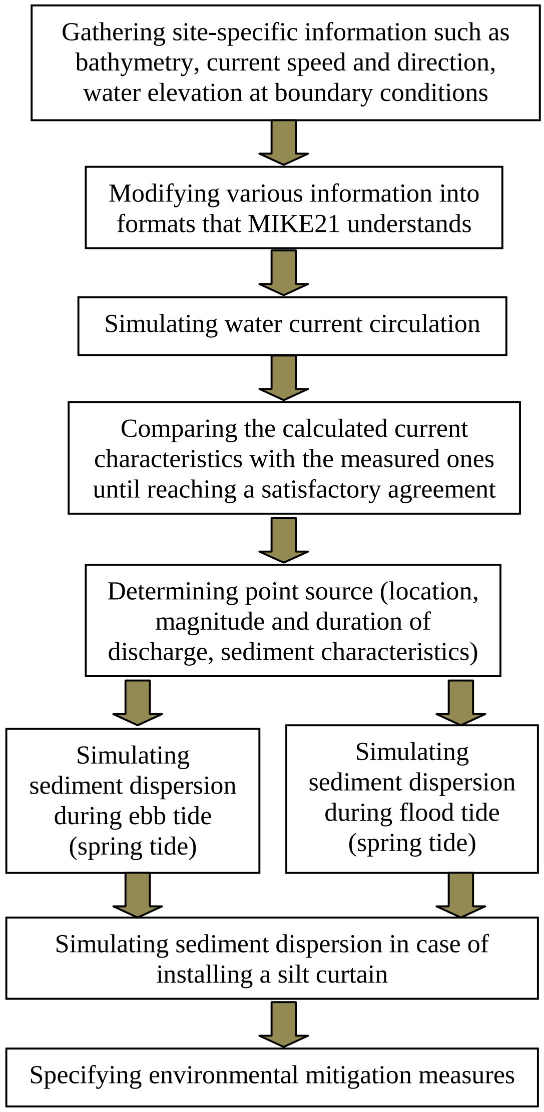

Fig. 6 A modeling process in this research

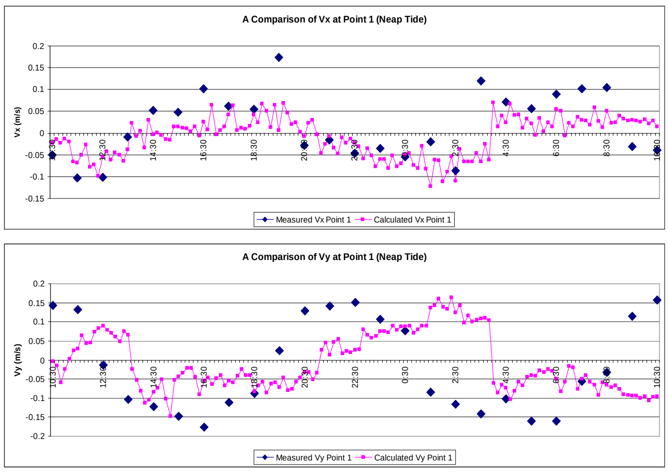

Fig. 7 Model calibration result at Current Station I during neap tide
RMSE for Vx = 0.066 m/s and RMSE for Vy = 0.138 m/s

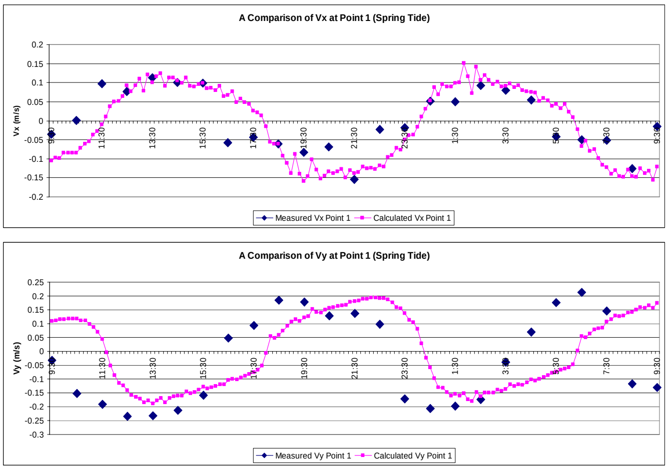

Fig. 8 Model calibration result at Current Station I during spring tide RMSE for Vx = 0.061 m/s and RMSE for Vy = 0.161 m/s

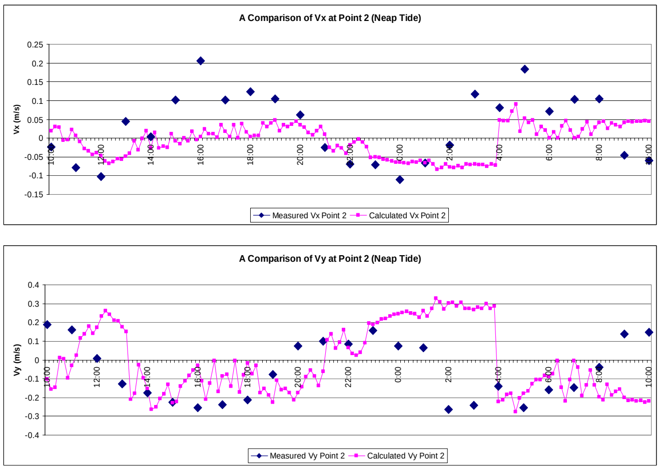

Fig. 9 Model verification result at Current Station II during neap tide RMSE for Vx = 0.089 m/s and RMSE for Vy = 0.238 m/s

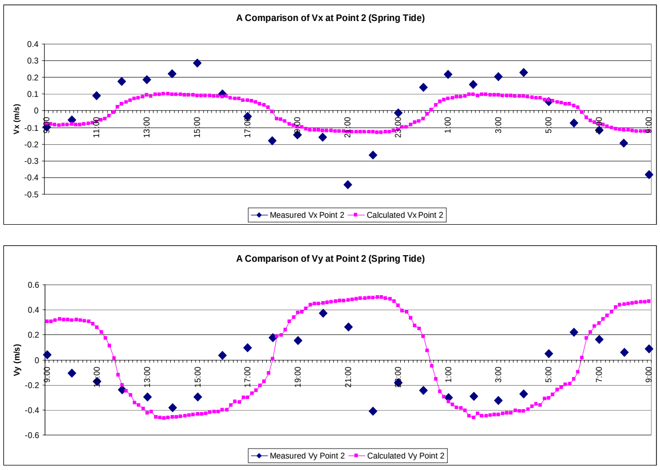

Fig. 10 Model verification result at Current Station II during spring tide
RMSE for Vx = 0.135 m/s and RMSE for Vy = 0.345 m/s

C. Sediment Source and Silt Curtain Installation

Finer sediments can disperse further away from their origin than the coarser ones. Therefore, a few assumptions were made in order to accurately specify characteristics of the sediment source for MIKE21. Firstly, the sediment was divided into three fractions, being 0.4 mm (50%), 0.2 mm (10%), and 0.01 mm (40%). Secondly, fall velocity was determined for each fraction. Thirdly, an interview with a port manager revealed that the total of 8,000 m^3 of seabed sediment would be removed within one month by a cutter suction dredger, resulting in a dredging quantity of 266 m^3/day or 14.96 kg/s.

An installation of silt curtain can reduce suspended solid concentration up to 75-99.99% [8-10]. The smallest apparent opening size of woven geotextile in the market is 0.18 mm. Although the fabric opening size is larger than a diameter of silt, the filtering effect is still very effective because of a clogging of the silt curtain by coarser portions of the sediment, retarding water flowing through the curtain [11]. Including the effect of silt curtain in MIKE21 was simply undertaken by reducing the quantity of sediment discharge at the source.

III. Results

A. Sediment Dispersion without a Silt Curtain Installed

The dredged sediment would disperse far away from the source. Direction of the sediment movement was dictated by the tide. During flood tide, the dredge spoil would move north (Fig. 11). In contrast, the suspended sediment would travel south during ebb tide (Fig. 12).

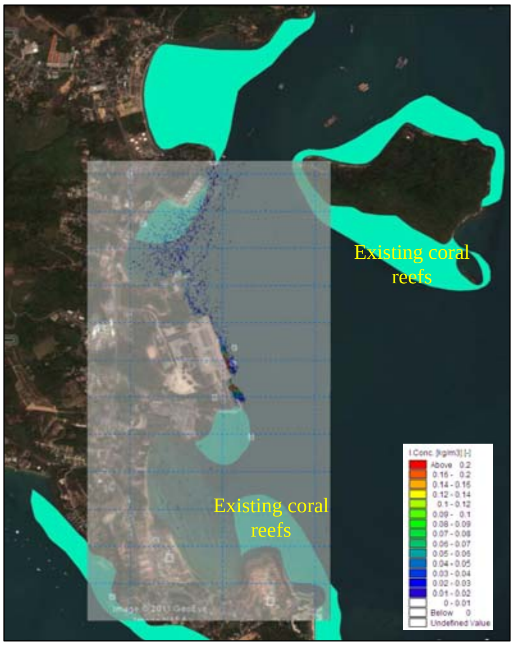

Fig. 11 Sediment dispersion during flood tide without a silt curtain

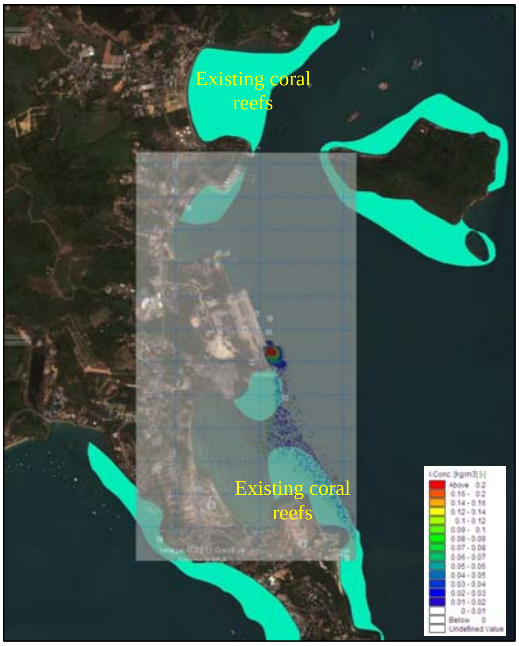

Fig. 12 Sediment dispersion during ebb tide without a silt curtain

B. Sediment Dispersion with a Silt Curtain Installed

Installing a silt curtain would reduce sediment movement. It was predicted that very little dredge spoil would not reach the coral reefs located north of the port during flood tide (Fig. 13). In the same manner, the sediment concentration arriving at the southern coral reefs during ebb tide would dramatically decrease if the silt curtain was installed (Fig. 14).

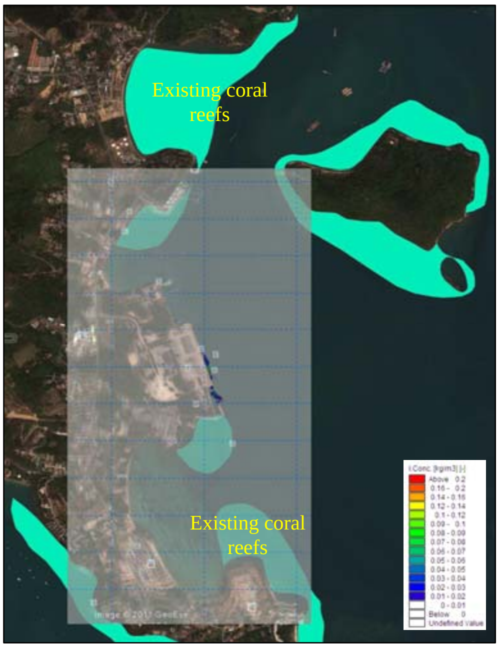

Fig. 13 Sediment dispersion during flood tide with a silt curtain installed

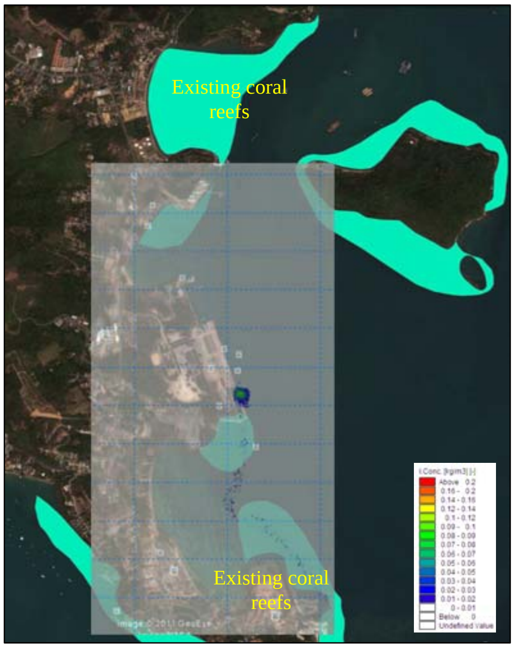

Fig. 14 Sediment dispersion during ebb tide with a silt curtain installed

IV. Discussion and Conclusion

Unplanned dredging may adversely affect coral reefs at Phuket port. Computer simulations could be helpful in scheduling the dredging activities so that the navigational channel improvement would not harm valuable coral ecology. The simulation results advised the port manager to carry out the dredging operation during flood tide because the dredge spoil would move northwards. Furthermore, the northern coral reefs were already damaged. Finally, a silt curtain should be utilized to reduce sediment concentration reaching the reefs.

In order to being able to derive the abovementioned dredging recommendations, a lot of efforts and resources were required. Readers may notice that the overall process of MIKE21 simulations took time since it involved collecting bathymetric, topographic, sediment, hydrodynamic conditions as well as surveying status and locations of existing coral reefs. The simulations themselves were also complex since setting up and calibrating the model demanded a lot of works. Moreover, they were costly and time-consuming. Investors who did not concern much on the environment might consider the simulations unworthy. However, in today's world where the environment is often a victim of the development, such investment is very necessary in order to protect and preserve the environment for our next generations. .

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