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PHAM THE VINH

RESEARCH ON THE ROLE OF TIDAL FLATS TO THE WATER LEVEL AND DISCHARGE OF SAI GON - DONG NAI RIVER

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SUMMARY OF TECHNICAL DOCTOR THESIS

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The project was completed at **Southern Institute of Water Resources Research**

Scientific instructor 1: Prof. Dr.Sc. Nguyen An Nien
Scientific instructor 2: Prof. Dr. Tang Duc Thang

Opponency 1:
Opponency 2:
Opponency 3:

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PREAMBLE

1. Necessity of the thesis topic

Downstream area of Sai Gon - Dong Nai River (SG-DN) is an important economic center of the southern region. This is a region with relatively low terrain, thick drainage network, influenced by tides. According to water level surveying data at hydrological stations from 1980 to 2015, the annual maximum water level in coastal areas due to the impact of rising of sea level is very clear (Vung Tau increases 0.45 cm/year). However, when being compared with the annual maximum rising of sea level in the river, this increase is much lower and inconsistent at regions (Nha Be increases 1.03 cm/year; Phu An increases 1.21cm/year). As a result, tidal flooding in the downstream of SG-DN River is getting worse and worse, although authorities have taken many measures to reduce. In reality, the terrain of river in Delta areas has changed significantly, the previous tide-flooded areas are not only replaced with industrial and residential areas, but also built protective dikes for agricultural production. Current flooding situation is partly due to the impact of changing the tidal flats. Therefore, this study clarifies the impact of tidal flats on the water level and flow rate on the main river under downstream of SG-DN river.

2. Study purposes

- Analysis is based on science to make arguments about changing tidal flats affecting water level and flow rate in the river bed.
- Based on the hydraulic model, simulating and assessing the impact of tidal flats on water level and flow rate on the river under downstream of SG-DN river.

3. Subject and scope of the study

Subject of the thesis study is tidal flats in the downstream of SG-DN river. Scope of thesis study includes all tidal affected area from Thu Dau Mot hydrological station on Sai Gon river and Bien Hoa hydrological station on Dong Nai river to the estuary.

4. Method of the study

The thesis has used the following methods: (i) Inheritance method; (ii) Synthesis and collection method; (iii) Analytical method; (iv) Mathematical model method; (v) Practical contact comparison method.

5. Scientific and practical significance of the thesis

a. Scientific significance: (i) Clarify the impact of tidal flats to the water level and flow rate in the river bed and on SG-DN river; (ii) Provide arguments to confirm the impact of tidal flats to the water level and flow rate in the river is very large and cannot be ignored.

b. Practical significance: (i) Change tidal flats greatly affect the water level and flow rate in the river. This impact in recent years is much larger than the impact of climate change and rising of sea level; (ii) Apply to study, design, construction, exploitation and operation of works in the downstream of SG-DN River in particular and for all low-hollow areas, affected by tides.

6. New contributions of the thesis.

- Establish the relationship between tidal flats and water level and flow rate in the river.
- Impact quantification of tidal flats on the water level and flow rate on the river under downstream of SG-DN river.

7. Structure of the thesis.

The thesis is presented in 140 pages, including 116 pictures, 15 tables and explanatory pages. Main contents of the thesis include preamble, 3 main chapters, conclusion and recommendations, are presented as follows:

Preamble
Chapter 1: Study overview
Chapter 2: Scientific basis and building study tools
Chapter 3: Study results and discussion
Conclusion and recommendations

Appendix is presented in 39 pages, consisting of 5 tables and 41 illustrations showing tidal flats in the downstream of SG-DN River, introducing the mathematical model used in the study, describing the establishment, calibrating and inspecting the model.

CHAPTER 1. STUDY OVERVIEW

1.1. General introduction

Flooding situation is a major concern in major cities in Ho Chi Minh City (HCMC), Dong Nai and Binh Duong. Main causes of flooding in the study area are as follows: (i) Heavy rain; (ii) Flood tide; (iii) Upstream flood; (iv) Climate change; (v) Urbanization; (vi) Subsidence. The largest rising of water level causing flood in the downstream of SG-DN River has been increasing in recent years and is mainly attributed to climate change. However, the largest rate of rising water level in Vung Tau is much lower than the largest water level in the river. Thus, in addition to factors that cause the sudden rising of water level in recent years, the study thinks of another cause. Whether the narrowing of tidal flats for economic development in the area that the flow rate is only concentrated in the river and causing the largest rising of water level outside the stream rise.

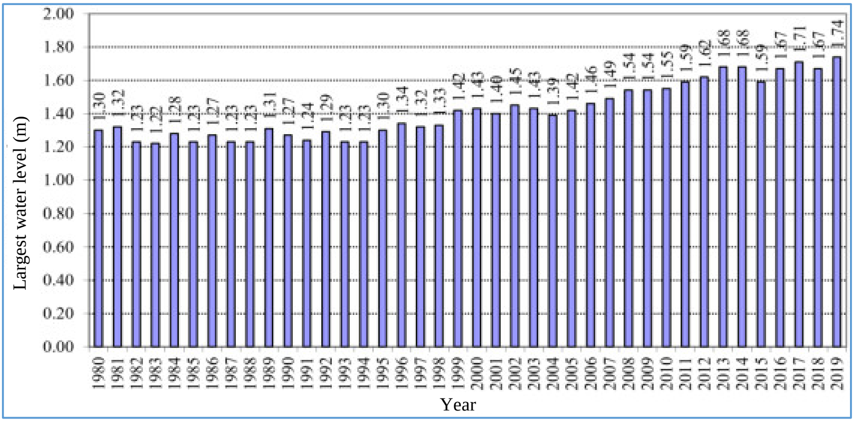

Figure 1: Annual largest water level in Phu An

Tidal flats in the downstream of SG-DN river are usually located along main rivers, canals and branches. Changed tidal flats in the study area are as follows: (i) Tidal flat has been converted to an agricultural production area: Total area of agricultural land accounts for 69.8% of the total natural land. In order to protect agricultural production areas, structures (girdle shaped dikes, open sluices, sluices ...) were constructed to control tides when the water level is high and drain water in case of low water during the cultivated period; (ii) Tidal flat after building flood control construction: The building of flood control constructions such as installation of tidal flap valves with Clape type ship locks, building tidal control sluices also disable the tidal cut of tidal flats and canals in the protected area; (iii) Tidal flats when leveling and building urban areas: The construction of residential land, administrative areas has completely lost most of natural tidal flats. Features of the backfilling area often has altitude exceeding the tide peak, so currents cannot penetrate these areas. This total land area accounts for 21.0% of the total natural land area in the study area; (iv) Tidal flats when building traffic works: The building of traffic works in the area also makes the relationship between river currents and tidal flats change compared to previous time. Currents on the main river no longer directly penetrate tidal flats but have to go further through branches, sluices, bridges. With small sluices, the currents cannot reach all tidal flats, making difference between the large water level in the river and in tidal flats and reducing the tidal cutting effect of flats.

1.2. Relationship between river and flood plain

Flood plain may appear along rivers, far from rivers. Tidal flats include water surface land, previous uncultivated agricultural land, mangrove forests, and unused land.

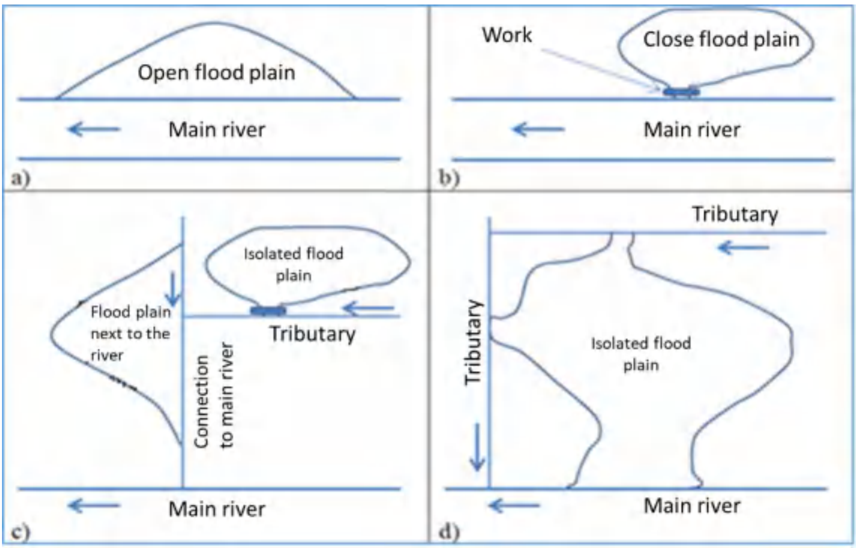

Figure 2: Type of tidal flats along main river and tributary

Relationship between tidal flats and the river can follow the form: (i) tidal flats along rivers (one or both sides, Figures 2, a, c) attached to the river cross-section is considered the extended space of river and (ii) isolated tidal flats (Figures 2, b, c, d). Connection between tidal flats and the river can pass through the structure and canal section (as simulated in KOD model or VRSAP model).

1.3. Previous studies

1.3.1. Studies in the world

- Actual hydrological measurements in several areas affected by tidal flats and the effect of changing tidal flats around the world demonstrate the rising of largest water level in the river rapidly. N.E. Vellingaa, A.J.F. Hoitink, M. van der Vegta, W. Zhangc, P. Hoekstraa (2014) had published an analysis of real water level measured over 70 years of 13 stations at the north of Rhine-Meuse river delta. They demonstrated that the mean water level in river has a parallel increase with mean sea level. Reference to largest and lowest water levels, the effect of human intervention on tides is greater than the rising of sea level.
- There have been many studies on the analysis of propagation of tidal wave at estuaries based on the linearization of hydrodynamic equations by ignoring inertia and density parameters in the momentum equations and linearization of frictional parameters. According to Leo C. Vanrijn (2004), propagation of tidal wave equation at estuaries can be written in form of propagation of tidal wave equation:

$$\eta = \hat{\eta}\cos(\omega t - kx) \quad (1.1)$$

In which:

$\hat{\eta}$: Tidal range

ω: Circular frequency ($\omega = 2\pi/T$)

k: number of waves ($k = 2\pi/L$)

- Studies on the effect of upstream to tidal extinction have also been mentioned. According to H. Cai, H. G. Savenije and M. Toffolo (2014), the effect of upstream leads to the rising of mean water level gradually at the upstream and has a significant effect on the propagation of tidal waves. Some studies have mentioned the impact of terrain on the tidal regime in river based on solving and simplifying hydrodynamic equations. Deltares (2013), has mentioned the large tidal amplification (increasing tidal range) in four European rivers (Ems, Elbe, Scheldt and Lore). According to the study results, in case of many flood plains, the flow rate at estuaries increases, deepens the river and loses hydraulic resistance.

1.3.2. Studies in the country

- Statistics and analysis on the largest water level at the downstream of SG-DN river are mentioned by studies in the country. Studies and projects carried out in this area have mostly taken into account the rising of water levels caused by climate change affecting water level in the river. Several studies and projects have taken into account the rising of water level when building flood control constructions. Solutions have mentioned the problem of improving canals, building more control reservoirs to increase the capacity of controlling currents due to rain.
- Some researchers have mentioned the problem of water storage in established hydraulic models. According to Nguyen Tat Dac (2005), storage cells are classified into two types (closed storage cells and open storage cells). According to Pham The Vinh and Nguyen An Nien (2012), from calculating the composition of water source, it is possible to determine the tide contained in the hollow cell. When tidal flats are filled, these resources are returned to main stream and increase the largest water level in the river.

From the above studies, it is necessary to clarify the impact of tidal flats to the flow rate and water level on the river by determining the relationship between tidal flats and water level and flow rate in the river through analyzing parameters in hydrodynamic equations as well as simulation by mathematical models.

CHAPTER 2. SCIENTIFIC BASIS AND BUILDING STUDY TOOLS

2.1. Scientific basis of the relationship between tidal flats to the water level and flow rate

Analyze scientific basis of the relationship between tidal flats, water level and flow rate in the river, the thesis has based on analyzing parameters of hydrodynamic equations and the propagation of tidal wave equation described by the function of circulating waves if the propagation of tidal wave to estuary is considered as undulate.

2.1.1. Impact of tidal flats width to the water level

- Continuity equation in the system of hydrodynamic equation written by dependent variable Q (x, t), Z (x, t) are written in the following form:

$$\frac{\partial Q}{\partial x} + Bc\frac{\partial Z}{\partial t} = q \qquad (2.1)$$

In which:

Q: Cross-sectional flow rate (m^3/s)

Z: Water level altitude (m)

Bc: Width of cross-section of rivers and flats (m)

q: Flow rate of middle area ($m^3/m.s$)

If dividing the width of river cross-section into two components (B and B_{flat}) and without flow rate, equation (2.1) can be written as:

$$\frac{\partial Q}{\partial x} + (B + B_{b\tilde{a}i})\frac{\partial Z}{\partial t} = 0 \qquad (2.2)$$

In which:

B: is the width of river cross-section (m)

B_{flati}: is the width of flat cross-section (m)

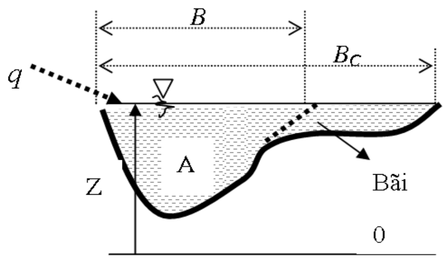

Figure 3: Typical river cross-section

Change of the equation (2.2):

$$\frac{\partial Q}{\partial x}+B\frac{\partial Z}{\partial t}=-B_{bãi}\frac{\partial Z}{\partial t} \qquad (2.3)$$

According to above illustration and according to (2.3) we see the right side ($-B_{bãi}\frac{\partial Z}{\partial t}$) as a current in the middle area. During the rising of tide, $Z_2 > Z_1$ and number $\frac{\partial Z}{\partial t} > 0$ and value $-B_{bãi}\frac{\partial Z}{\partial t} < 0$. Thus, when currents in the middle area is positive, the largest water level in river increases and vice versa. According to the value of the left side of equation (2.3), if the flat width is large, the value of right side is small and the largest water level in the flat and river is reduced. Thus, the flat width is inversely proportional to currents in the middle area and reduces the largest water level in river.

- If the propagation of tidal wave into estuaries is considered as undulate, according to Leo C. Vanrijn, with the estuary without inflow current (q), wide river bed (Bc >> H) with a rectangular cross-section with constant width, the propagation of tidal wave equation can be written as follows:

$$\eta = \hat{\eta}\cos(\omega t - kx) = \hat{\eta}\cos(\omega(t-\frac{x}{c})) \qquad (2.4)$$

In which:

$\hat{\eta}$: Wave range;

ω: Circular frequency (ω = 2π/T);

c: Velocity of wave propagation (c=L/T= ω/k);

k: number of wave (k= 2π/L);

T: Wave cycle;

L: Wave length.

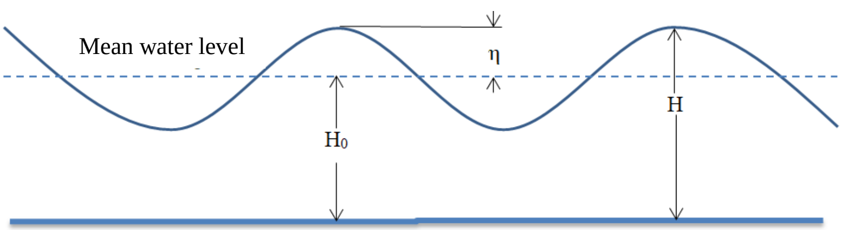

Figure 4: Illustration of the tidal wave parameters

Velocity of wave propagation in the river according to Leo C. Vanrijn (1989) is calculated by the formula:

$$c = \sqrt{\frac{Ag}{B_c}} \tag{2.5}$$

If considering the cross-section of river bed and tidal flat as rectangular, the depth in tidal flat (H_{flat}) as small, (2.5) can be written as follows:

$$c = \sqrt{\frac{HBg}{B + B_{bãi}}} \tag{2.6}$$

Considering in the case changed wave due to rising river bed terrain (partial reflected wave, Figure 5). Wave length ($L_2 = c_2T$) decreases due to constant wave cycle (T). According to the equilibrium equation of liquid mass:

$q_2=q_1-q_r$ với $q = c\eta$

Thus:

$$c_2\widehat{\eta}_2 = c_1\widehat{\eta}_1 - c_1\widehat{\eta}_r \tag{2.7}$$

At the low collar step, equal wave range, we have:

$$\widehat{\eta}_2 = \widehat{\eta}_1 + \widehat{\eta}_r \tag{2.8}$$

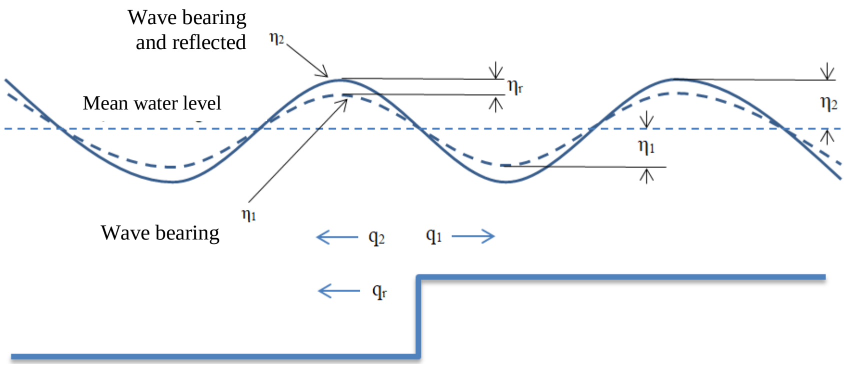

Figure 5: Illustration of wave reflection due to changed depth

Replace (2.7) with (2.8), the wave range increases compared to the case of no reflection as follows:

$$\widehat{\eta}_r = \widehat{\eta}_1 \frac{c_1 - c_2}{c_1 + c_2}$$

Similarly, considering the case of changed waves due to entering the river, taking into account of river tidal flats, waves are absorbed by tidal flats (Figure 6). According to the equilibrium equation of liquid mass:

$$\widehat{\eta}_r = -\widehat{\eta}_1 \frac{c_1 - c_2}{c_1 + c_2} \quad (2.9)$$

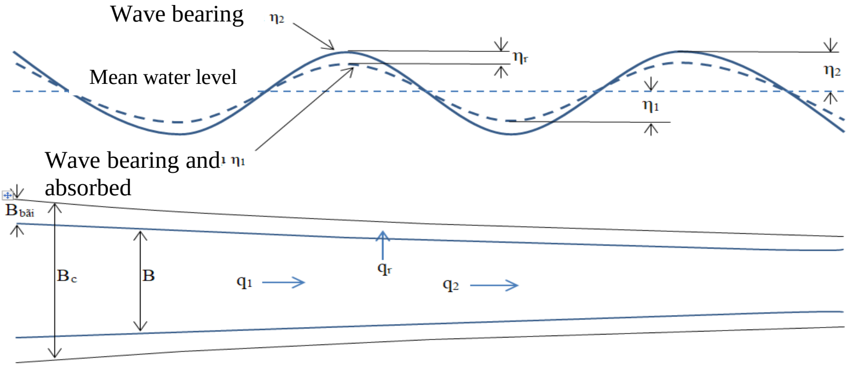

Figure 6: Illustration of wave absorption due to changing tidal flats

Replace value c in (2.6) with the equation (2.9), we have:

$$\widehat{\eta}_r = -\widehat{\eta}_1 \frac{\sqrt{H_1 g} - \sqrt{\dfrac{H_2 Bg}{B + B_{bãi}}}}{\sqrt{H_1 g} + \sqrt{\dfrac{H_2 Bg}{B + B_{bãi}}}} \quad (2.10)$$

Due to deep river bed, it is possible to consider the water level altitude (H1 = H2), then (2.10) will become:

$$\widehat{\eta}_r = -\widehat{\eta}_1 \frac{1 - \sqrt{\dfrac{B}{B + B_{bãi}}}}{1 + \sqrt{\dfrac{B}{B + B_{bãi}}}} \quad (2.11)$$

If placing: $r_b = \dfrac{B}{B + B_{bãi}}$ (2.12)

In which: r_b is the ratio between the river width including the flood plain. The this ratio is small, the tidal flat is large ($0 \le r_b \le 1$)

Then the equation for replacing (2.12) with (2.11) will become:

$$\widehat{\eta}_r = -\widehat{\eta}_1 \frac{1 - \sqrt{r_b}}{1 + \sqrt{r_b}} \quad (2.13)$$

According to the equation (2.13), with constant river width (B) and water column depth (H), if flat width is large, r_b value is small leading to the decrease in wave range η_r.

2.1.2. Impact of tidal flat width to the flow rate

Regarding the flow rate in the presence of flats, the flow rate after passing through tidal flats (upstream of the flood plain) decreases with value q_r as follows:

$$q_r = -\widehat{\eta}_1 \sqrt{gH_1} \frac{1-\sqrt{r_b}}{1+\sqrt{r_b}} \quad (2.14)$$

If written in dimensionless, and placing $\beta_b = \dfrac{\widehat{\eta}_r}{\widehat{\eta}_1}$ (the ratio between wave range decrease and wave range in the presence of tidal flats, ($-1 < \beta_b \leq 0$), β_b can be written as follows:

$$\beta_b = \frac{\widehat{\eta}_r}{\widehat{\eta}_1} = \frac{q_r}{\widehat{\eta}_r \sqrt{gH_1}} = -\frac{1-\sqrt{r_b}}{1+\sqrt{r_b}} \quad (2.15)$$

An example with specific data for equations (2.13) and (2.15): Assuming the river width B = 1,000m; tidal range η_1 = 1,5m; water level altitude H = 10 m, tidal flat width is assumed from 100m to 1.000m. After calculating results as shown in Figure 7.

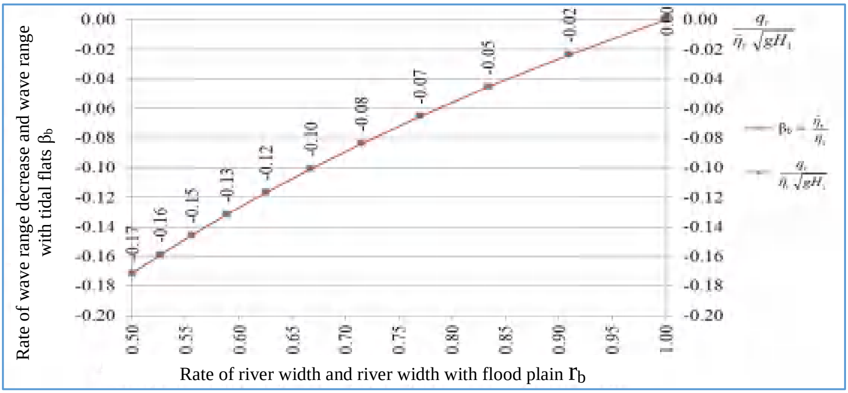

Figure 7: Relationship between r_b with β_b

From the above results, it can be seen that the width of tidal flats has an impact on the decrease of largest water level on the river, the width of flats is large, the decrease in water level on the river is large. In dimensionless analysis, if the ratio r_b is small (tidal flat is large), the ratio β_b is small (the decrease in water level is large).

2.1.3. Impact of river bed cross section to water level and flow rate

In the case of expanding the river bed, as we know when the cross section is extended horizontally or deeply, the flow rate in river (section q_1 has not been extended) is smaller than the flow rate in river (q_2): $q_1 < q_2$. Follow the wave propagation formula (2.4) and in the absence of tidal flats ($B = B_c$), rectangular river bed then:

$$c = \sqrt{gH} \text{ và } q = \eta\sqrt{gH} = \eta\sqrt{g(H_o + \eta)} \qquad (2.16)$$

Considering in the above two cases we have:

$$q_1 = c_1\eta_1 = \eta_1\sqrt{g(H_o + \eta_1)} \qquad (2.17)$$

$$q_2 = c_2\eta_2 = \eta_2\sqrt{g(H_o + \eta_2)} \qquad (2.18)$$

Thus, if $q_2 > q_1$ then according to the equation (2.17) and (2.18); $\eta_2 > \eta_1$ and the extension of cross section makes the increase of tidal range.

2.2. Documents for the study

2.2.1. Terrain documents

Terrain data includes: (i) River cross-section terrain of all rivers and canals in the downstream of SG-DN river is mainly measured from 2006-2018; (ii) Altitude map of 1/10.000 and 1/2.000 of downstream provinces of Dong Nai river; (iii) Scale of irrigation, transport, construction and infrastructure works.

2.2.2. Meteorological and hydrological documents

National meteorological and hydrological documents from 1980 to 2018.

2.2.3. Land use documents

Figures include: Land use developments in provinces of Dong Nai, Binh Duong, Ho Chi Minh City, Ba Ria - Vung Tau and Long An in the study area: 2000, 2010 and 2015..

2.2.4. Remote sensing data

Satellite image data includes categories: Landsat 1-2, Landsat 4- 5, Landsat 7, Landsat 8 with resolution of 30m. The above images were collected in 1980, 1990, 2000, 2010 and 2015.

2.3. Tools used in the study

2.3.1. Tools in land use structure analysis

In the analysis of satellite images, ENVI software is used. Based on spectral reflection characteristics of types of objects classified into 5 types of land: residential land - construction land, agricultural land, water surface land, forest land and unused land. Identify types of land use to be divided, then select sample areas on the corresponding image to be compared with 2015 land use map.

2.3.2. Tools in flood plain simulation

To describe the correlation between parameters of tidal flats with water level and flow rate, the thesis uses a hydraulic model to simulate and evaluate. MIKE model applied in the research includes: (i) Test model for simple river network and (ii) Hydraulic model for the downstream of SG-DN river.

- Test model consists of 2 tributaries with river cross-sections described the same as Sai Gon and Dong Nai rivers. Studies on impact of tidal flats on the river water level and flow rate based on changing the size and location of flood plain. All other input data, parameters in the model do not change when calculating simulation.
- Hydraulic model for the downstream of SG-DN River is based on a one-way, two-way model that describes connections between river and flood plain, connections across the building. The model is also calibrated and tested to be close to actual conditions.

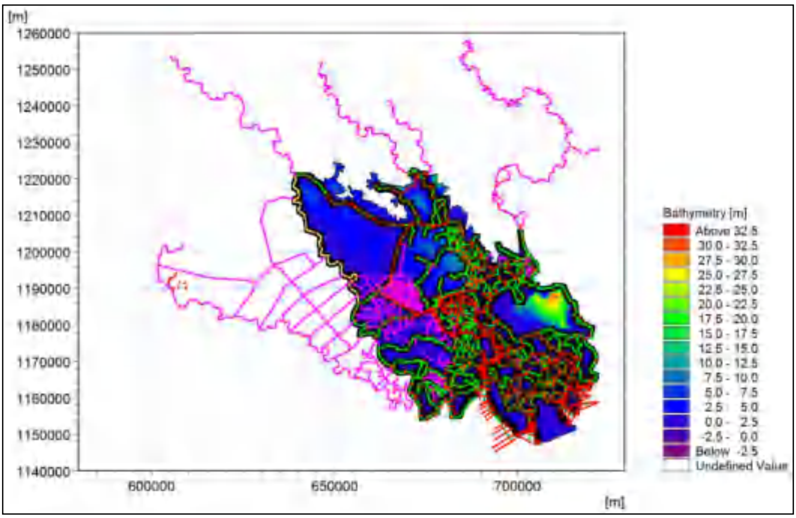

Figure 8: Hydraulic network connecting 1D and 2D of study area

2.4. Land use development in the study area

2.4.1. Land use development is based on data collected by provinces

According to study results of the thesis based on land use data in 05 provinces, the structure of land use has changed quite a lot. Total residential land area in five provinces was about 47,680 ha in 2000, increasing to 92,100 ha in 2015 (increase 93,2% compared to 2000). The statistic water surface area in the area was about 167,310ha in 2000, and in 2015 it decreased to 126,550ha (down 24.4% compared to 2000).

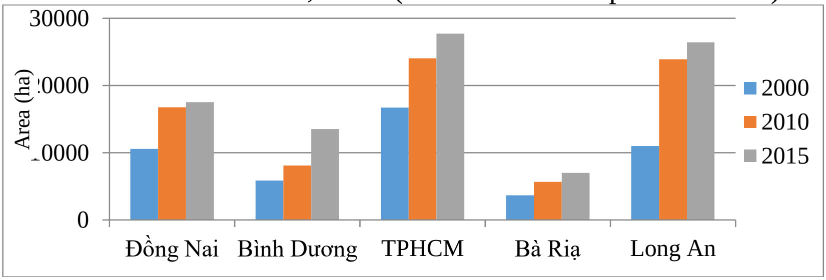

Figure 9: Change of residential land use area from 2000 - 2015

2.4.2. Land use development is based on satellite image analysis

According to study results of analyzing satellite images of the thesis in years 1980, 1990, 2000, 2010 and 2015. Area of construction land in the downstream of SG-DN River (including residential land, traffic land, construction construction, irrigation, infrastructure ...) increased quite large, total construction land area in the downstream of Dong Nai river was about 118,750ha in 1980, increased to 138,290 ha in 1990 (increased 16.5% compared to 1980) increased to 152,540 ha in 2000 (increased 28.5% compared to 1980), increased 235,890 ha in 2010 (increased 98.6% compared to 1980) and increased 288,360 ha in 2015 (increased 142.8% compared to 1980).

Thus, over the past 35 years, the area of construction land has nearly tripled compared to previous period. If considering from 2000 to 2015, the period of rapid infrastructure construction, the area of construction land has nearly doubled compared to 2000. The change in land use structure is quite large, causing tidal flats narrow or even disappear in some areas. These changes are one of reasons that need to be clarified to assess their impact on change in water level and flow rate in the river. The above documents will be used for hydraulic simulation of narrowing tidal flats in the study of thesis.

CHAPTER 3. STUDY RESULTS AND DISCUSSION

3.1. Analysis results of water level change in the river are based on actual measured data

According to analysis results of largest water level from 1980 to 1999, the largest water level in Vung Tau increased by 0.94 cm / year, but water level in Phu An only increased by 0.42 cm / year. Considering the period from 2000-2018, water level in Vung Tau increased by 0,13 cm / year, but water level in Phu An increased to 1.81 cm / year. This proves that, over the past 20 years, the largest water level in Phu An has increased significantly. To clarify the impact of tidal flats to the largest water level in river when separating effects of rain in the area and flood in the upstream, the largest water level in May (dry season) is used for the analysis. Analysis results in the period 1980-2018, the largest rising of water level in river still increase much more than at the sea: Vung Tau increases by 0.38 cm/year; Nha Be increases 1.10 cm/year; Phu An increases 1.18 cm/year; Thu Dau Mot increases 0.92 cm/year; Bien Hoa increases 2.46 cm/year; Ben Luc increases 1.07 cm/year. This proves that the impact on narrowing of tidal flats is one of the reasons for the largest rising of water level in river in both flooding and dry seasons.

For shape of the largest water level along the river, the annual largest mean water level in May with a rainbow from Phu An to Nha Be (Figure 10), where tidal flats along the river have been greatly reduced.

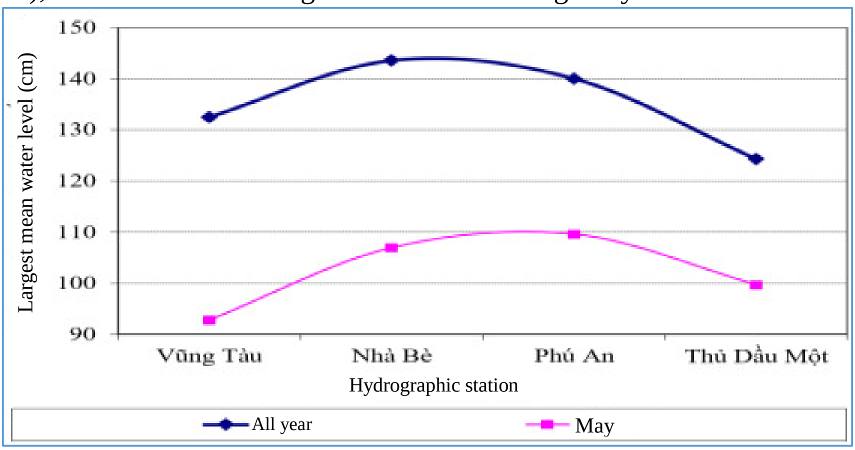

Figure 10: The annual largest mean water level along the river in May

3.2. Study results of the test model

Study results of test model are presented as follows:

(i) At the location of tidal flats, tidal range tends to shrink, leading to decrease in water level, and the smallest water level increases. Thus, when it is necessary to reduce the water level for one location, tidal flats must be placed at that location. (Figure 11).

(ii) If considering the process of water level at tidal flat locations, if the tidal peak water level is high, the tidal cutting ability of flats is large. If the area of flat location is large, the impact of tidal flats to the water level decrease is large. Based on the largest decrease of water level and the changed area of tidal flats, the relationship of the largest decrease of water level and the area of tidal flats can be established (Figure 12).

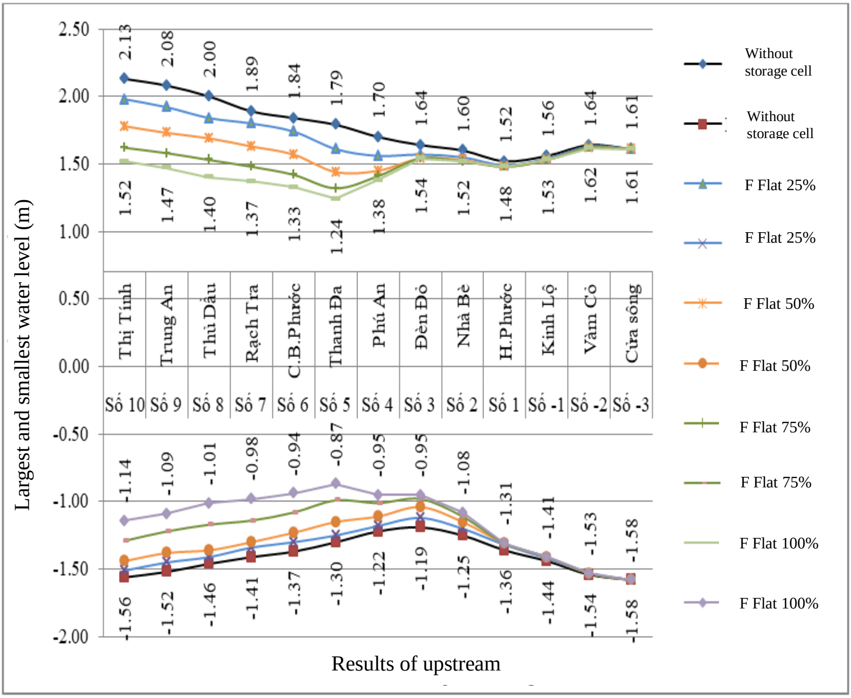

Figure 11: Change of largest and smallest water level when the area of tidal flats in Thanh Da changes

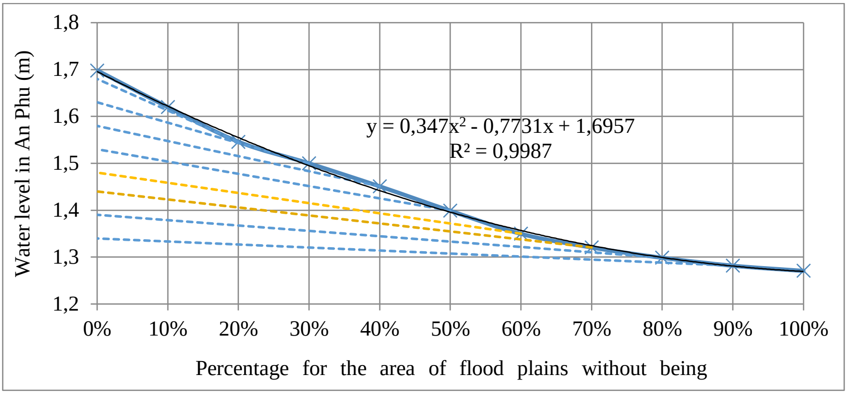

Figure 12: Largest change of water level in Phu An when the area of tidal flats in Phu An changes

(iii) Considering the change of flow rate in the river in the absence of tidal flats. In the presence of tidal flats in the river at the downstream, tidal flats increase and flow rate in the river at the upstream of tidal flats decreases. This may lead to a change in river velocity and is one of the reasons for erosion or sedimentation for river bed.

(iv) Tidal flat level affects the tide peak and foot water level at each location depending on the tide foot at that location. Thus, tidal flats do not need to be deep, but their impact on the largest water level is still large (Figure 13).

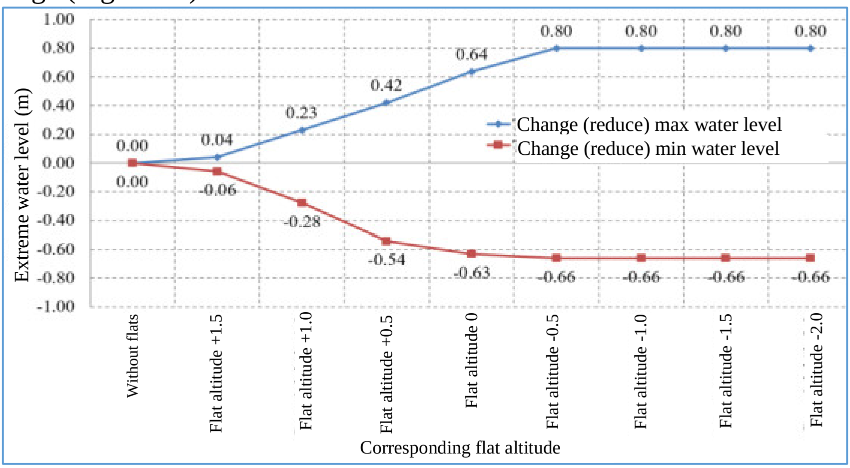

Figure 13: Correlation of changes in largest and smallest water level and changed flat altitude at the tidal foot of -0.5 m (at Thu Dau Mot)

(v) Tidal range increases as the river cross-section in the downstream increases. This proves that, for the current Soai Rap river, the dredging of this river bed has increased the largest water level in Phu An and Nha Be (Figure 14).

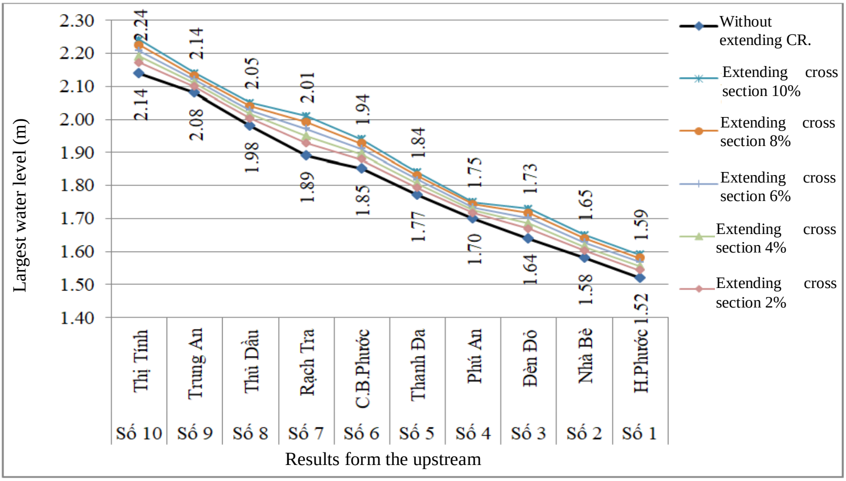

Figure 14: Largest water level in case of cross section extension

3.3. Study results on impact of tidal flats to the water level and flow rate at the downstream of Sai Gon - Dong Nai river

Calculation results of the model for the downstream of SG-DN River are shown as below:

(i) Impact of construction land so far has increased the largest water level on river by 17 cm, the impact of agricultural lands so far has increased by 25 cm (Figure 15). Total impact of the site development so far has increased the largest water level on river by 42 cm; (ii) If considering the increase in water level according to climate change (17 cm in Phu An) and the largest increase in water level due to narrowing tidal flats (19 cm in Phu An), the narrowing of tidal flats caused by man is higher than the rising of sea level.

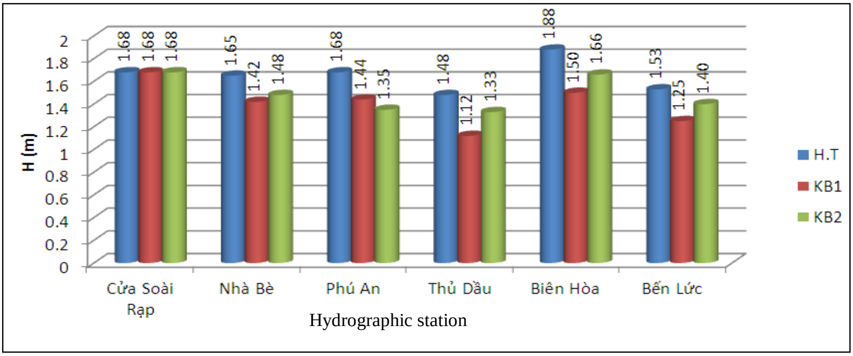

Figure 15: Current largest water level (H.T) and upon considering the impact of agricultural land (KB1) and construction land (KB2)

Flow rate at the river locations also decreased significantly when compared with the current case and with the absence of agricultural land and construction land production areas. If the impact of agricultural land and construction land has decreased the area of tidal flats, the largest flow rate at Soai Rap gate is decreased by 83% and the smallest flow rate is decreased by 85%.

(ii) According to the analysis, at present, the downstream of SG-DN River has 23% of tidal flat area that can interact with tides, of which Can Gio area accounts for 68,3% of this area, the rest of downstream only 31.7%. If low-hallow areas do not exist (except for Can Gio area, KB4), the largest water level on the main river will have an average increase of 19 cm compared to present water level. When low-hallow areas do not exist in the future (including Can Gio area, KB5), the largest water level on the main river will have an average increase of 25 cm compared to the current situation (Figure 16).

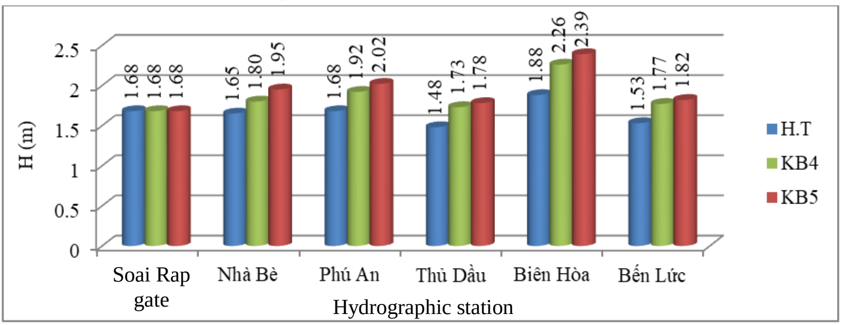

Figure 16: Largest increase in water level in the river is forecasted without low-lying areas

(iii) To assess in details the change of land use structure of an area to water level in the main river. The study has selected Sai Gon South area with an area of about 17,500 ha. According to the calculation results, total flow rate passing through tidal flats and canals of all Southern Sai Gon area in one tidal cycle when not being narrowed yet can be up to 7.24 billion m^3. When tidal flats do not exist, the total flow rate accessing tidal flats is only about 2.17 billion m^3 in one tidal cycle (only about 30%). Tidal peak water level at Phu An increases about 12 cm (from +1.58 m to +1.70 m altitude). The largest water level in Nha Be increases about 15 cm (from altitude +1.54 m to +1.69 m), this increase is higher than in Phu An due to many rivers in Southern Sai Gon (Cay Kho, Muong Chuoi, Can Giuoc, Song Kinh ...) connected to the location near this hydrological station. The largest water level in Phu My Hung increases about 20 cm (from altitude +1.49 m to +1.69 m), compared with the largest increase in water level outside the main river, this increase is larger due to this area will be the main impact area of tidal flats leveling (Figure 17). This proves that the tidal flats space in Southern Sai Gon has had a great impact on the largest water level on river. Flow rate on the main river will also have a big change, on Sai Gon River, flow rate will increase to about 14.5%. On Dong Nai River from Muong Chuoi to Red Mui Den, flow rate can be increased by 21%. At Soai Rap river from Hiep Phuoc to the East sea, flow rate is reduced by less than 10.7% compared to the time when tidal flats are not narrowed.

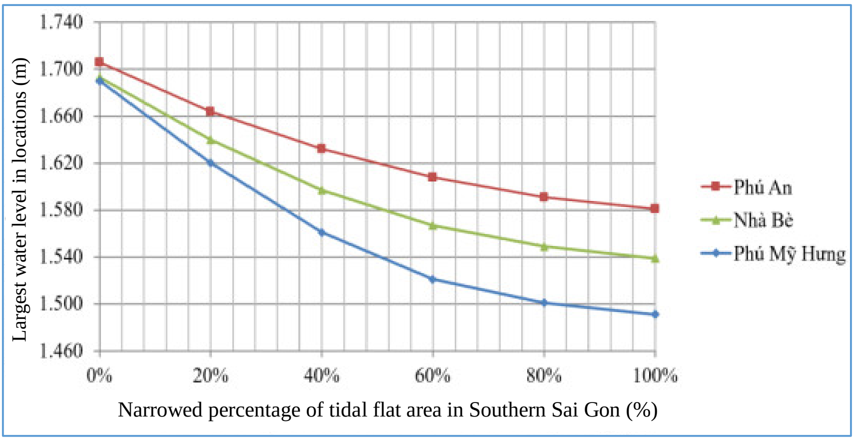

Figure 17: Relationship of largest tidal peak water level at locations and percentage of tidal area of Southern Sai Gon

3.4. Solution to minimize the impact of rising tidal peak water level

In addition to human impacts, impacts of climate change will also increase the largest water level in the river. There are many solutions for flood control in the area, girdle shaped dike and construction of protective sluices when the water level rises, and can enhance elevation to prevent flooding. For present girdle shaped dike that is often combined with traffic way, the altitude enhancement of dyke leads to connections of the surrounding infrastructure. Enhancement of foundation is also very difficult when the land has been constructed, especially for housing works.

To reduce the largest water level in the river, some solutions have been mentioned: (i) Narrow Soai Rap estuary by building a dam for Soai Rap river, reducing tidal energy and narrowing tide range; (ii) Solution of building dyke for Vung Tau - Go Cong sea to control flooding for the study area is also a solution to impact the estuary for reducing the largest water level in the river. The above studies are a good technical solution in controlling the tidal peak water level, but the impact of these large works on the ecological environment and construction cost should be considered. In this study, the thesis proposes solutions to restore the previously narrowed tidal flats. If the agricultural production areas want to use in regulating the tidal current during flood tide season, only open tidal sluices, clear canals, these areas will participate in reducing the tidal peak. Thus, these areas can only use cultivation during low flood tide season and reduce tidal peak water level during high flood tide season. Tidal flats in the simulation are distributed along Sai Gon River from Thi Tinh Sai Gon River estuary and on Dong Nai River from Bien Hoa to Hiep Phuoc with a total area of 430km^2.

According to calculation results, the water level in Phu An now decreased from + 1.68m to +1.50m (decreased by 18cm), at Thu Dau Mot, decreased from +1.48m to +1.23m. With altitude of the largest water level as above, it will significantly reduce flooding in the study area. Thus, the solution of returning low-hallow areas, reducing water level in river, and bringing currents back to the former nature in terms of techniques is possible. However, it is necessary to study based on both economic and social aspects. On the other hand, not only this solution can be applied, but it can be combined with other solutions such as the effect of narrowing a part of estuary to reduce tidal energy from the sea, thereby lowering the tidal peak water level in rivers.

3.5. Construction results correlate with the area and location of tidal flats with the largest water level in river

Based on simulation data by mathematical model, building a relationship on the largest water level decrease in Phu An with the tidal flat distance according to each specific area (Figure 18). A set of simulations made in this study including changes in both tidal location and the area of tidal flats to provide results of water level depending on the area of tidal flats and the distance from tidal flats to Phu An. From these results, we can build a correlation function between the water level decrease in Phu An with the area of tidal flats and location of tidal flats.

Thus, when knowing the distance from tidal flats to the calculation location and the area of tidal flats, the water level decrease in Phu An can be calculated. Results also show that the relationship between the largest water level decrease and the area in the test model results, the relationship between the largest water level decrease and the tidal width in the test model results, showing the rationality with theoretical analysis on propagation of tidal wave of estuaries.

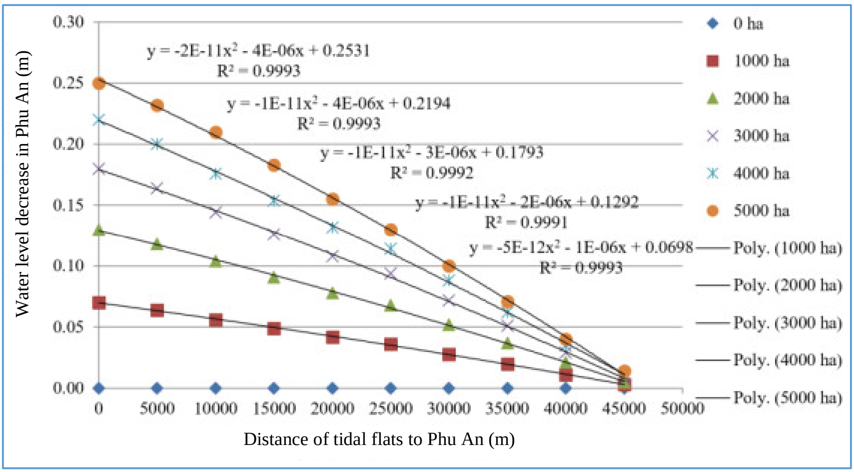

Figure 18: Relationship between the largest water level decrease in Phu An when changing the location from Phu An to Hiep Phuoc and the area of tidal flats

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The terrain of river bed and flats along the river always change under the influence of natural factors and human, these changes affect the water level and flow rate in the river. Forms of terrain can be mentioned as: (i) River cross-section terrain including river bed cross section and side flats; (ii) Low-hollow areas at the upstream are flood retention areas; (iii) Downstream of areas affected by tide are tidal flats. The thesis focuses on the change of water level and flow rate in the river when tidal flats are narrowed.

The thesis has used theoretical analysis to determine the relationship between the width of tidal flats and water level and flow rate in the river. The thesis also uses land use documents through local data collection and satellite image analysis to identify tidal flats. To clarify the impact of tidal flats on the water level and flow rate in the river, the thesis has built test model to simulate tidal flats in many cases. For applying practical calculation for the downstream of SG-DN River, the thesis uses hydraulic model (1-D, 2-D) to describe the impact of tidal flats on the water level and flow rate in the main river at the downstream of SG-DN River. The thesis also simulates the calculation of the largest water level in the future when tidal flats disappear and proposes solutions to reduce the water level in the river based on the viewpoint of restoring flood plains.

Thus, it can be seen that tidal flats in the study area are a very important factor affecting the tidal regime. According to analysis results, the human impact in narrowing tidal flats causing the largest water level is larger than the impact on rising of sea level. Therefore, human need to have more appropriate concepts and behavior in the exploitation and protection of tidal flats in the area. This study is applied to the downstream of SG-DN river, but in principle and general rule, it can be applied to other river basins with tidal influence.

Further researches

Factors of land subsidence, deformation of the river bed, wind impact, salinity composition, shape of tidal flats and structures affecting the propagation of tidal wave into estuaries have not been mentioned in this study. In next studies, more studies on these factors should be taken to give complete results.

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