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# Using Mike 21 ST model to assess the sand mining project in Lo river

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**Abstract**

With the aim of assessing the impact of sand mining project environmental Lo River, subjects used the method of sediment transport modeling in rivers, using Sand Transport module in the hydrodynamic model Mike 21 for a particular project. The result was to determine the feasibility of a sand mining project on the Lo river. The subject has shown that the effects of sand mining project on the flow rate and changes in river bed surface and it is negligible. The method can be applied in order to calculate in other mining projects.

*Keywords:* Mike model, sand mining, hydrodynamic model

## 1. General

Nowadays, river sand mining is one of the most important issues that causes lowering water level of river in the dry season. Sand mining has led to the river bed is lowered and direct impact on agricultural practices that cause problems when irrigating. The loss of sediment is due to not only sand mining in the river, but also sediment trapped in the reservoir. However, the later is inevetable, therefore people can only reduce the loss of sand by having effect on the later reason - river sand miningMoreover, according to pevious researches on the reservoir showed that the amount of sand loss due to retaining in the reservoir is not much, so the main reason is river sand mining. This suggests that the loss of river sand can be handled by sand mining management. With rapideconomic development in recent years, Vinh Phuc and are faced with the serious environmental issues; including sand mining, especially on sand mining Lo is a huge impact on farming activities of the people. Therefore, it is essential to build a model assessing the impact of sand mining project in order to recover the river bed.

## 2. Subjects and Methods

### 2.1 Research Subjects

The research obbject in this study is a sand mining project of Bac Ai Construction Investment Advisory JSC. at three towns Duc Bac, Don Nhan and Phuong Khoan in the Song Lo District, Vinh Phuc province.

### 2.2 Research Methodology

To handle the question of assessing the impact of sand mining project, the authors approached the problem by modeling simulating. According to the resolution of the problem will be approached through the Mike 21 model and more clearly by two hydrodynamic module and sand transport module. The MIKE 21 model is specialized engineering software DHI (Danish Hydraulic Institute) that has been built and developed for

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about 20 years, is used to simulate the flow and water quality, transportation sediment, oil spills, wave propagation in estuaries, rivers, irrigation systems, canals and other water systems. In MIKE 21 model, the hydrodynamic module (HD) is the central part of the model, however, depending on the purpose for which we combined use with other modules in a rational and scientific manner. With the aim of calculating water quality data for model calculations include data on hydrology, hydraulics and water quality. However, in specific circumstances, sometimes do not have enough data to measure the flow to record the input to the hydrodynamic model, so we have to find ways to build and restore the data flow from the available data.

### 2.2.1 Theoretical basis of the Hydrodynamic module

Module hydrodynamic model (HD) is the central part of the system MIKE 21 model and forms the basis for most of the modules, including: flood forecast, load diffusion, water quality, sand transport and oil spill. Hydrodynamic module of MIKE 21 solves the equations according to the flow in order to ensure continuity and conservation of momentum (the Saint Venant equations). The basic features of the model system MIKE 21 is a modular structure with a variety of modular synthesis are added to simulate the phenomena related to the river system. In addition to the hydrodynamic module, MIKE 21 also has additional modules for:
- Hydrodynamic (HD);
- Advection/Dispersion (AD);
- Environment module (ECO Lab);
- Non-Cohesive Sediment(Sand)transport (ST);
- Particle Tracking (PT)...

In the two-dimensional hydrodynamic model for the flow of Newton fluids, the following elements are required:

- Law of conservation of momentum
- Law of conservation of mass
- Conservation of salinity and temperature

Mathematical basis of the MIKE 21 is the equation of conservation of mass, the average Reynolds and 3-dimensional Navier-Stokes equations, including the effects of turbulence and variable density, temperature together with the conservation equation and salinity.

$$\frac{1}{\rho c_s^2}\frac{\partial P}{\partial t}+\frac{\partial u_j}{\partial x_j}=SS$$

$$\frac{\partial u_i}{\partial t}+\frac{\partial\left(u_i u_j\right)}{\partial x_j}+2\Omega_{ij}u_j=-\frac{1}{\rho}\frac{\partial P}{\partial x_j}+g_i+\frac{\partial}{\partial x_j}\left(v_T\left\{\frac{\partial u_j}{\partial x_i}+\frac{\partial u_j}{\partial_j}\right\}-\frac{2}{3}\delta_{ij}k\right)+u_i SS$$

$$\frac{\partial S}{\partial t}+\frac{\partial}{\partial x_j}\left(Su_j\right)=\frac{\partial}{\partial x_j}\left(D_s\frac{\partial S}{\partial x_j}\right)+SS$$

$$\frac{\partial T}{\partial t}+\frac{\partial}{\partial x_j}\left(Tu_j\right)=\frac{\partial}{\partial x_j}\left(D_T\frac{\partial T}{\partial x}\right)+SS$$

In which:

ρ- local acceleration
$c_s$ -speed of sound in seawater
$u_i$ - velocity in the direction
$\Omega_{ij}$ - Coriolis force
P - Fluid pressure

δ - Kronecker coefficients of the delta
k - turbulent kinetic energy
S - salinity
T - temperature
$D_S$ and $D_T$- dispersion coefficient related

$g_i$- the gravity vectors t - denotes time

$\nu_T$ - turbulent vortex

The basic equation of the model to account for the unstable case is a system of equations including continuity equation and the momentum equations (Saint Venant equations) with the following assumptions:

- The flow is one-way flow, depth and velocity of longitudinal change of river bed.
- The flow changes slowly along the river bed leads to hydrostatic pressure dominates, the vertical acceleration is ignored.
- River bed axis is considered as a straight line.
- River bed slope is small and fixed bottom, ignore erosion and deposition.
- It is possible to apply the drag coefficient of stable turbulent flow to unstable flow to describe the effects of dragging.
- The liquid is incompressible and unchanged weight through flow.

### 2.2.2 Theoretical basis of the Sand Transport model

MIKE 21 ST is a module in the MIKE 21 application that suites for calculating non-cohesive sediment (sand) transport rates. You can calculate sand transport based on pure current information, or you can take waves into consideration too.

In addition to sand transport rates, a simulation gives the initial rates of bed level changes. This is sufficient to identify potential areas of erosion or deposition, but cannot results full morphological model. MIKE 21 ST can simulate sand transport rates in a wide array of settings, including natural environments such as tide, estuaries and coast lines, and man-made constructions such as harbours and bridges. Tide, wind, wave and current can all be taken into consideration for optimized precision in the simulations.

In MIKE 21 ST software, we need to pay attention to the following factors:

- Constant or spatially varying bed material (i.e. median grain size and gradation)
- Five different sand transport theories available in pure current conditions:

– The Engelund and Hansen total-load transport theory

– The Engelund and Fredsøe total-load (determined as bed load + suspended load) transport theory

– The Zyserman and Fredsøe total-load (bed load + suspended load) transport formulation

– The Meyer-Peter and Müller bed-load transport theory

– The Ackers and White total-load transport formulation

- Two simulation methods available in combined current and wave conditions:

– Application of DHI's deterministic intra-wave sediment transport model, STP

– Bijker's total-load transport method

- The STP model provide these features to MIKE 21 ST:

– Arbitrary direction of wave propagation in respect to the current

– Distinguish between breaking and unbroken waves

– Geometric properties of bed material is described through a single grain size or a grain size distribution curve

– Plane/ripple-covered bed

- When using the STP model in combined current and wave simulations, two-dimensional (2DH) or quasi three-dimensional (Q3D) sand transport methods are available
- Speed up simulations by using predefined sand transport tables
- Finite differences technique on space-staggered rectangular grid
- Courant-Friedrichs-Lewy stability criterion

*Engelund & Fredsøe Transport Theory*

The total-load transport rate $q_t$ is calculated as the sum of the bed-load transport $q_b$ and the suspended load transport rate $q_s$

$$q_t = q_b + q_s$$

It is assumed that bed-load transport takes place in one single layer of thickness equal to one grain diameter d. The bed-load transport $q_b$ is calculated as

$$q_b = 5p\left(\sqrt{\theta'} - 0.07\sqrt{\theta_c}\right)\sqrt{(s-1)gd} \qquad \text{If } \theta' > \theta_c$$

Where p is the probability that all particles in a single layer will be in motion, θ' is the dimensionless bed shear stress (Shields parameter) related to skin friction and $\theta_c$ is the critical bed shear stress for initiation of motion. $s$ is the relative density of the bed material.

θ' is defined as $\theta' = \dfrac{U_f'^2}{(s-1)gd}$

p is defined as $$p = \left[1 + \left[\frac{\frac{\pi}{6}\beta}{\theta' - \theta_c}\right]^4\right]^{-1/4}$$

with β = the dynamic friction coefficient.

Following the ideas of Einstein (1950), the suspended load $q_c$ is evaluated as

$$q_c = 11.6U'_f c_b a\left[I_1 \ln\left(\frac{30h}{k_N}\right) + I_2\right]$$

With $c_b$= the bed concentration of suspended sediment, $U_f'$ = the shear velocity related to skin friction, a = 2d= the reference level for $c_b$, I1 and I2 = Einstein's integrals, h = the water depth and $k_N$ = Nikuradse's equivalent roughness = 2.5d.

$$c_b = \frac{0.65}{(1+1/\lambda)^3} \text{ with } \lambda \text{ is defined as: } \lambda = \sqrt{\frac{\theta' - \theta_c - \frac{\pi p \beta}{6}}{0.027 s\theta'}} \text{ if } \theta' > \theta_c + \pi p\beta/6$$

*Engelund & Hansen Transport Theory*

The dimensionless rate of total-load transport Φt is calculated as

$$\Phi_t = 0.1 \frac{C^2}{2g} \theta^{2.5}$$

with C = Chezy's number and

$$\Phi_t = \frac{q_t}{\sqrt{(s-1)gd^3}}$$

with $q_t$ = the total load sediment transport and $g$ = gravitational acceleration. The dimensionless bed shear stress $\theta$ is defined as

$$\theta = \frac{U_f^2}{(s-1)gd}$$

Where: $U_f$ is the shear velocity related to total friction

$d$ is the grain diameter

$s$ is the relative density of the bed material.

# 3. Results and discussion

## 3.1 Grid computing area

To perform the calculations and apply the model Mike in the study area firstly we are going to convert the area to grid.

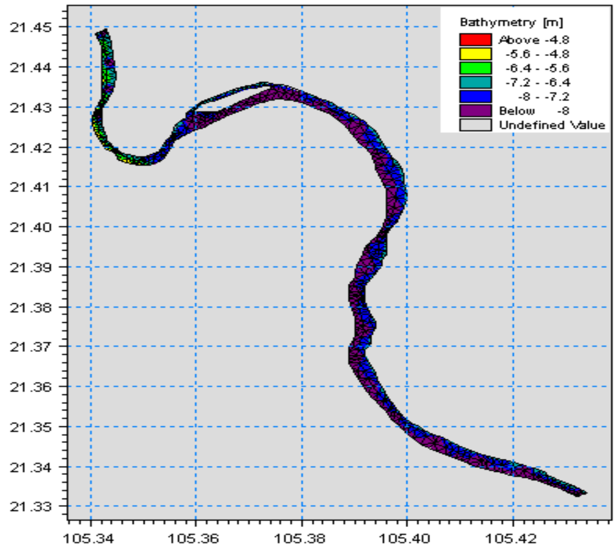


Figure 1: Regional grid mapping calculations

## 3.2 Setting up the hydrodynamic module

Regional climate divided into two distinct seasons. Rainy season usually lasts about 5 months (from May to November), water level often rises, and sand mining cannot be deployed. In dry season, water level is lower; it is good condition for the extraction by suction method to dump so sand mining products mainly in the dry season. Therefore, hydrodynamic boundary inputs are designed with the flow and the average water level period in the dry season. Unstructured mesh terrain area calculations are used for the two cases. After simulate case current status, conduct to simulate case 2 with the input records kept unchanged, then simulate 2 more sources views expressed river sediment extraction process by location in the plan. Hydraulic calculation results the following two cases: (i) without sand extraction and (ii) with sand extraction which are indicated in the pictures.

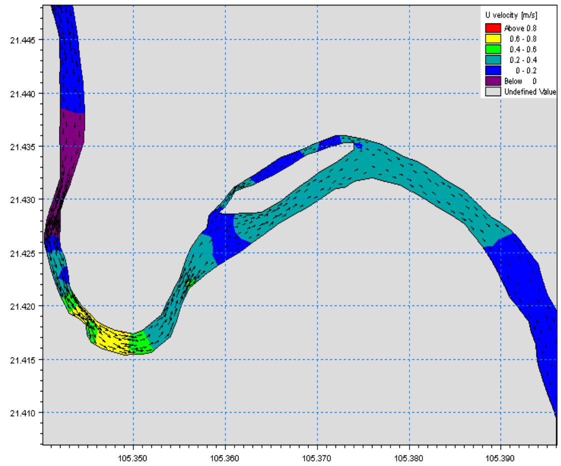


Figure 2: The U velocity without extraction

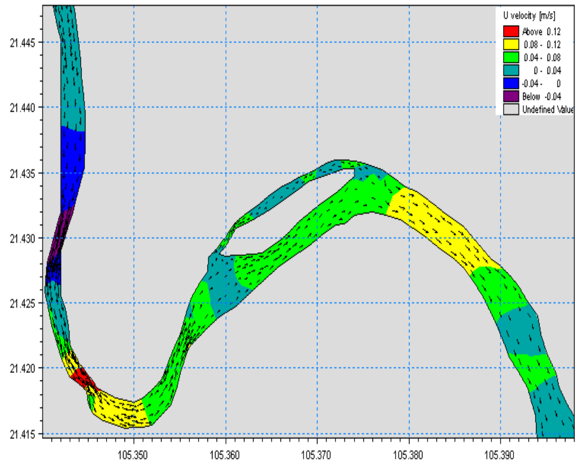


Figure 3: The U velocity with extraction

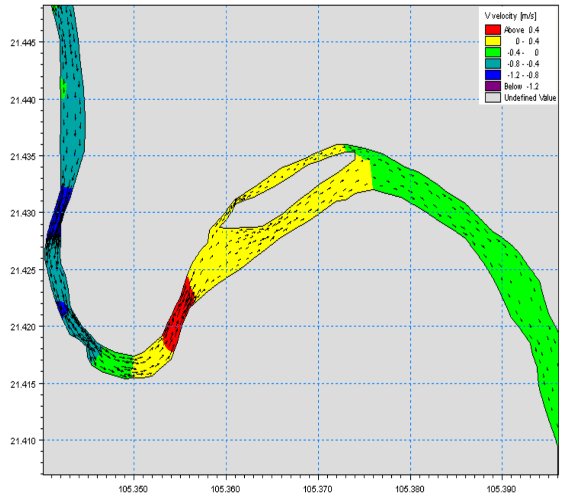


Figure 4: The V velocity without extraction

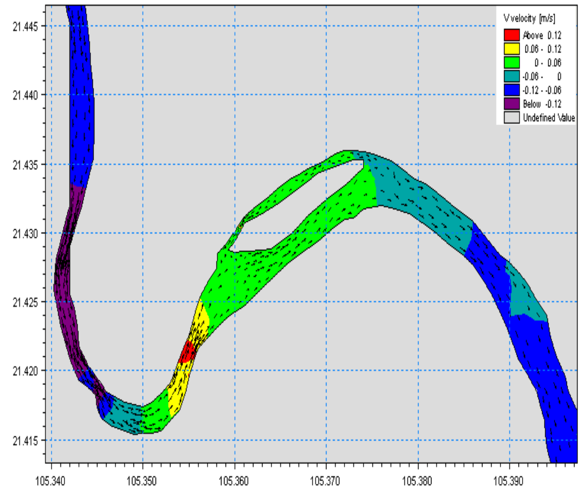


Figure 5: The V velocity with extraction

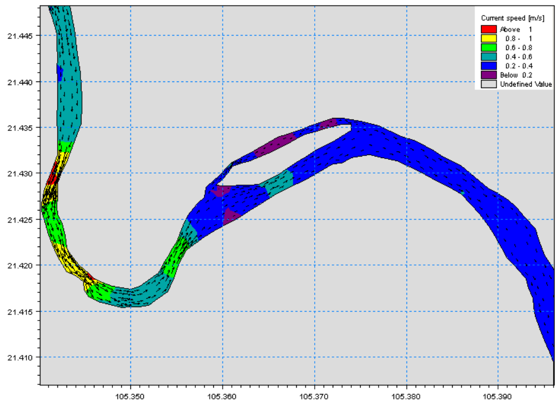


Figure 6: speed of flow without extraction

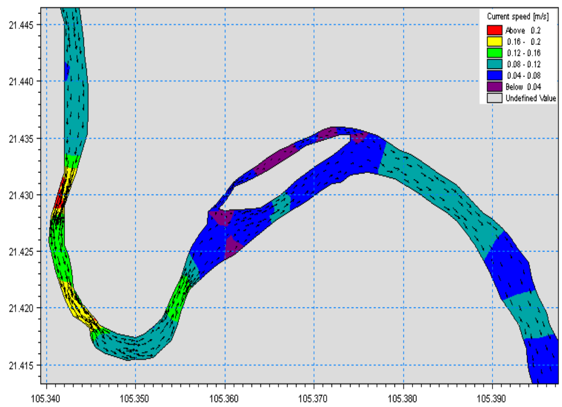


Figure 7: Speed of flow with extraction

Hydrodynamic results for two separate cases above can be seen quite suitable simulation model study area, flow rate and flow direction is relatively stable, it is suitable for the area not study the influence of the tides.

## 3.3 Setting up the Sand Transport module

To assess the level of compensation erosion study area, using the oscillation results in bottom sediment module. There are Lo River sediment characteristics:

Table 2.2: Characteristics of the sediment Phuong Khoan and Duc Bac

| Grain at the county level | Phuong Khoan | Duc Bac |
|---|---|---|
| < 0.1mm | 2.65% | 2.01% |
| 0.1mm - 0.25mm | 3.8% | 3.5% |
| 0.25mm - 0.5mm | 16.3% | 4.0% |
| 0.5mm - 2.0mm | 76.94% | 88.11% |
| > 2.0mm | 0.31% | 2.38% |

According to 2 synthetic tables above, the major particles size is 0.5 mm to 2.0 mm, so they are used to simulate sediment movement. Simulations are carried out through two steps: Step 1 with untapped conditions, step 2 will be carried out in addition to two sources of exploitation conditions in the region. Two data sources: Zone I: Phuong Khoan, received on an area of 21.4 hectares, has been identified: sand and gravel in class C1 + C2 reserves of about 1,769,782 $m^3$; peeled land reserves: 417,300 $m^3$. Zone II: Duc Bac, on an area of 15.37 hectares, with of sand C1 + C2 reserves of about 674 706 $m^3$; land reserves of peel: 24 505 $m^3$. Total reserves of sand and gravel extraction is: 2,444,488 $m^3$. Reserves of ground peeled: 441,805 $m^3$. Depth of exploitation: exploitation of + 2.0 m C.D (National elevation). Total capacity exploitation P = 98,000 $m^3$ per year.

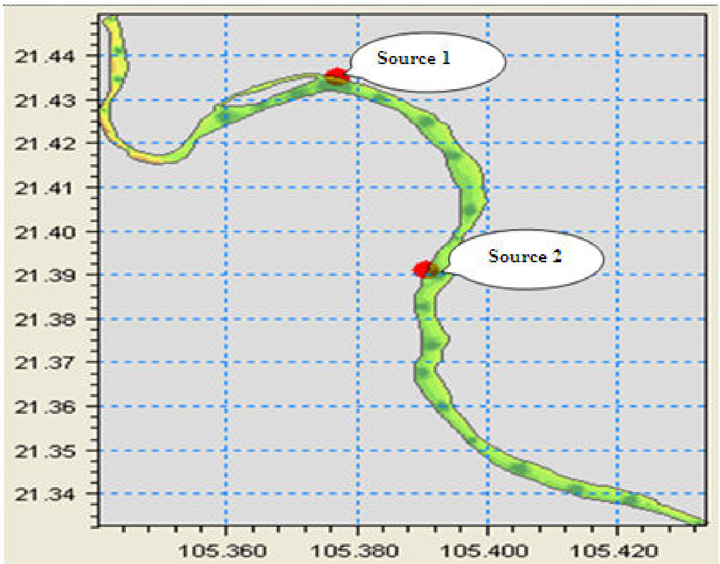


Figure 8: The location of 2 sources

Results calculated sediment module as follows:

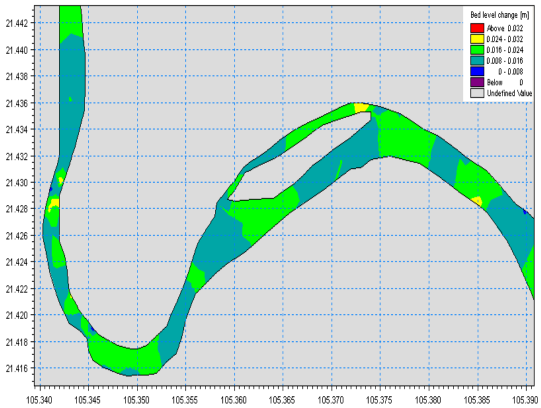

Figure 9: Bed level changes in current condition

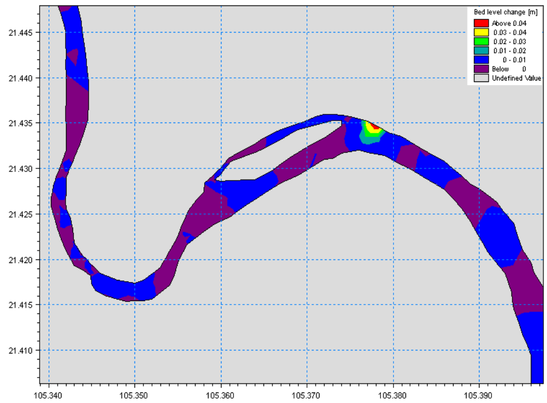

Figure 10: Bed level changes in extraction

- Figure 9 shows the bed level changes in current case, the value of bed level changes ranged up to 3.5 cm (quite suitable for inland river)
- Figure 10 shows the bed level changes after extraction case P = 98,000 $m^3$/year capacity. The results show that substrate vibrations increase, but the value varies in the range of 1 - 4 cm. It can be found that at the center position the bed level changes is the largest only 4cm (area appears in red in the figure is the location mining source 1. As far from the mining resources, the fluctuation is increasingly smaller. When conducting sediment extraction, mining resources, often appear whirlpool and high substrate usually tends to decrease, causing erosion near the extraction point.

Hence, the measure of the changing of the river bed in current and after exploitation is smaller (0.5 cm). The result shows that exploitation activities of project do not change the river bed of calculated location. During the exploitation, erosion and accretion are local variation.

## 4. Conclusion

(1) With the application of two hydrodynamic module and sand transport module topics have handled the problem of assessing the impact of sand mining project to the river's environment. When applied hydrodynamic module calculates the change before and after the mining project. The change included the U velocity, V velocity, flow speed. When applied to the sediment transport module has obtained the status change of the substrate and after extraction.
(2) The results of the hydrodynamic module, the subject of obtained results is that the flow characteristics change not significantly so can see the scale of the mining project does not affect too large to flow.
(3) The results from the sediment transport module, the subject of obtained results is the difference of the substrate changes tend to increase, but not too high. The change was found to be highest at the source of exploitation, as far as resources to exploit the smaller the degree of change.

## References

Einstein (1950), H. The Bed Load Function for Sediment Transportation in Open Channel Flows. Technical Bulletin No. 1026, U.S. Department of Agriculture, Soil Conservation Service, Washington D.C.

Engelund, F. and Hansen(1976), E. A Monograph on Sediment Transport in Alluvial Channels. Nordic Hydrology 7, pp. 293-306.

Engelund, F. and Fredsøe (1976), J. A sediment transport model for straight alluvial channels. Nordic Hydrology, 7, pp. 296-306.

Investment consulting corporation construction Bac Ai (2010), Minning projects "Sand minning, gravel in the Phuong Khoan, Don Nhan, Duc Bac in Song Lo District, Vinh Phuc province".