SIMULATION METHODODLOGY OF SEDIMENT IMBALANCE IN CALCULATION AND FORECAST MORPHOLOGICAL CHANGES AT DOWNSTREAM OF THAI BINH RIVER

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Abstract: *Hydraulic regime and morphology of a river section is in equilibrium if there is no human impact. However, under the human action impacts, the hydraulic regime and morphology of a river section have changed. The sediment imbalance in the river is usually caused by two factors, including the decline of sediment discharge from upstream when reservoirs were built and the sand mining. In particular, the sand mining process has a significant influence on the internal morphological changes as well as the river morphology at downstream section. In this article, a method of simulating the sand mining process on a mathematical model is presented and some results of morphological river prediction for the Thai Binh river are also shown in case of existing sand mining activities at the river upstream parts.*

Keywords: *Simulation methods, sediment imbalance, sand mining, morphology, Thai Binh river.*

1. INTRODUCTION

The Red - Thai Binh River system is a large river system in the North of Viet Nam. On the system, there are many large hydropower reservoirs in operation such as Son La, Hoa Binh, Tuyen Quang, Lai Chau and Thac Ba hydropower plants. These reservoirs have been put into operation to reduce flooding for the downstream during the rainy season, increase discharge water for agriculture irrigation for the Northern Delta during dry season, and also provide a stable power source for economic and society development. However, the presence of upstream reservoirs has reduced a large amount of sediment transport to the downstream, the river beds at the downstream of these reservoirs have been eroded and lowered significantly. Along with that, sand mining activities at the downstream of reservoirs cause the imbalance of sediment in the rivers, which leading to phenomenon of riverbed lowering at the main river's downstream of the Red and Thai Binh river system.

When studying the river morphological changes, there are many methods of calculating and forecasting the river bed changes, such as: measuring the actual riverbed topography annually; using remote sensing images over time; building dynamic physical model; building morphological hydraulic models of 1D or 2D to evaluate, calculate and forecast changes in riverbeds, estuaries and coastal areas. Each method has different advantages and is suitable for each specific requirement of the research institution and management unit.

Therefore, in this report, an overview of some related studies inner Viet Nam and abroad is presented to clarify the situation of research to predict morphological changes in the condition of sediment imbalance, and at the same time to develop one method of predicting morphological changes, which is suitable for the current research conditions and data situation in our country.

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2. OVERVIEW OF RESEARCH METHODS

The imbalance of sediment means that the process of transporting sediment in rivers, estuaries and coastal areas is no longer according to the laws of nature, but these processes are affected and changed under the human activities. Some common methods are usually used in researching and forecasting the changes of the riverbed such as: surveying and measuring methods; method of using remote sensing images; methods using physical models; methods of using mathematical models.

From many documents which relating to methods of calculating and forecasting river bed changes inside country or abroad case study, there are some comments as follows:

+ Topographic survey method: this is an important method when accurately assessing the level of topographic change in different periods from the past upto now. However, the problem of predicting the trend of topographic changes in the future is only trend and qualitative. Even so, it is an important reference when applying other more modern methods.

+ Method of using remote sensing images: this is the method that is also widely used today. However, this method mainly studies the topographic changes of shorelines, riverbanks or floating areas on the water surface. For the riverbed area, which is located below the water surface, is difficult to interpret, so this method is not used in this research. The results of forecasting topographic changes for future is also trend of forecasting.

+ Physical modeling method: The physical model is used in the study of the hydraulic regime (hard-bed model) and the riverbed evolution (dynamic-bed model) which is considered as one of the important research tools now, with the support of the modern and automatic equipment, the analysis results therefore have higher accuracy and reliability. However, the studying and calculating of riverbed changes using this method are executed in a limited scope and in detail with high cost, so it should only be applied in case of really importance and urgent.

+ Mathematical modeling method: this method is applied widely and popularly during the development of technology and computers. Currently, in calculation and forecasting the riverbed changes, it is no longer difficult to perform simulations of river topography, river structures, sediment transport, etc., that is because of continuous development and improvement of 1D, 2D, 3D mathematical models with increasingly detailed capabilities in simulation and calculation, such as HEC, SOBEK, MIKE, DELFT, TELEMAC models...With flexible capabilities when providing calculation scenarios and quick results, this method is widely used in research, calculation and forecasting changes of river bed, estuaries and coastal areas. However, in the study of river bed evolution, when considering the process of sediment imbalance, the 2D models are still limited in small space scope and short estimated time. When simulating many sand mining locations and forecasting for a long time of 5 years, 10 years or longer, the 2D models are difficult to simulate. Fortunately, the disadvantages of 2D models are done well on 1D models such as HEC RAS, MIKE 11 ST models... Therefore, the method of forecasting river bed morphology changes when sediment imbalance occurs will be executed using the 1D morphological and hydraulic modeling tools. It is possible to choose one of the multi 1D models because their simulation capabilities are the same. With the experience of using MIKE family models in many projects and these are the models that the management unit has copyright, therefore in this study, the author uses the MIKE 11 HD, ST model to serve calculating and forecasting the river bed evolution.

3. BUILDING CALCULATION METHODS AND SOME RESULTS OF EXPERIMENTAL FORECAST IN THAI BINH RIVER

3.1 The decline of sediment and sand demand for economic development in the downstream area of the Red – Thai Binh River

The imbalance of sediment at the downstream of the Red - Thai Binh Rivers due to the decrease in the sediment amount from upstream and the increased demand of sand mining for infrastructure development, specifically as follows:

**** The decline of sediment from the upstream of the Red - Thai Binh river system***

The decrease in the amount of sediment from the upstream to downstream of the Red -Thai Binh river systems is evaluated through the element of the suspended sediment mass and the sediment total amount. The suspended sediment masses (turbidity) at hydrological stations at the upstream and downstream of the Red River such as Hoa Binh, Yen Bai, Vu Quang, Son Tay, Hanoi, Thuong Cat in the periods of 1970-1988, 1989-2000, 2001- 2007, 2008-2014 and 2015-2021 are all declined over time. At Son Tay hydrological station in the period of 1970-1988, the average turbidity was 590 g/m^3, but in the recent period of 2015-2021, it was only 136 g/m^3; similar to the Thuong Cat hydrological station, it was 523 g/m3 in period of 1970-1988 and it was only 128 g/m^3 in period of 2015-2021.

According to the table 1, (one part was referred in the ministerial project [2] and remain part also was updated to the present time in 2021), the total amount of sediment at three main hydrological stations on the Da, Thao, Lo rivers and at the Son Tay hydrological station has decreasing trend in recent years. Specifically, the total amount of sediment in Son Tay in the period 1970-1985 was 100.85 million m^3/year, but from 2001-2021, it decreased to 18.76 million m^3/s each year.

Table 1: Decline in total amount of sediment in Red River system

Stage	Average amount of sediment per year in each upstream river (million m^3/year)			Total amount of sediment transport to downstream (million m^3/year)		Average total amount of sand exploited in the period (million m^3/year)
	Da river	Thao river	Lo river	Sum of three rivers	Sediment mass at Son Tay station	
1970-1985	46.81	31.81	7.96	86.57	100.85	
1986-2000	8.57	51.23	13.54	73.34	56.44	
2001-2021	2.70	21.91	4.51	29.11	18.76	
2001-2005	*6.92*	*43.05*	*10.56*	*60.53*	*38.82*	16.67
2006-2010	*2.83*	*32.28*	*4.20*	*39.31*	*21.90*	29.61
2011-2015	*0.75*	*6.94*	*2.32*	*10.01*	*8.41*	34.78
2016-2021	*0.28*	*5.37*	*0.95*	*6.6*	*5.89*	**37.80**

Source: Reference to ministerial project [2] and update

**** The demand for sand mining for infrastructure development in the downstream area of the Red and Thai Binh River system and the planning for sand mining.***

According to the reference data from the ministerial-level project [2] in the Table 1, the total mass of sand mining increasing over periods while the amount of sand transport from Upstream to downstream tends to decrease up to now. The average total amount of sand exploited in the 2001-2005 period is 16.67 million m^3/year, but it is 37.8 million m^3/year in the 2016-2021 period.

Following results of the independent state-level project [3], planning on location and mass of sand mining is 288 locations and total masses of about 683.8 million m^3. These data were used as input data for the mathematical model of calculation and prediction the river morphology in case of imbalance of sediments.

3.2 Building a sand mining simulation method on a one-dimension morphological and hydraulic mathematical model

Before simulating the sand mining process, a one-dimensional hydraulic model and a one-dimensional morphological model when there is no sand mining simulation need to be built. In the overview of research methods, the method of using 1-dimensional mathematical model in simulation should be selected. With many different one-dimensional mathematical models, it is possible to choose a model for simulation calculation. In this study, with the experience of participating in many topics and projects in the Red - Thai Binh River basins using hydraulic models MIKE 11 HD which is a copyrighted model, the author has inherited this set of models in building a method to simulate the sand mining process and forecast river morphology evolution in future.

3.2.1 Scope of one-dimensional morphological and hydraulic models and calibration, verification work

- *Scope of the morphological and hydraulic models:* The upper boundary includes: Da river (downstream of the Hoa Binh hydropower), Thao river (from Yen Bai hydrological station), Lo river (from Vu Quang hydrological station), Pho Day river (from Quang Cu hydrological station), Cau river (from Gia Bay hydrological station), Thuong river (from Cau Son hydrological station), Luc Nam river (from Chu hydrological station), Day river (from Ba Tha hydrological station) , Hoang Long River (from Hung Thi hydrological station) and the lower boundary are 9 estuaries: Day, Ninh Co, Ba Lat, Tra Ly, Thai Binh, Lach Tray, Van Uc, Cam, Da Bach.

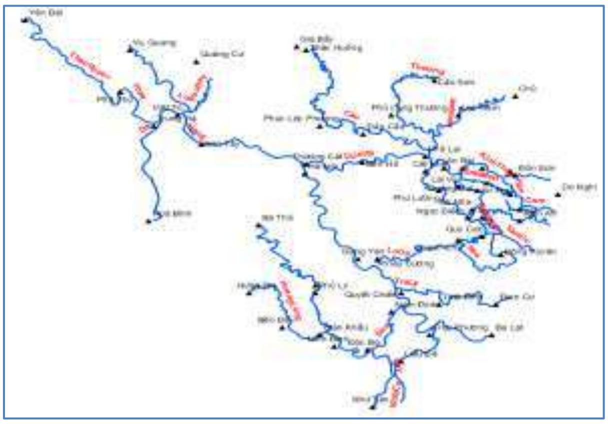

Figure 1: Scope of the river network studied on a one-dimensional mathematical model

- *Calibration and verification of 1D hydraulic model:* For model calibration, using data from July 1st, 2012 to September 30th, 2012 and from July 15th, 2018 to July 30th, 2018; for model verification, using data from August 25th, 2008 to November 30th, 2008 and from October 9th, 2017 to October 19th, 2017. The adjusted results of water level and discharge at hydrological stations on the river system are all reliable and will be presented more detail in another report.

- *Calibration and verification of 1D morphological models:* For model calibration, using data from 1/1/2016 – 31/12/2021; for model verification, using data from 1/1/2011 – 31/12/2015; 01/1/2001 – 31/12/2005 and 1/1/2006 – 31/12/2010. The results of calibration and verification of sediment discharge are relatively reliable and acceptable. In addition, the relationship between sediment discharge and water discharge is used to compare between observation and simulation at several hydrological stations such as Son Tay, Ha Noi and Thuong Cat in some years. The results will be presented in more detail in another report.

3.2.2 Simulation of sand mining process on a one-dimensional morphological model

After the one-dimensional hydraulic and morphological models have been established for the Red and Thai Binh river systems, and the results of calibration and verification are reliable and acceptable. The process of removing sediment from the model over time will be studied and established.

<u>* Simulate the process of collecting sediment over time of the year:</u>

Along with the identification of sand mining locations, the annual total amount of sand exploited in each area, it is necessary to simulate the sand mining process to include in the calculation model. Analyzes to simulate sand mining process based on actual sand mining conditions and situation over the years.

+ Set up the actual sand mining process to include in the prediction model:

The sediment data is determined at the inlet boundaries such as Hoa Binh, Yen Bai, Vu Quang, Gia Bay and Chu in the form of suspended sediment discharge. Therefore, when simulating the sand mining process, we can simulate by the discharge of sediment lost from the model over time at some locations along the rivers in the study area. When simulating the sand mining process, there is only the amount of sand to be lost, the amount of water discharge in the model at the same location must be remained. In each river paragraph where sand mining, the “Pointsourse” points in the model are established close to each other to avoid local erosion at that area. In fact, sand mining takes place only in the dry season and the middle water season (the transition months), but in the flood season, there is almost no or very little exploitation. Therefore, in this study, the authors hypothesized:

- In the four driest months (from December to March of the following year): each month exploits 15% of the total amount of sediment for the whole year;

- In the transition months between the dry season and the flood season (from September to November and from May to June of the following year): each month exploits 5% - 10% of the total amount of sediment for the whole year;

- In the months of the main flood season (July and August), there are not exploition.

Amount of sediment removed from river each month is described in detail the as shown in the table below:

Table 2: Distribution of sand mining rate in months of the year

Month	1	2	3	4	5	6	7	8	9	10	11	12
% (Month /Year)	15%	15%	15%	10%	5%	5%	0	0	5%	5%	10%	15%

+ Simulation of the removing sand process from the river bed

- In the model, the removing sediment is expressed in the form of sediment transport discharge (unit m3/s), while the actual exploittion sand data is m3/year. Therefore, it is necessary to divide the amount of exploited sand of whole year in each area according to the months and days according to the distribution ratio in the table 2 above.

- The sand mining process is simulated over time and is divided by percentage according to the months of the year, the days in each month are the same. For the month that there is a big difference between days, exploited sand amount should be interpolated which it tends to increase or decrease so that the model is not too shocking. The sand mining process line at a specific location is described as shown below.

- The amount of sediment removed from the model is simulated as suspended sediment, the amount of bottom sediment is not considered. However, according to studies and measurements, in the total amount of sediment transported, the amount of suspended sediment usually accounts for 80% and the bottom sediment accounts for about 20% of the total amount of sediment. Therefore, the total amount of simulated sediment removed from the model is 1.25 times the amount of sediment determined above.

- The amount of sediment removed from the model is determined as "Point Soure" points. This is advantageous when using 1-way sediment transport models, whether the licensed model MIKE 11 ST or the free HEC-RAS model can be used to simulate process of sediment extraction out of the model. The sediment discharges removed from the model are negative values. There are 288 sand mining sites on the Red and Thai Binh river systems, but many points are outside the simulation range and there are many sites with small sand amount close to each other that will be aggregated; hence there will be 168 sand mining sites that counted into Point Source points in the model.

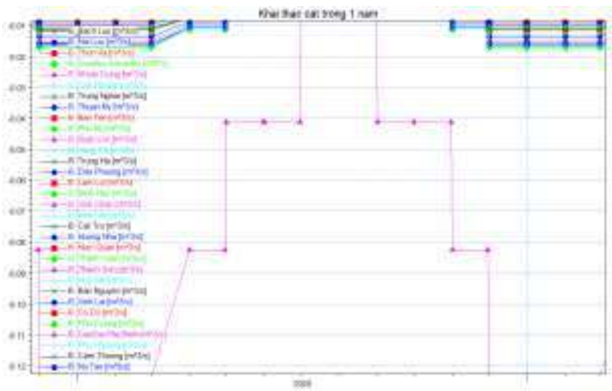

Figure 2: Simulation of mining sand over time at some locations

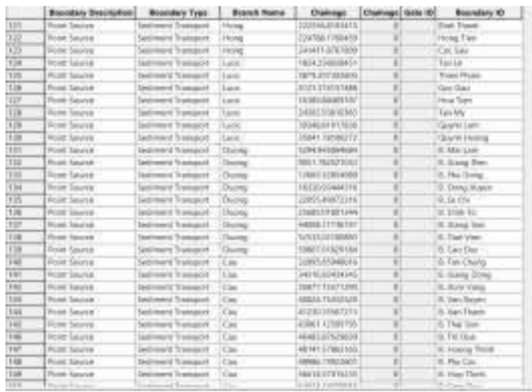

Figure 3: Setting up sand mining locations in the model

<u>* Simulation of sand mining process after 5 years, 10 years:</u>

Each sand mine is mined for a certain period of time. With a large area and large reserves, the time for sand mining will be longer than in areas with smaller reserves. Therefore in the process of licensing and mining will allow how long that area to be exploited. With 138 points capable of exploiting sand on the main rivers of the Red and Thai Binh river systems, it is necessary to divide the points that can be exploited in a certain time depending on the total reserves of each location.

In this study, the research team recommends that the mining license period for each location depends on the sand reserves as follows:

Table 3: Sand extraction time with different reserves

No	Reserves (m^3)	Mining time (year)
1	< 100.000	1
2	100.000 -200.000	2
3	200.000 -500.000	3
4	500.000 -1.000.000	5
5	1.000.000-1.500.000	7
6	>1.500.000	10

Therefore, according to this dividing, the sand mining simulation is not the process of continuously removing sand at all sites for 5 or 10 years in the future, but only mining sand in a certain time. For example, when considering the changes of bed river topography after 10 years, for locations with a sand reserve of over 1.5 million m^3 can exploit sand for 10 consecutive years, but for sites with a small reserve of 0.1-0.2 million m^3, the sand mining is simulated and lost only in the first 2 years and 8 years later, the sand take out of model is zero. The process of topographic change in that area will be caused by the impact of natural flows, not no human impact. The process of simulating the time of sand collection at each different location will reflect the reality closerly and avoid the quickly changes of terrain when the amount of sand is lost quickly in a short time. This method of simulating sediment loss will be calculated and tested on some river sections.

3.3. Results of experimental forecasting of morphological changes in the lower Thai Binh river

3.3.1. Research scope and test calculation scenarios

a. Research scope

The scope of research and testing calculation simulate the sand mining processes in the Duong river, Thai Binh river and Kinh Thay river.

b. Calculation scenarios

+ Hydrological scenario: using the timeseries of water discharge and sediment discharge from 2001 to 2021, then choose three representative years for the years of high flood and silt in 2008, the year of average flood and mud in 2018 and there are floods, small mud and sand 2019.

+ Scenario of sand mining: calculating with two cases including not considering the sand mining process and considering the planned sand mining process.

+ Prediction period: after 5 years, 10 years from the start year of 2022.

3.3.2. Prediction results of river morphology change when sediment imbalance occurs

The results of river morphology prediction are given including the river bed elevation change and the total amount of sediment transported through that river section. Some results which represent the calculated scenarios for rivers in the study area including Duong river, Thai Binh river (from Pha Lai to Gua) and Kinh Thay river.

a. Changes in river bed elevation when imbalance sediments occurring

The results which are presented as below, are the calculation river bed elevation in 5 and 10 years later in two cases: excluding sand mining process and including sand mining process for the year of high flood and sedimentation (2008) calculated for the Thai Binh river; year of average flood and sediment (in 2018) calculated for Duong river and year of small flood and sediment calculated for Kinh Thay river

The results in the table above show that there is a difference between 2 cases of including sand mining process and excluding sand mining process. The changes in the case of the sand mining process is simulated compared to the case without simulation. The change in Duong river is greater than in Thai Binh and Kinh Thay rivers.

Table 4: Predicted bottom elevation of the Duong river with the typical year for average flood 2018

Cumulative distance (Km)	Initial bottom elevation (m)	Excluding sand mining process (m) (1)		Including sand mining process (m) (2)		Change (m) (2)-(1)		Note
		after 5 years	after 10 years	after 5 years	after 10 years	after 5 years	after 10 years	
0.0	-4.82	-7.67	-9.52	-7.76	-9.80	-0.086	-0.288	Inlet
0.8	-17.13	-14.17	-16.51	-14.31	-16.69	-0.144	-0.184	Long Tuu
3.4	-9.20	-9.03	-10.12	-9.10	-10.24	-0.069	-0.114	Gia Thuong
3.6	-7.25	-7.12	-8.16	-7.19	-8.26	-0.066	-0.103	Thuong Cat
7.4	-21.69	-19.22	-19.54	-19.31	-19.62	-0.085	-0.079	Cong Thon
11.8	-11.98	-12.12	-10.69	-12.12	-10.86	-0.005	-0.176	Vang
12.3	-12.65	-9.19	-8.22	-9.18	-8.31	0.008	-0.087	Doc Loi
23.3	-19.57	-17.38	-18.55	-17.45	-18.64	-0.064	-0.084	Tri Phuong
29.6	-13.44	-13.55	-14.63	-13.56	-14.62	-0.013	0.009	Tan Chi
33.7	-8.73	-13.73	-13.56	-13.73	-13.58	-0.007	-0.019	Ben Ho
40.4	-13.38	-13.82	-15.89	-13.83	-15.88	-0.015	0.006	Mon Quang
46.9	-6.86	-7.26	-7.10	-7.28	-7.16	-0.018	-0.056	Thai Hoa
48.3	-6.44	-7.04	-7.02	-7.06	-7.06	-0.013	-0.039	Song Giang
50.9	-8.89	-6.79	-6.97	-6.78	-6.98	0.004	-0.011	Cong Thi
55.0	-10.43	-8.74	-7.38	-8.86	-7.46	-0.121	-0.084	Kieu Luong

On the Duong river, when simulating the sand mining process, the riverbed evelation is forecasted decreasing the largest after 5 years by about 12-14 cm, while the largest elevation decreasing after 10 years is predicted about 18-29 cm.

On the Thai Binh river, when simulating the sand mining process, the riverbed evelation is forecasted decreasing the largest after 5 years by about 2 - 4 cm, while the largest elevation decreasing after 10 years is predicted about 12 - 20 cm.

On Kinh Thay river, when simulating the sand mining process, the riverbed elevation is forecasted decreasing the largest after 5 years by about 2 - 3 cm, while the largest elevation decreasing after 10 years is predicted about 8 - 9 cm.

From the results of simulation above, the changes of calculation riverbed elevation in 2 cases on Duong river is much higher than on the Thai Binh and Kinh Thay rivers. Reasons caused such results are: (1) on the Duong river, there are 9 sand mining sites while there is no sand mining site on the Thai Binh and Kinh Thay river; (2) flow on the Duong river is influenced by the Hong river flow therefore it is less influenced by tides than that flow in the Thai Binh and Kinh Thay rivers.

Beside the results of calculation in 2 cases of sediment imbalance and sediment balance for 3 rivers Duong, Thai Binh and Kinh Thay, this research shows that for various flood and sediment flow regimes, the changes in riverbed elevations are different when consider in the same situation of mining sand. Below are the figures of forecasted terrain change after 10 years on Duong, Thai Binh and Kinh Thay rivers, taking into account the sand mining process.

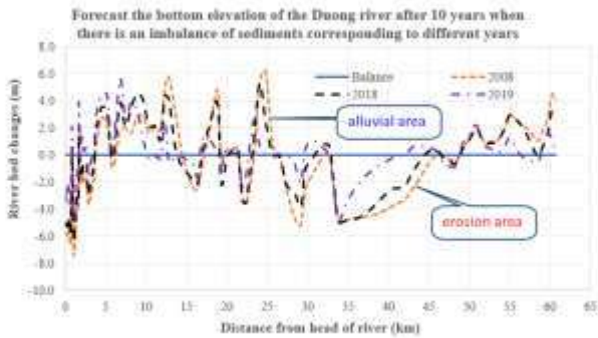

Figure 4: Forecast of erosion and accretion on Duong river with the same amount of mud and sand loss

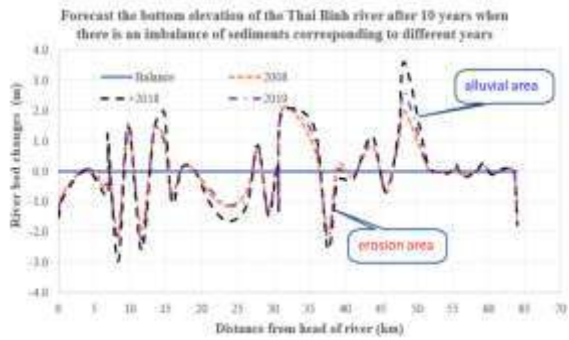

Figure 5: Forecast of erosion and sedimentation on Thai Binh river with the same amount of sediment loss

As stated above, because the Duong river is mainly affected by the flow from upstream and there are lots of sand mining sites, the topographic variation on the Duong River is higher than that of the Thai Binh and Kinh Thay river. On the Duong river with the big flood in 2008, there was a greater degree of topographic variation compared to the medium flood of 2018 and the minor flood in 2019, especially with strong fluctuations with the trend of erosion in the area at the mouth of the Duong river to the area at the Thuong Cat station, while at the end of Duong river, there is a tendency to accretion.

On the Thai Binh and Kinh Thay rivers, the fluctuation is no longer follow the same rules as on the Duong river. On the Thai Binh river, the flood that caused more topographic changes was the medium flood in 2018. On the Kinh Thay river, it was found that most of the topographic changes in the river section did not have much difference between flood events except at the inlet area, where is prone to erosion and the accretion area at km17 of the river section.

b. The change in the total amount of sediment *transferred through the river section:*

When describing the sand mining process, beside the change in river bottom elevation on the river section, the total amount of sediment after 5 years and 10 years is forecasted when considering sand mining process, there is also a decrease compared with no sand mining simulation. Calculation results at some locations on Duong, Thai Binh and Kinh Thay rivers are as follows:

Table 5: Expected total sediment reduction when simulating sand mining

River	Year	Excluding sand mining process (million m^3)		Including sand mining process (million m^3)		Degree of decline (million m^3)		Rate of decline (%)		Location
		after 5 years	after 10 years	after 5 years	after 10 years	after 5 years	after 10 years	after 5 years	after 10 years	
Duong	2008	20.55	36.25	20.35	35.55	0.2	0.7	0.97	1.93	River head
	2018	14.75	27.4	14.6	26.8	0.15	0.6	1.02	2.19	
	2019	5.4	11.25	5.37	10.9	0.03	0.35	0.56	3.11	
	2008	6.04	15.75	6.0	15.2	0.04	0.55	0.66	3.49	End of the river
	2018	4.42	9.32	4.39	9.05	0.03	0.27	0.68	2.90	
	2019	1.11	2.0	1.1	1.97	0.01	0.03	0.90	1.50	
Thai Binh	2008	2.89	4.39	2.85	4.31	0.04	0.08	1.38	1.82	Before distributary
	2018	2.45	3.84	2.4	3.77	0.05	0.07	2.04	1.82	
	2019	1.79	2.86	1.75	2.8	0.04	0.06	2.23	2.10	
	2008	1.25	1.92	1.23	1.88	0.02	0.04	1.60	2.08	After distributary
	2018	1.06	1.72	1.02	1.68	0.04	0.04	3.77	2.33	
	2019	0.76	1.28	0.74	1.24	0.02	0.04	2.63	3.13	
	2008	0.98	1.28	0.97	1.26	0.01	0.02	1.02	1.56	Before the distributary of the Gua River
	2018	0.95	1.25	0.94	1.23	0.01	0.02	1.05	1.60	
	2019	0.91	1.26	0.89	1.24	0.02	0.02	2.20	1.59	
Kinh Thay	2008	1.64	2.47	1.62	2.43	0.02	0.04	1.22	1.62	After distributary
	2018	1.39	2.12	1.38	2.09	0.01	0.03	0.72	1.42	
	2019	1.03	1.58	1.01	1.56	0.02	0.02	1.94	1.27	

The results show that, when simulating the sand extraction, the total amount of sediment also decreases compared to case of not exploiting sand. With each different degree of decline in each river and with each different flood flow regime, there is also a different level of total sediment reduction.

On the Duong river, the total amount of mining sand forecasting for 5 years and 10 years later reduces from 1.99-2.0% on average until stop exploiting sand. For the river head area, the level of decline is from 0.85-2.41%, and for the end area of river, the decline level is from 0.75-2.63%.

In the Thai Binh river, the total amount of mining sand forecasting for 5 years and 10 years later reduces from 0.8-2.52% on average until stop exploiting sand. For the river head area, the level of decline is from 1.89-1.91%, and for the river end area, the decline level is from 1.42-1.58%.

On the Kinh Thay river, the total amount of mining sand forecasting for 5 years and 10 years later reduces from 1.29-1.43% on average until stop exploiting sand.

4. CONCLUSIONS AND RECOMMENDATIONS

Through the analysis and evaluation above, we can see that using the one-dimensional hydraulic mathematical model and the one-dimensional morphological model in forecasting river morphology changes in case of sediment imbalance at many locations with mining activities or in a complex river system is appropriate and necessary.

The approach method of sand extraction from the model according to the months of the year and according to the time of extracting sand depend on sand reserves at each location is appropriate with reality. The results of experimental forecasting of morphological changes in Duong, Thai Binh and Kinh Thay rivers show that the decreasing trends on river bottom elevation and total amount of sediment transported through the river section when simulating sand mining process at 168 mining points in the Red and Thai Binh river system compared to when not simulating the sand mining process.

When simulating the sand mining process, the amount of lost sediment taken out of the model is only the amount of suspended sediment, while in reality, the bottom sediment is included. Therefore, in calculating the amount of sediment lost from the model, the amount of bottom sediment is converted to the amount of suspended sediment. This is one of the limitations when calculating simulations using this method.

The predicting of river bed morphology changes on the Red and Thai Binh river systems currently has many limitations such as mainly using topographic data measured over time to predict trends. In the coming time, it is necessary to combine mathematical modeling methods, topographic survey methods and investigation of planned and illegal sand mining sites in order to increase the ability and accuracy to predict the trend of changes in the main river channel.

In addition, this is also a tool in calculating and determining the reserves of sand that can be exploited, the exploitation time for each mining location that has the less effect to the morphology of that river section.

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