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Current velocity field in section of Sai Gon river during operation of flood control structures

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Abstract. The largest economic center in Vietnam - Ho Chi Minh City, is facing increasingly serious riverbank erosion, one of the main reasons being the flow. Therefore, in this study, the flow velocity field on the Saigon River section is accurately analyzed in different time intervals with the help of MIKE 11 and MIKE 21 models. The simulation results show that The number of flow velocities in the middle of the river is 3-4 times greater than that of the two banks. However, between high tide and low tide, the flow on both sides of the river is faster than the main flow, especially in the upper part of the winding banks, such as the section from Ben Nghe sluice to Tan Thuan, sewer and river section from An Loi Dong Ward police station to Thu Thiem Bridge 2. The velocity value on the studied river section, in most cases, exceeds the allowable value of the non-erosion velocity of the bed material particles. , riverbanks, as well as suspended sediment particles. Therefore, the erosion process on both sides of the river will occur regularly and continuously, so urgent measures are needed to protect the riverbank. During the operation of the anti-flood sluice, the flow velocity will decrease slightly before sluices also appear as whirlpools. The flow velocity on the Saigon River has a complex distribution and changes from time to time depending on the flood discharge from Dau Tieng Lake and the tidal currents of the East Sea.

1 Introduction

Rivers are natural flows on the continent's surface, fed by rain, groundwater, and melt water [1-3]. Rivers play the role of water transfer in the hydrological cycle of the basin and, at the same time, represent the characteristics of water security, ecology, and the environment of a region, city, or country [4-7]. Maintaining the stability of river flow is a topical issue for ensuring the life and production process of people living on both sides of the river. The Sai Gon River originates in low hills, with a relative height of about 150 m in Binh Phuoc Province, flows through the Dau Tieng reservoir (Tay Ninh), through Binh Duong Province, and further to Sai Gon [8, 9]. At the Red Cape Crossing, the Sai Gon River joins the Dong Nai River to form the Sai Gon-Dong Nai River system and then flows into the sea. The total length of the Sai Gon River is 256 km, of which the section flowing through

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Ho Chi Minh City is 80 km [10]. [Over the past decades, Binh Duong and Ho Chi Minh City have always been the leading economic centers of the country, with the GDP index always in the top 5 regions with the highest GDP in Vietnam [11, 12]. Due to the economic growth of this region, it is impossible not to note the role of the Sai Gon River, with the largest inland waterway system in terms of scale and throughput in Vietnam. In addition, Ho Chi Minh City is also the largest urban area in Vietnam, with a population of over 9 million. Therefore, any change in the flow and morphology of the Sai Gon River will also greatly impact economic development, as well as the lives of the people of Ho Chi Minh City in particular and the provinces on both sides of the river in general.

Fig. 1. Erosion on bank of Sai Gon River

There are many reasons leading to river landslides, such as geological characteristics, sand mining, infrastructure construction, urban development, and the impact of shipping, in which the hydrological regime of river flow is one of the main factors causing erosion [13-17]. The Sai Gon River is influenced by the upstream flow and the tide in the East Sea with a semi-diurnal tidal regime. This makes the hydraulic regime of the Saigon River more complex and different from that of many rivers in the world. Therefore, it is necessary and urgent to study and evaluate the change in the flow of the Sai Gon River. Moreover, since mid-2016, Ho Chi Minh City has begun a project to build 6 flood control sluices on the tributaries of the Sai Gon River following Prime Ministerial Decree № 1547 / QD-TTg to protect the central region from the problems of climate change and sea level rise. Therefore, when carrying out these works, how it will affect the flow regime on the Sai Gon River is a question that needs to be answered.

Several studies have been carried out on flood control structures and the Sai Gon-Dong Nai river basin issues. Nguyen and Binh [18] showed that when precipitation and tide peaks occur at the same time, the protective capacity of the tide control lock system in Ho Chi Minh City is negligible, Do Dac Hai [10] and Phu Quynh [19] concluded. Construction of anti-tide structures in the inner part of Ho Chi Minh City will definitely affect the hydro regime and water quality in the lower reaches, including the problem of salt intrusion. Sensitivity to climate change, sea level rise, and land use in this area is shown in studies by Tran [20], Van [21], To Nu [22] modeling flood levels and proposing flood control drainage solutions for the Van Thanh-Ho Chi Minh area. Shong [23] and Hoang [24] studied the consequences of unloading an oil reservoir in the lower reaches of the Sai Gon River.

Therefore, this study aims to understand and analyze the effect of flow on riverbank erosion through a two-dimensional flow velocity field, considering the impact of flood protection structures. The article's results will become an important scientific basis for providing solutions to prevent and overcome the erosion of the two banks of the rivers, combined with urban planning in a modern and sustainable direction.

2 Methods

To build a 2D model, a section of the Sai Gon River from the Sai Gon Bridge to Diamond Cape was selected (marked in red) (Fig. 2). This is a very important section of the river, on one side of which is the political and economic center of Ho Chi Minh. On the other, the Thu Thiem district, which is planned to be turned into an economic center, the largest financial and international trade center in Vietnam. 2 out of 6 flood control sluices are also being built on this section of the river, namely Ben Nghe and Tan Thuan.

Fig. 2. Location of study area.

In this paper, the hydraulic module (HD) of models MIKE 11 and MIKE 21 is used to study the flow velocity field in the section of the Sai Gon River.

MIKE 11 HD computes transient water levels and discharges in rivers and estuaries using an implicit, one-dimensional, finite difference formulation (higher-order fully dynamic Saint-Venant equations) that are solved using the 6-point Abbott-Ionescu method [25]. It applies to vertically homogeneous flows ranging from steep rivers to tidal estuaries. You can also model flow through various structures, such as wide crest weirs, culverts, control structures, control structures, bridges, and user-defined structures. Input data for the MIKE 11 HD model include river network, cross-sectional parameters, and water level discharge values at boundary points. The Sai Gon-Dong Nai river network is shown in Figure 3.

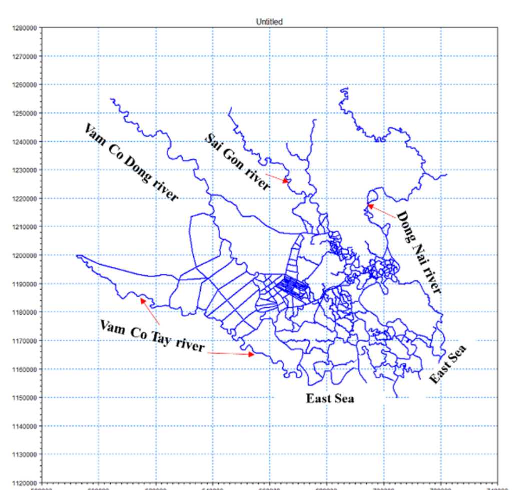


Fig. 3. Saigon – Dongnai River network on MIKE 11.

MIKE 21FM is a 2D hydrodynamic model that simulates water levels and currents in rivers, estuaries, bays, and coastal areas. Simulation model of two-dimensional unstable flow for the flow layer [26,27]. The system of modeling equations includes continuity equations combined with momentum equations describing the change in water level and discharge. The relief of a section of the Saigon River according to the Mike 21FM model based on the results of the survey of the authors, carried out in September 2022, is shown in Fig. 4. The water level and discharge results from the Mike 11HD model will be shown in fig. entry boundary for Mike 21FM model.

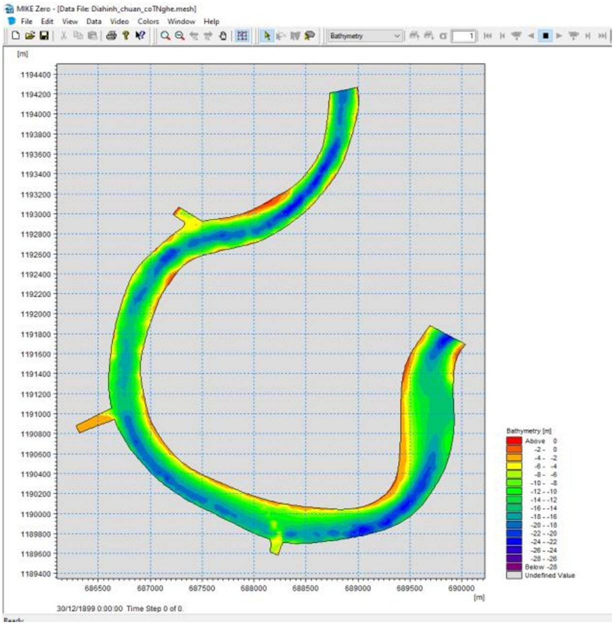


Fig. 4. Topography of Sai Gon River section from Sai Gon Bridge to Cape Diamond.

To study the change and distribution of the flow velocity field on the Sai Gon River during the operation of anti-flood locks, design scenarios for the year 2000 were selected, when the historical flood caused great damage, great for the Mekong River Delta and the Sai Gon-Dong Nai region. The flood discharge of the Dau Tieng reservoir in 2000 and the water level in Vung Tau in 2000 are shown in Figure 5.

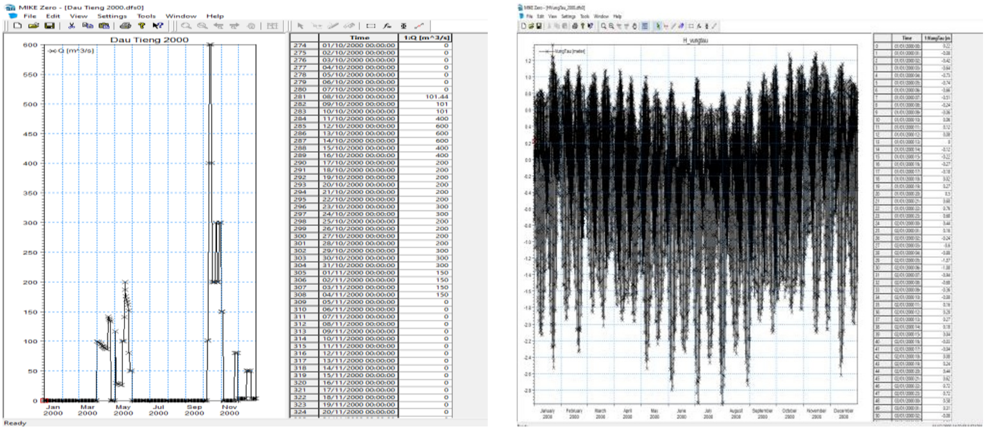


Fig. 5. Flood discharge of the Dau Tieng reservoir (a) and the water level in Vung Tau (b) in 2000

3 Results and Discussion

The Mike 11HD model is calibrated using actual data measured at hydrological stations from October 1, 2010, to December 15, 2010, and verification at Bien Hoa, Thu Dau Mot stations from June 1, 2009, to June 16, 2009. A good fit is seen between simulated and observed water levels over different periods. The Mike 21 FM model was tested with the water level at the Phu An measuring station from October 1 to November 31, 2013 (Fig. 6).

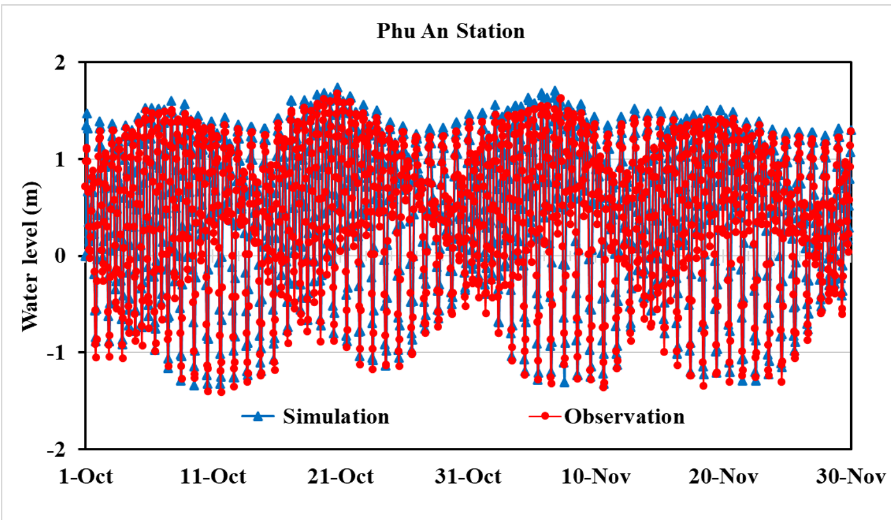


Fig. 6. Water level in Phu An station, time measurement from October 1 to November 30, 2013

The accuracy of the numerical results was assessed using the coefficient of determination (R^2) and the Nash-Sutcliff coefficient (E_f), shown in Table 1. According to the efficiency criteria of Moriasi [28-30], the coefficients R^2 and E_f show that the model has high reliability in modeling the flow.

Table 1. Performance of Mike 11 and Mike 21 for water level modeling.

Station	Mike 11HD (01.06.2009 - 16.09.2009)		Mike 21FM (01.10.2013 – 30.11.2013)	
	R^2	E_f	R^2	E_f
Bien Hoa	0.91	0.83	-	-
Thu Dau Mot	0.97	0.91	-	-
Phu An	-	-	0.98	0.96

The section of the river from Sai Gon Bridge to Diamond Cape has a topography consisting of many meandering sections, which is influenced by upstream flood flows and tides in the East Sea. Therefore, the hydraulic regime is very difficult with a continuous change in flow direction for 1 day.

a) During the dry season, when there are no flood gates

During the first months of the dry season, Dau Tieng Reservoir only releases enough water for irrigation and daily life, so the flow of the Sai Gon River is affected by the tide of the East Sea, with 2 high and low tides in 1 day.
Considering the field of flow velocities in the period from high tide to low tide, it was found that both at high tide and at low tide, the flow in the middle of the river is always the

largest, then gradually decreases towards the two banks. At low tide, the current speed is 2 times greater than at high tide; specifically at low tide, the average speed in the middle of the river is about 1.6 m/s, while on both river banks, it is only about 0.4 m/s. However, locally in the area of the Tan Thuan sluice, there is a place with a very high speed (V_{max} = 2.96 m/s); this is seen in Figure 7.

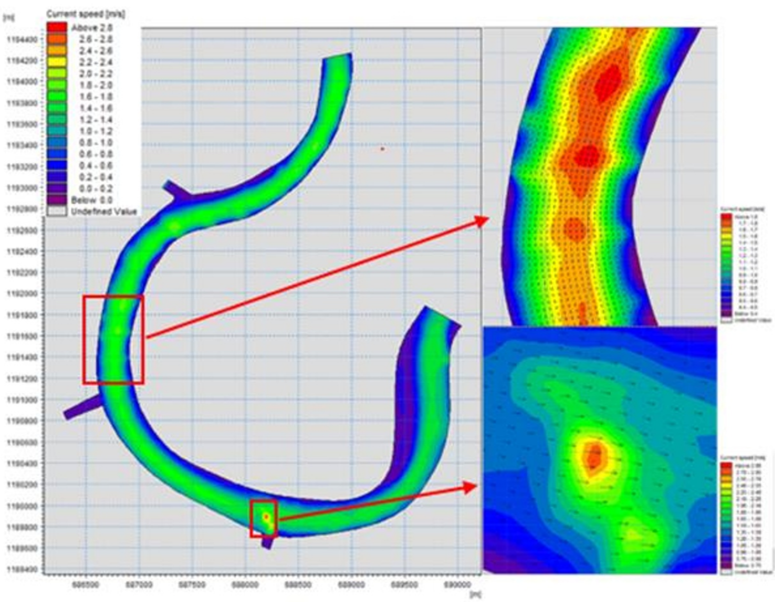


Fig. 7. Flow velocity field on Saigon River section at low tide.

At high tide, the average current speed in the middle of the river is about 0.7 m/s, while on both sides of the river, it is only about 0.3 m/s. The area of the Tan Thuan sluice is still the place with the strongest current. In addition, at the end of the high tide period and the beginning of the low tide period, the runoff in the river has a very special distribution (Fig. 8). At this time, the main stream on the river tends to flow upstream, but on both sides of the river, water flows back downstream at a speed 2-3 times the speed of the main stream. Not only do eddy currents appear in a place about 1 km from Cape Diamond, but also the speed in the whirlpool area is low, only about 0.1-0.2 m / s.

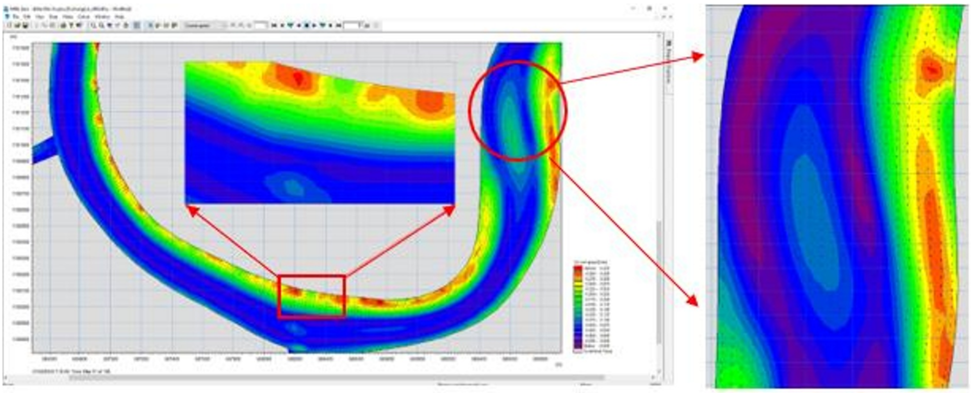


Fig. 8. Distribution of flow velocity at end of low tide and beginning of high tide.

During the peak months of the dry season (April and May), the Dau Tieng Reservoir releases large volumes of water, resulting in a great change in flow velocity distribution. At first, with a new tide, simultaneously with the upstream flow, a velocity distribution is formed in 2 directions, as shown in Figure 9. The middle river current is the upstream flow to the lower reaches. The sides of the river are the tide flowing upstream. In some curvilinear river sections, the updraft flows close to the shore, while eddy currents with a maximum speed of about 0.4 m/s are still observed at a distance from Diamond Cape. In general, at this time, the current velocity is not too high.

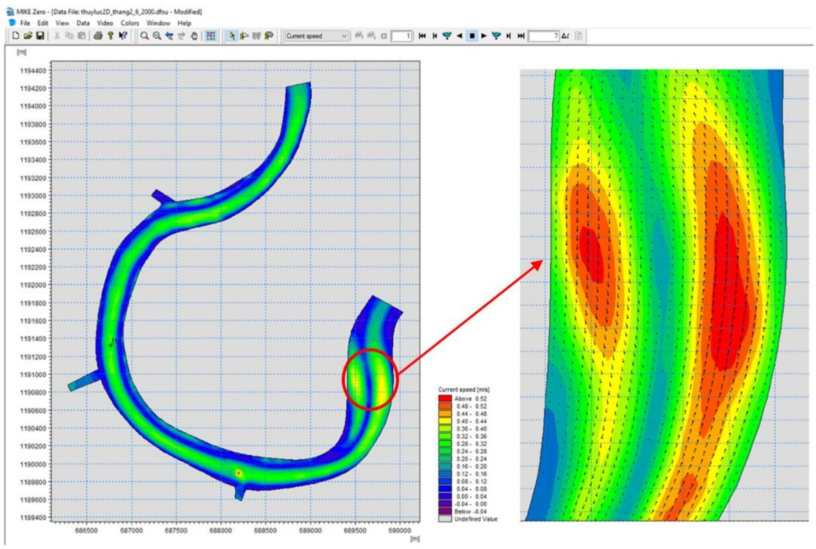


Fig. 9. Flow velocity distribution in initial phases of tide in April-May.

After that, the tide intensified and became the river's main course with an average speed of about 1 m/s in the middle of the channel, about 0.7 m/s on the right bank, and 0.4 m/s on the left bank. At Tan Thuan sluice, the maximum flow velocity is still about 1.5 m/s (Fig. 10).

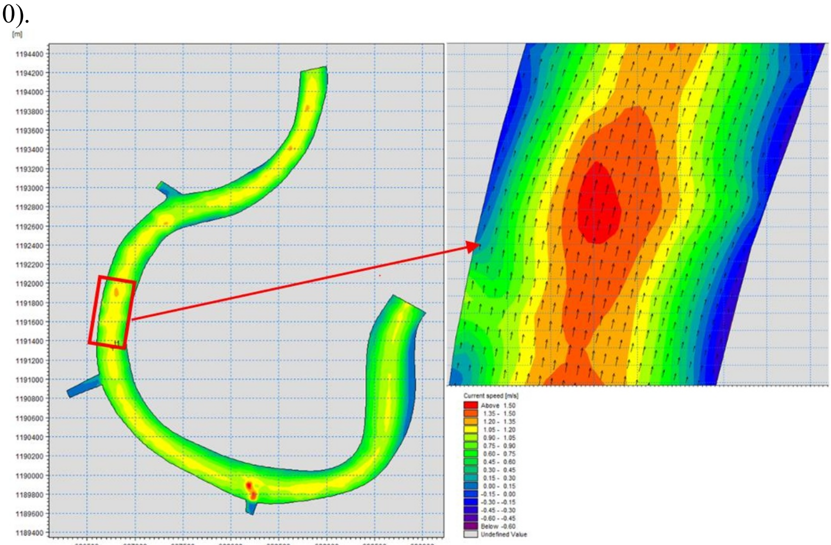


Fig. 10. Distribution of flow velocity during high tide in April-May.

When the tide recedes in combination with the upstream currents, the speed in the river is high, in many places about 1.7 m/s, and in many places on both sides of the river, the speed reaches a high speed of about 1 m/s. However, the section of the river has a length of about 1 km on the left bank near Diamond Cape; the speed is very low, only about 0.2 m/s (Fig. 11).

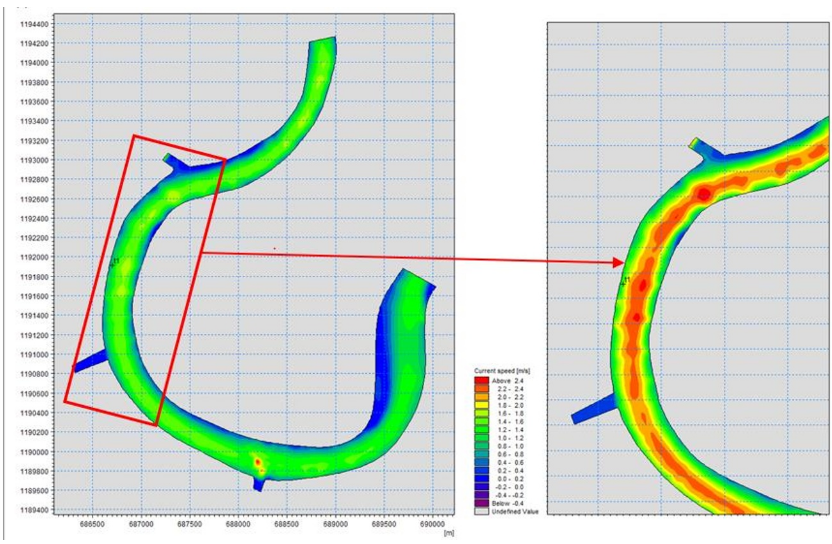


Fig. 11. Distribution of flow velocity during low tide in April-May.

b) Flood season, when there are no flood gates

The year 2000 was a year of severe flooding in the Mekong Delta and the southeast region. In mid-October 2000, the Dau Tieng reservoir released a very large volume of water (Q_{max}=600 m3/s). At high tide, the speed in the middle of the current is about 0.7-0.8 m/s and decreases to about 0.4-0.45 m/s on both sides, but the right bank (view from above) is high, slightly larger (Fig. 12).

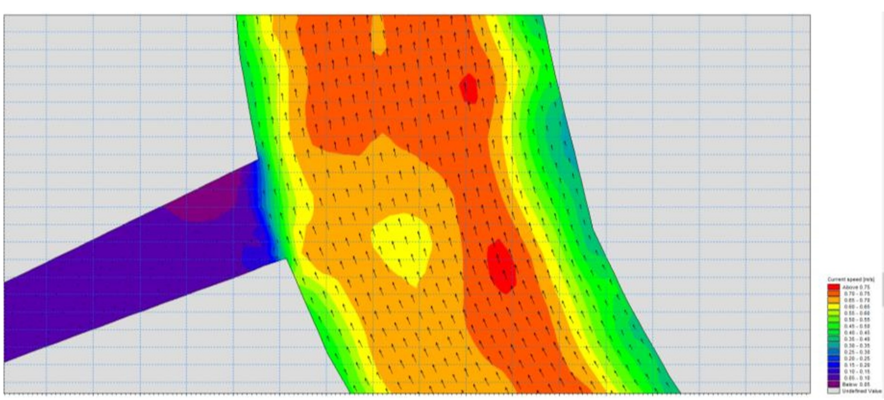
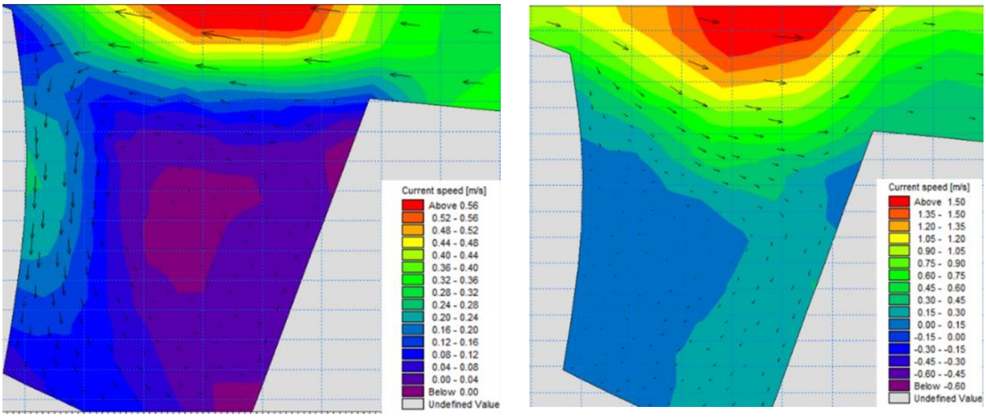


Fig. 12. Distribution of flow velocity in high water during high tide.

At low tide, the speed along both river banks is about 0.4-0.5 m/s, and the right bank is still slightly higher, and in the middle of the current, the speed is about 1.5-1.6 m/s. However, in the area of the Tan Thuan sluice, the speed is very high, almost 3 m/s; in addition, in the branch of the channel leading to the Tan Thuan sluice, there is a vortex to the left in the direction of the current at high tide high (Fig. 13a) and to the right at low tide with a low speed of about 0.1-0.2 m/s (Fig. 13b).



(a) (b)

Fig. 13. Distribution of flow velocity in area of Tan Thuan sluice in high water at high tide (a) and low tide (b).

As in the dry season, from the end of the low tide period to the beginning of the high tide period, the flow velocity field in the river is quite special. In particular, the main flow in the middle of the river flows downstream, and the two banks flow upstream at a higher speed of about 0.2-0.3 m/s. At a site about 1 km from Diamond Cape, a whirlpool formed with the highest speed of about 0.5 m/s on the left bank (Fig. 14).

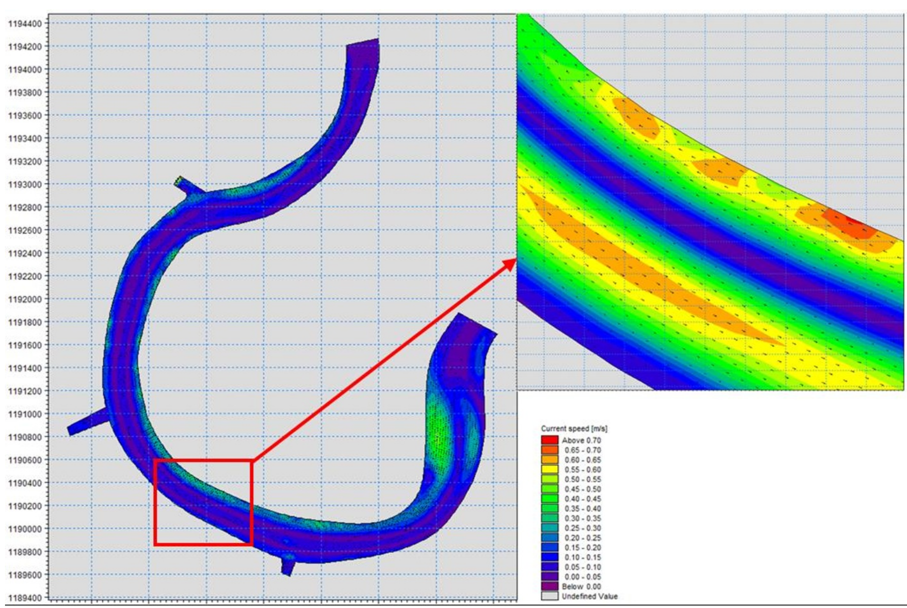


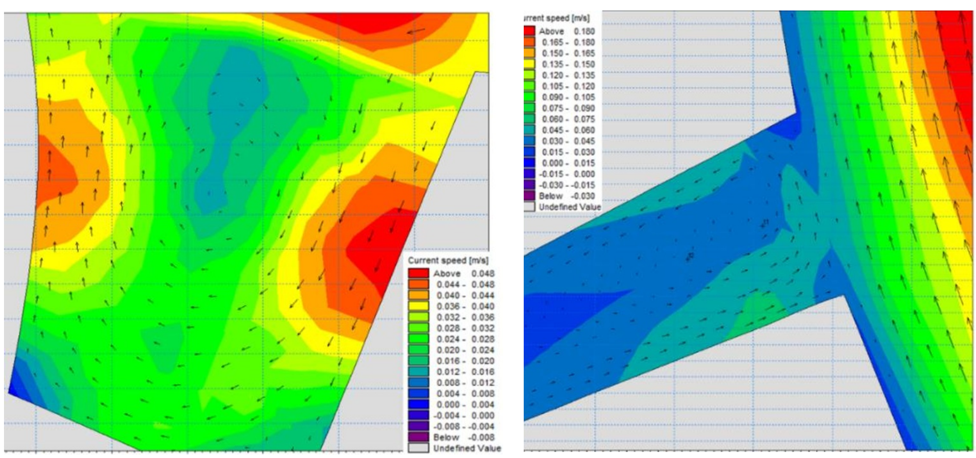
Fig. 14. Distribution of flow velocity at end of low tide to beginning of high tide.

Conversely, at the transition from the end of the high tide period to the beginning of the low tide period, the main channel flows upstream, and the two banks flow downstream.

However, at this time, the main current has a higher speed, and on the right bank, in the section from the Ben Nghe sluice to the Tan Thuan sluice, the main current flows close to the coast. At the same time, at this time of the current change, the left bank in the direction of looking from the upper current to the lower one always has the highest speed, then the speed in the middle of the new current gradually increases and exceeds the value by two banks. In addition, the flow velocity in the channel (where there are anti-flood locks) averages about 0.1-0.2 m/s, which is much less than the velocity in the river and on the right bank.

c) If there are anti-flood locks

During the operation of anti-flood sluices, the field of flow velocities does not change significantly during low water and during high water. The speed values across the river from the left bank to the right or along the river are all reduced compared to the absence of a flood sluice, but the difference is small. In addition, at the beginning of the channel (where the locks are located), there is a circular flow with a small average speed of about 0.1-0.15 m/s (as shown in Fig. 15).



(a) (b)

Fig. 15. Eddy currents in front of Tang Tang sluice (a) and in front of Ben Nge sluice (b)

The geological survey results on the right bank through wells and sediment sampling in the river indicate that the surface material of the riverbed and two banks is represented mainly by silt particles 0.002-0.08 mm in size and clay particles less than 0.002 mm in size. Therefore, according to the Vietnamese standard TCVN 4118:2012, the non-erosive velocity of dirt and clay particles V_{kx} = 0.26 m/s. As for applying the Goncharov formula, the non-erosive velocity V_{kx} = 0.35 m/s. It shows that with the value and distribution of velocity as analyzed above, the Sai Gon River is always in a state of erosion; this process is most pronounced in the riverbed when the average velocity in high water is about 0.7-0.8 m/s, and in dry from 0.5 to 0.6 m/s, this is seen in Figure 16. In addition, since the geological structure of the two banks of the river is soft soil, silt, and clay, and the flow in the river is like a flow upstream flow, and the tide, the process of erosion occurs on both banks of the river.

Especially in meandering sections of the river, in many cases, the main stream flows close to the shore, accelerating the bank erosion rate and increasing the scale of landslides. However, the area around Tan Thuan sluice is always the highest, so the risk of erosion on the river bed and near the shore is very high. In addition, Tan Thuan sluice is the gateway to the floating market, where hundreds of boats and boats ply daily, so the appearance of local high speed will be very dangerous for boat traffic.

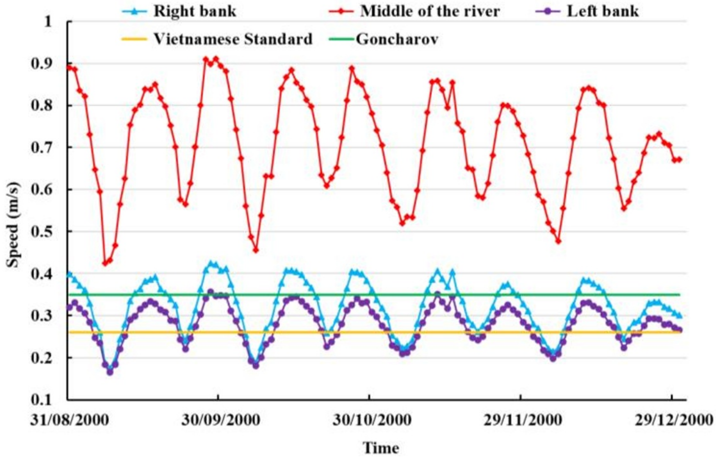


Fig. 16. Estimated flow velocity and non-erosive velocity

Under the action of the currents, the river bank will be continuously eroded over time and following the height of the water level. The river bed will be eroded faster than the river bank due to the high flow rate, so local erosion pits will be formed, gradually expanding and deepening into the two banks to the limit, which will cause instability and landslides. At the beginning of the canal, when flood sluices are in operation, the appearance of whirlpools at low speed will also affect the movement of small boats and create the risk of increasing the amount of sedimentation.

4 Conclusions

i. The flow velocity on the Sai Gon River has a complex distribution. It varies from period to period depending on the flood flow from the Dau Tieng reservoir and the tidal currents of the East Sea.

ii. The value of the current velocity in the middle of the river is about 3-4 times greater than on both banks. However, between high tide and low tide, the current on both sides of the river has a higher velocity than the main stream, especially on the curved bank peaks, such as the river bank from Ben Nghe sluice to Tan Thuan sluice and the section of the river from An Loi Dong police station to Thu Tiem 2 bridge.

iii. Velocity values in the studied section of the river, in most cases, exceed the allowable values of the non-erosive velocity of particles of channel material, river banks, as well as particles of suspended sediment; therefore, the erosion process on both sides of the river will occur regularly and continuously. Therefore, it is urgent to take measures to protect the river bank. At the local level, there are several places with the maximum speed that will make this process stronger and more serious, for example, the place near Tan Thuan sluice, the river bank from Ben Nghe sluice to Tan Thuan sluice, and the section of the river from An Loi Dong police station to Thu Thiem 2 bridge.

iv. When operating flood sluices, this will not greatly affect the current velocity field on the Sai Gon River but only slightly reduce the value of the current velocity; along with the appearance of a vortex in front of the rivers, sewerage can affect the movement of boats and easily cause sedimentation.

v. For the first time, the velocity field of the Saigon River flow is shown specifically in two-dimensional images, and the results of the article have great scientific significance, helping managers have a detailed, specific view of the flow distribution. It also explains part of the cause of landslides in this area.

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