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MORPHODYNAMICS OF HUE TIDAL INLETS, VIETNAM

Nghiem Tien Lam[1], Marcel J. F. Stive[2], Henk Jan Verhagen[3], and Zheng Bing Wang[4]

ABSTRACT: Morphodynamics of a tidal inlet system on a micro-tidal coast in a tropical monsoon influenced region is modelled and discussed. Effects of tides, waves, river flows and system configuration on the inlet morphologies are investigated with the aid of process-based state-of-the-art numerical models. Seasonal and episodic behaviour of the inlet system under the influence of the forcing processes is then described, modelled and explained.

1. Introduction

Tidal inlets are a common feature found along barrier coasts throughout the world. About 13 percent of the world's continental coastline consists of barriers interrupted by tidal inlets giving access to the back barrier bays or lagoons (Schwartz, 1973). Tidal inlets play an important role in exchanging water and providing a navigational pathway for ships and small boats to travel between the open oceans and sheltered waters. The importance of inlets is demonstrated by the increasing interests and the large number of inlet improvement activities for navigation such as the construction of jetties and breakwaters, dredging of channels, and the operation of sand bypassing facilities (FitzGerald, 2005). Therefore, they have been the subject of investigation since the early twentieth century (e.g., Lorentz, 1926; O'Brien, 1931; Escoffier, 1940). However, tidal inlets which are under the influence of episodic river flows and/or the seasonal climatic variation are much less studied. Although a few studies have been carried out on the seasonal variation of tidal inlet such as the seasonal opening of tidal inlets (Tanaka et al., 1996; Elwany et al., 1998; Ranasinghe and Pattiaratchi, 1999), morphodynamics and behaviour of tidal inlets in the tropical monsoon areas like in the Central Coast of Vietnam are still poorly understood. Many

[1] Corresponding author. MSc, Water Resources University, 175 Tay Son, Hanoi, Vietnam; E-mail: lam.n.t@wru.edu.vn. Present address: PhD student, Delft University of Technology, Faculty of Civil Engineering and Geosciences, Section of Hydraulic and Offshore Engineering, P.O. Box 5048, 2600 GA Delft, The Netherlands, Tel. +31 15 278 7692, Fax: +31 15 278 5124; E-mail: T.L.Nghiem@tudelft.nl

[2] Professor, Delft University of Technology, Faculty of Civil Engineering and Geosciences, Section of Hydraulic and Offshore Engineering, P.O. Box 5048, 2600 GA Delft, The Netherlands; E-mail: M.J.F.Stive@tudelft.nl

[3] Ass. Prof., Delft University of Technology, Faculty of Civil Engineering and Geosciences, Section of Hydraulic and Offshore Engineering, P.O. Box 5048, 2600 GA Delft, The Netherlands; E-mail: H.J.Verhagen@tudelft.nl

[4] Dr., WL | Delft Hydraulics and Delft University of Technology, P.O. Box 177, 2600 MH Delft, The Netherlands; E-mail: zheng.wang@wldelft.nl

questions concerning inlet behaviour in this area such as inlet channel migration (Figure 2) or the problem of whether to or not to close a newly opened breach, have not been answered. This paper presents some results in an effort to explain the behaviour of the tidal inlet system in this area.

1.1. *Study area*

The tidal inlets of Hue, namely Thuan An and Tu Hien, are located in Thua Thien-Hue province on the Central Coast of Vietnam (Figure 1). The inlets connect a large lagoon system, the Tam Giang-Cau Hai lagoon, to the sea. The Tam Giang-Cau Hai lagoon is a series of connected lagoons with the total surface area of 220 km^2. As the lagoon and inlet system is providing the living resources for about 300,000 inhabitants in the surrounding area, the system state is very important in terms of navigation, aquaculture, agriculture, fishery and coastal inundation in the area.

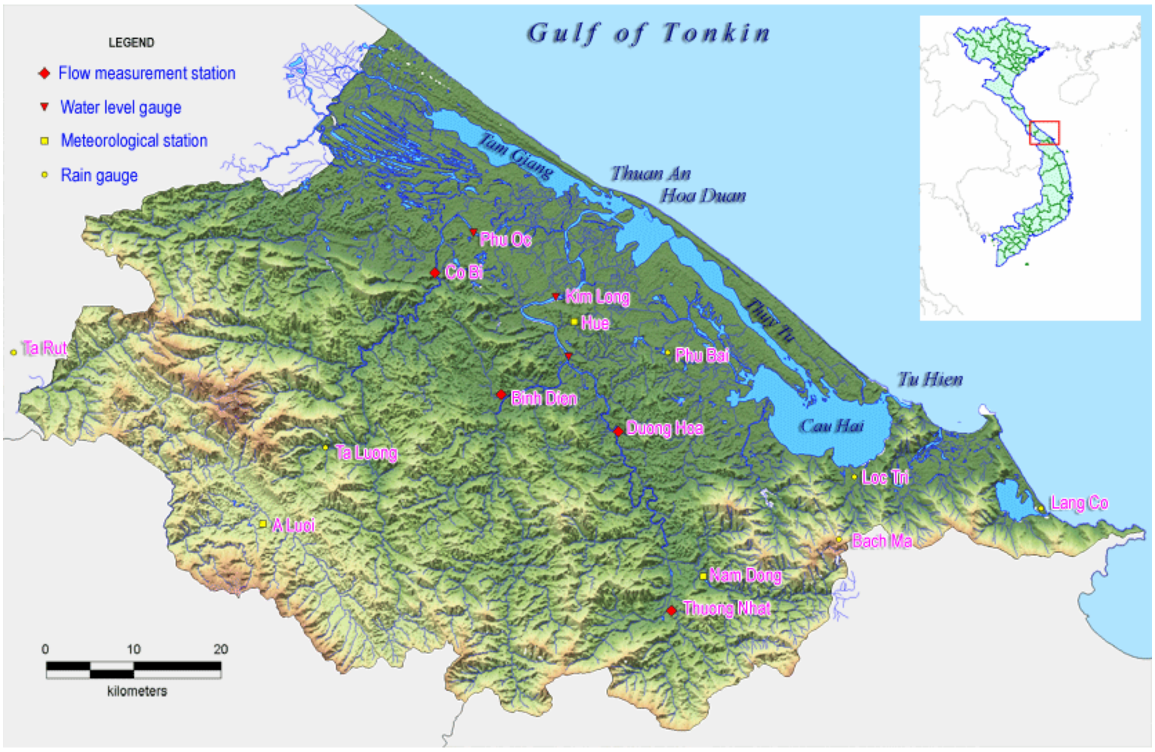


Figure 1 Map of the lagoon and inlet system in Thua Thien-Hue province, Vietnam

1.2. *Geographical conditions*

Located in a tropical monsoon influenced area, the morphology of the inlets is controlled not only by interacting marine processes such as tides, wave climate, coastal currents, but also by strong river discharges. The influences of these governing factors are controlled by the monsoon climatic regime.

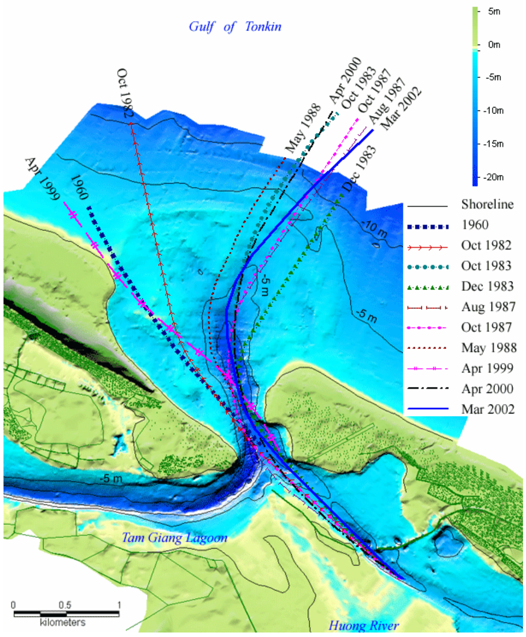


Figure 2 Bathymetry and lines showing historical changes of Thuan An channel

1.2.1. *Northeast or winter monsoon season*

The northeast monsoon prolongs from mid-October through February after crossing the warm and humid South China Sea, it brings abundant precipitation to the coastal mountains of Central Vietnam. Also from early September through November typhoons commonly strike along this coastline. The typhoons drive in from the east and rapidly dissipate to rain-storms when spoiled by the Truong Son Mountain Range. Northeast winds and typhoons create a flood season lasting from September through December. Although the flood season lasts only four months, it accounts for more than 70% flow volume in a year. The heavy precipitation that normally accompanies typhoons causes inordinate river floods in the Huong river basin. The topographic characteristics of the basin which is steeply highly sloping promotes that the flood water is rapidly discharged to the coast and thereby inundating the narrow coastal plain. Water height difference at two sides of the inlets may reach 2 m, creating very high flow velocity in the inlets and causing dramatic changes to the inlets. Also if the process of scouring the inlets is too slow then the water may overflow the sand barrier and create breaches at the weakest points to allow additional discharges. A tropical depression in early November 1999 with the maximum rainfall intensity of 120mm/hour has produced a serious flooding of the central coastal provinces of Vietnam that killed 324 people and caused an economic loss of 112 million US dollars (Huynh et al., 1999). The flood also scoured tidal inlet channels. The cross-sectional area of the Thuan An inlet has increased from 3250 m^2 to 6200 m^2, and the cross-sectional area of the Tu Hien inlet has increased from to 600 m^2 to 1800 m^2. The flood also breached the sand barrier at Hoa Duan to create a new inlet with a cross sectional area of 1750 m^2 (Figure 3). In the northeast monsoon season, northeast winds create a rough sea with dominant waves coming from E, NE or NW. Northeast monsoon waves usually cause coastal erosion.

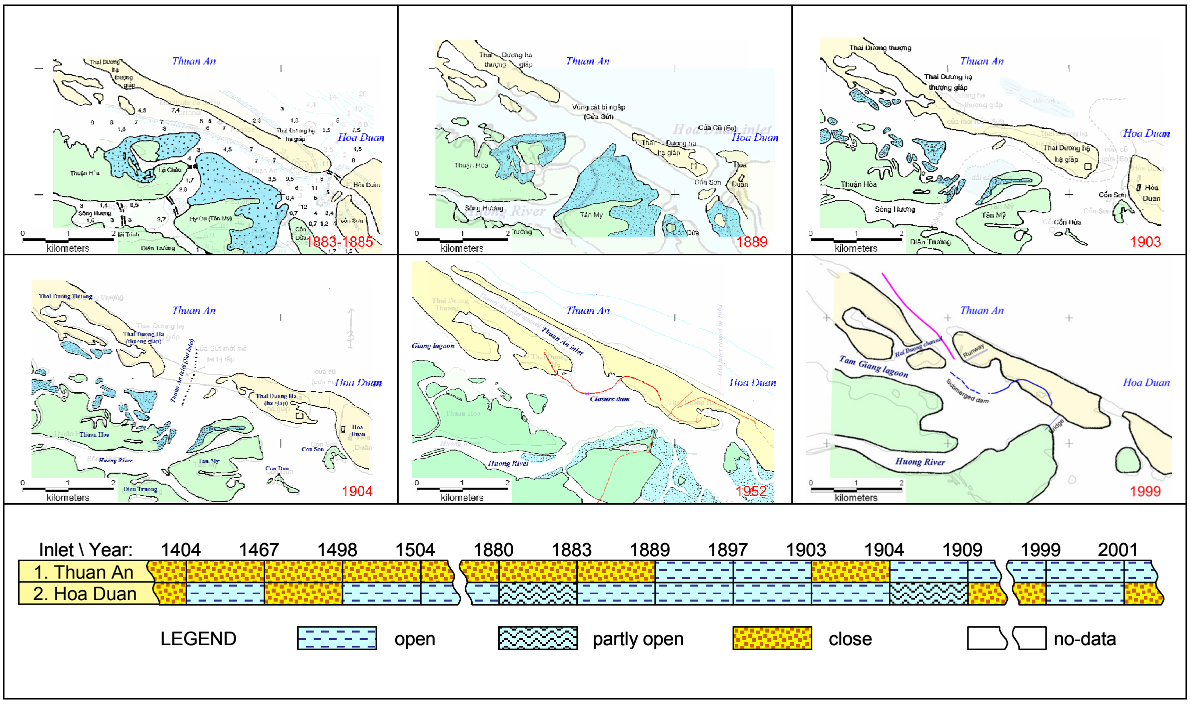


Figure 3 Configuration changes of Thuan An inlet

1.2.2. *Southwest or summer monsoon season*

The rest of the year is the period of the dry season lasting for eight months when river flows significantly diminish. Especially, when the southwest monsoon takes over from May until September, when the southwest winds after passing the Truong Son Mountain Range have been dried out and become very hot, river flows become lowest. In this season, dominant waves are from SE inducing longshore sediment transport north-westward in the coasts near the Thuan An inlet. Because the tidal range in the area is less than 0.5m (that is smallest along the Vietnamese coast), wave action becomes dominant. Characterized as micro-tidal wave dominated, the tidal inlets become unstable. The ratio presenting the overall stability of tidal inlets according to Bruun (1968, 1978, 1986) P/M_{tot} for the Thuan An and Tu Hien inlets is about 10 – 60 and 10 – 20, respectively (Lam, 2002). These values indicate that the Thuan An inlet is in a "fair to poor" stability situation and the stability situation of the Tu Hien inlet is categorized as "poor". Longshore sediment enters the Thuan An inlet and shoals its channel and ebb tidal delta creating difficulties for navigation. Prevailing longshore sediment transport from SW causes the inlet gradually migrates north-westward (Figure 3). In the Tu Hien inlet, because a rocky headland limits the coast just at the southern side of the inlet so the dominant sediment transport entering the inlet is from the northwest direction. The northern sand spit gradually develops and grows south-eastward (Figure 4). If in the following flood seasons, river flows can not breach through the sand spit, then the channel will continue to decline and to migrate south-eastward. At the end of the inlet migration and development process, the entrance is relocated at Loc Thuy nearly 3 km southern of the original location Tu Hien, the channel width decreases from 200 m to 50 m and the depth decreases from 3 - 4 m to only 1 m. This cyclic development usually takes many years. The last cycle took 9 years starting in 1990 at Tu Hien and relocated at Loc Thuy in the period

1994-1999 until the historical flood of November 1999 happened (Figure 4). According to Thanh et al. (2000), the morphologic cycle now becomes shorter.

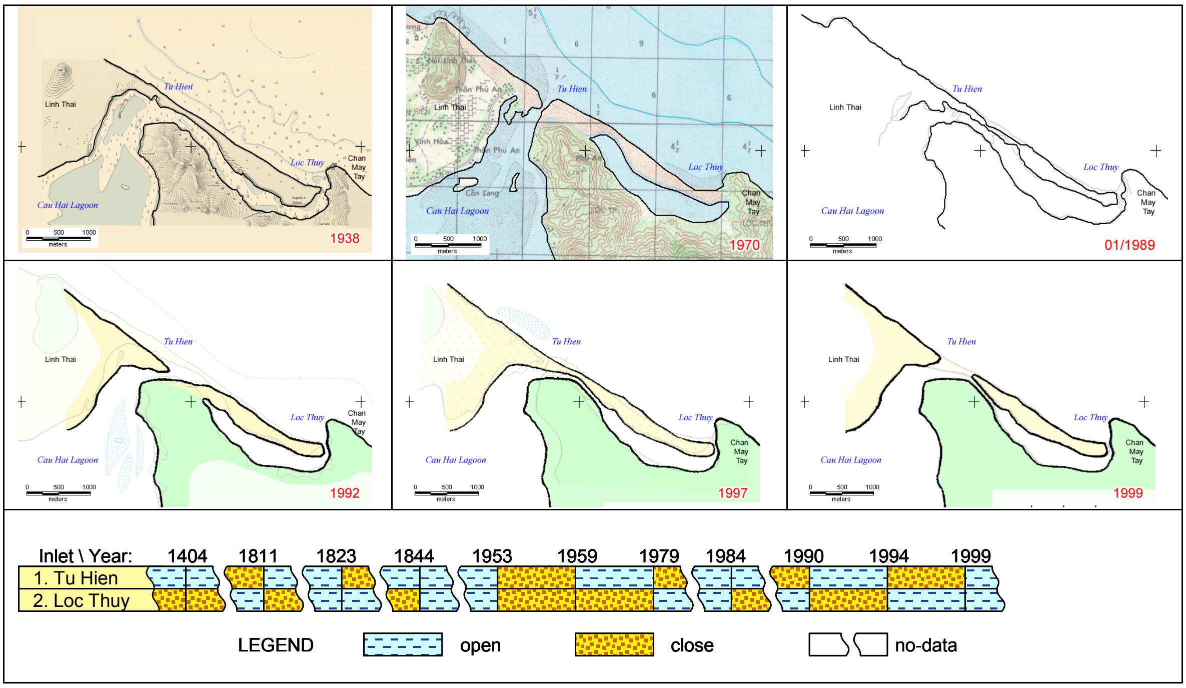


Figure 4 Cyclic evolution of Tu Hien inlet

To get acquainted with the hydrodynamics of the inlet system, Lam et al (2002, 2003) used a one dimensional hydrodynamic model DUFLOW to analyze the effects of river flows, tides and inlet configurations on the inlet flow velocities and confirmed that river flows are the most important influence in the flood season. The study pointed out that the presence of the new inlet opened at Hoa Duan will cause the existing inlet of Thuan An to decline. Futhermore it was found that the changes in the Thuan An and Hoa Duan inlets have little effect on the hydrodynamics of the Tu Hien inlet, or in other words, the hydraulic characteristics of the Tu Hien inlet are relatively independent of the changes of the Thuan An and Hoa Duan inlets. The reason of this is the topographic high caused by the bars in the old ebb-tidal delta in south of the Thuy Tu lagoon.

The further step is the study on the effects of river floods and wave actions on the morphology of the tidal inlets. The analysis on morphodynamics of the lagoon and tidal inlet system has been carried out using a numerical modelling approach.

2. Model description

2.1. *Hydrodynamic model of tides in coastal waters*

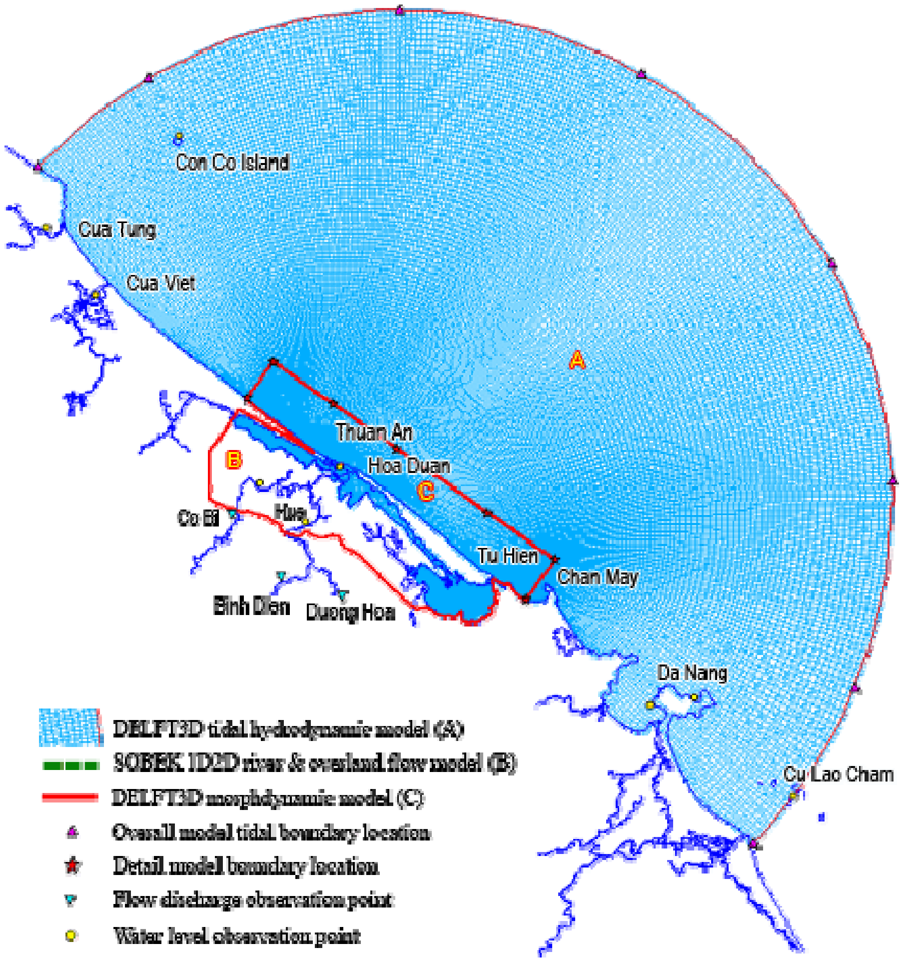


Figure 5 Detailed morphodynamics model

Although there is no long-term data of hydrologic and oceanographic observations available in the coastal area of TT-Hue, many hydrologic, topographic and sedimentary data sets have been collected recently after the historical flood of November 1999. The data sets, especially the tidal water level data, are usually short, inconsistent with different reference levels, different qualities and accuracies, because they are collected by different organizations or projects. To have an accurate information on the tides in the sea side and to evaluate the available data sets, a 2D numerical model of tidal forcing in the area has been setup based on Delft3D (Figure 2). Boundary conditions for the model are tidal constants extracted from the global ocean tides based on satellite altimetry data such as GOT00.2 (Ray, 1999), NAO.99b (Matsumoto et al., 2000), TPXO6.2 (Egbert and Erofeeva, 2002), and CSR4.0 (Eanes and Bettadpur, 1995). The model has been setup to include in its domain the stations having long-term data in surrounding areas such as Da Nang, Cu Lao Cham and Con Co, and has been calibrated and validated based on observations available at these stations.

2.2. *Hydrodynamic model of river flows*

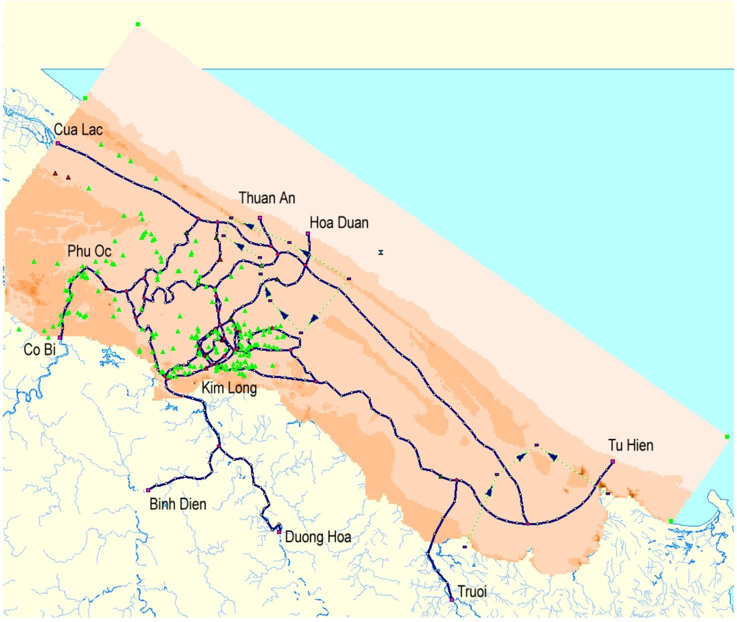


Figure 6 Hydrodynamic model of flow in rivers and floodplain

The lagoon and inlet system of Hue receives water from a drainage basin of about 4000 km^2. Fresh water discharges into the lagoon through a dense river network with two main rivers: the Huong (Perfume) River with its catchment area of 2623 km^2 and its mouth located near the Thuan An inlet, and the O Lau River with its catchment area of 745 km^2 discharging to the Tam Giang lagoon. During the flood season, peak discharge of the Huong River may reach 12000 – 14000 m^3/s (Tuan et al., 2001). The flood water not only flows in the river channels but it also overflows on the floodplain. Flood flow is considered as the main factor for the fast changes in the inlet morphology so the consideration of its effect is important. Unfortunately, there is almost no flow observation available in the lagoon and inlet areas. Flow discharge is measured only at upstream of the rivers in the mountainous or non-tidal influenced area. In the tidal effected area, water level is observed at Kim Long and Phu Oc stations located upstream from the Thuan An inlet 20 km in the Huong River and 30 km in the Bo River, respectively. To simulate river flow contribution to the morphological change of the inlet properly, a numerical model for the river network and floodplain has been setup based on SOBEK-Rural.

SOBEK is an integrated numerical modelling package for river, urban or rural management developed by WL | Delft Hydraulics. It is based on the 1D De Saint Venant equation for river/channel network and 2D shallow water equations for overland flow. The 1D and the 2D hydrodynamic equations are solved simultaneously using the very robust implicit scheme known as the Delft scheme (Frank et al., 2001). For the application of Hue area, the model couples 1D module to simulate flow in the river network and 2D overflow module for the floodplain (Figure 3). The 1D river network schematization has been extended 45 – 65 km upstream to include the flow and water level stations so that the observations at these stations can be used for the upstream boundary conditions as well as for model calibration and verification. The 2D part of the model is a 200-m DEM of the coastal water and low land area. The results from the tidal hydrodynamic model are used as the downstream boundary conditions for this model.

2.3. *Morphodynamic model of lagoon and inlet system*

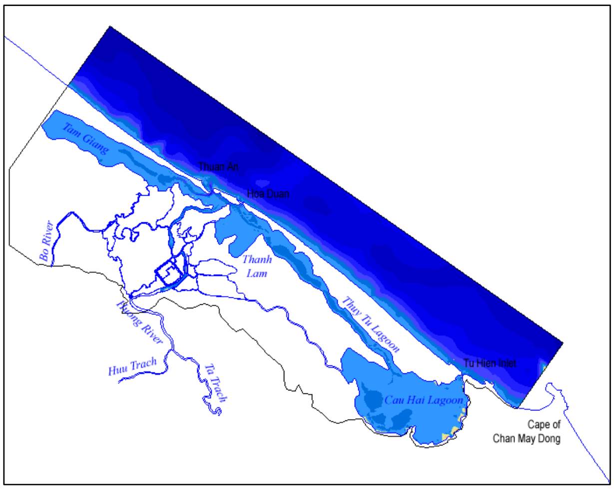


Figure 7 Detailed morphodynamic model

The results from the hydrodynamic models of ocean tides and river flows finally are used as boundary conditions for the detailed morphodynamic model of the lagoon and inlet system. This model has been setup based on Delft3D modelling package developed by WL | Delft Hydraulics. Delft3D is an integrated modelling suite for the free surface water environment. It is a flexible framework consisting several modules which simulates two and three-dimensional flow, waves, water quality, ecology, sediment transport and bottom morphology and is capable of handling the interactions between these processes. This study utilizes three modules of Delft3D: Delft3D-FLOW, Delft3D-WAVE and Delft3D-MOR. The hydrodynamics and transport module Delft3D-FLOW solves the unsteady, multi-dimensional shallow water equations derived from the 3D Navier Stokes equations for incompressible free surface flow (under the Boussinesq assumptions) on a orthogonal curvilinear, boundary fitted grid in horizontal direction and the σ-grid or the Cartesian Z-grid in the vertical direction. The partial differential equations are discretized and solved on a staggered grid by the ADI method (WL | Delft Hydraulics, 2006). The 2D version of Delft3D-FLOW has been applied for this study. The wave module Delft3D-WAVE is based on the third-generation wave model SWAN to compute wave propagation, wave generation by wind, non-linear wave-wave interactions and dissipation, for a given bottom topography, wind, water level and current fields. The sediment transport and morphology module Delft3D-MOR supports both bed-load and suspended load transport of non-cohesive sediments and suspended load of cohesive sediments. But the application for Hue considers only non-cohesive sediments using Van Rijn's (1993) method for river flow study and Bijker's (1971) method for wave action.

Domain of the morphodynamic model for Hue includes the lagoon and inlets and extended to the continental shelf at a water depth of 30 m. The model grid is curvilinear with the minimum grid size at the inlet locations of less than 50 m. In addition to the river flows and tidal forcing, the actions of waves and winds are also taken into account in the model. Information about waves and winds is derived from the observed data at Con Co Island located offshore northwest of the area (Figure 5). For the long-term morphologic simulation of the system, the "morphological factor" technique (Roelvink, 2006) has been applied.

3. Results and discussion

3.1. *Tidal hydrodynamics*

The model results show that the tidal acting force in the inlet areas is mainly due to the M_2 component with an amplitude of H_{M2} = 0.15 - 0.185 m. The one-year-cycle component Sa has about the same amplitude of 0.15 m. Smaller components are S_2, O_1 and K_1 with amplitudes in the range of 0.023 – 0.066 m. Other components including shallow water components such as M_4, M_6 are negligible. For example, the M_4 component has an amplitude of H_{M4} = 0.001 m outside the Thuan An inlet, when it enters the lagoons its amplitude increases to 0.002 m in the Tam Giang lagoon and to 0.005 m in the Thuy Tu lagoon. The distortion of ocean tides in the lagoon also mainly happens to M_2. Outside the Thuan An inlet it has H_{M2} = 0.185 m. After passing the inlet, it reduces to 0.146 m. These values in the Tam Giang lagoon and at the southern end of the Thuy Tu lagoon are 0.045 m and 0.067 m, respectively. The M_2 component has much distorted in the Tu Hien inlet, it reduces from 0.182 m outside the inlet to 0.104 m in the inlet and then to 0.032 m in the flood delta. In the Cau Hai lagoon, this value remains 0.021 m. This result suggests that the effect of tidal asymmetry on the inlet morphology can be neglected and the tides in the inlets work as in the pumping mode.

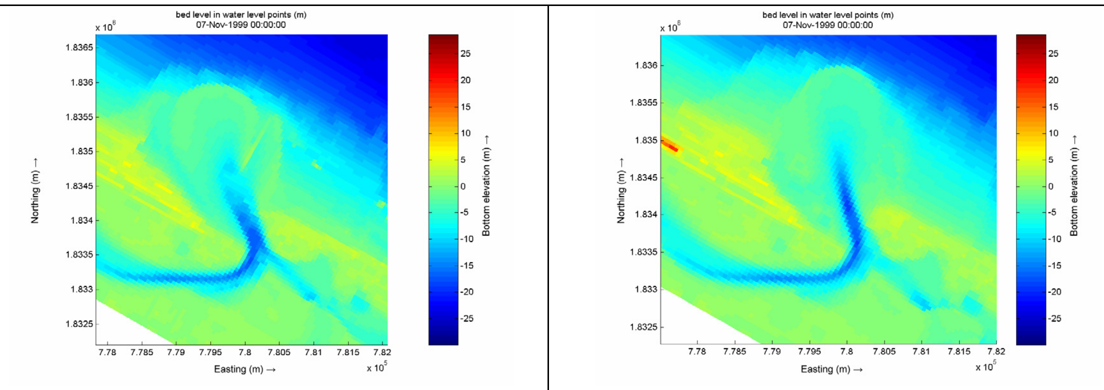
Among the global ocean tide models, the tidal constants extracted from GOT00.2 and NAO.99b and used as model boundary conditions give the most suitable results with the observations, except the Sa component which is not well represented in the global ocean tide models.

3.2. *River flow influences*

During river floods, strong flow velocity can occur in the inlets. For example, maximum velocity in the Thuan An inlet during the flood of November 1999 may reach 2.5 – 3.0 m/s. At the inlet, water flows as a strong flow jet which widens and deepens the inlet channel and gorge. Strong currents due to river-flood scour the inlet channel and deepen its bottom level from -10 m to -14 m.

In the Thuan An inlet channel and its ebb tidal delta, the direction of the flow jet is relatively stable. The direction of the flow jet in the inlet and the ebb delta depends on the side which the dominant river flood discharge comes from. If the flood water dominantly comes from the southern side of the inlet, i.e. mainly contributed by the rainfall on the Huong River catchment, the jet current will head north or northwest and turn the inlet channel to the same as its direction (Figure 8a). If the flood water coming from the northern side is stronger caused by much rainfall happens on the catchments of the O Lau and Bo rivers then the jet current will have a tendency of perpendicular to the coast that turns the inlet channel to the northeast direction (Figure 8b).

Outside the ebb delta, the flow direction changes according to the tidal currents in the sea in the along shore direction. Sediment is mainly removed in the channel and the ebb delta and transported to the terminal lobe of the ebb tidal delta where the flow velocity decreases significantly. The bottom erosion and accretion pattern simulated for the Thuan An inlet in the flood November 1999 presents a good agreement with the topographic survey data (Lam, 2006).



a) Southern flood flow dominant | b) Northern flood flow dominant

Figure 8 Influence of river floods on Thuan An channel orientation

3.3. *Wind wave influences*

In the dry season which lasts eight months from January to August, the morphology of the inlets is mainly influenced by the action of waves and tides. The morphological change in the inlet areas then behaves correspondently to the seasonal variation of wave action.

The wave climate observed at Con Co shows that, during the month of September when the southwest monsoon ends and the northeast monsoon starts, the dominant waves may come from NW, NE or SW depending on the domination of which monsoon wind in that period (Figure 9d). In the next months from October to December, the northeast monsoon winds become most active and the dominant waves are mainly from N or NE directions (Figure 9e). The months from September through December are also the period in which typhoons and tropical cyclones operate most actively. Therefore in these months, the sea is quite rough with wave height of about 1.5 – 2.5 m. Waves during the typhoons may be as high as 6 m. But these months are also the flood season when the inlets are dominated by the river flows so the influences of sea waves are mainly restricted to the coasts.

In the end of winter from January through March, the prevailing waves are NW with the significant wave height H_S = 1 – 2 m (Figure 9a). Because the alignment of the coastline is in the NW – SE direction, the magnitude of the south-eastward longshore sediment transport is largest in these months (Figure 10a,b). In this period, just after the inlet channels have been deepened by the river floods and when the river flow diminishes, the channel cross sections become too large and the tides are too weak to remove the sediment entering the inlet channels. The inlets are hungry for the sediment and become the large sediment sinks. These cause the erosion of the adjacent coasts at both sides of the inlets, especially the updrift coasts on the northern sand barriers of the inlets. The evident for this can be seen at the coast of Hai Duong commune located on the north side of the Thuan An inlet. Every year, along 3 km of this coast near the Thuan An inlet, the sand dune is eroded for 15 – 20 m during the winter time. The beach is accreted back 10 – 15 m during the summer months resulting the retreat rate of this beach is approximately 5 m/year (Hoi et al., 2001). Simulation results also show that the southeast monsoon waves in these months gradually move onshore part of the sediment which is transported to the terminal lobe by the river floods to fill in the channel and build up the ebb deltas and the coasts.

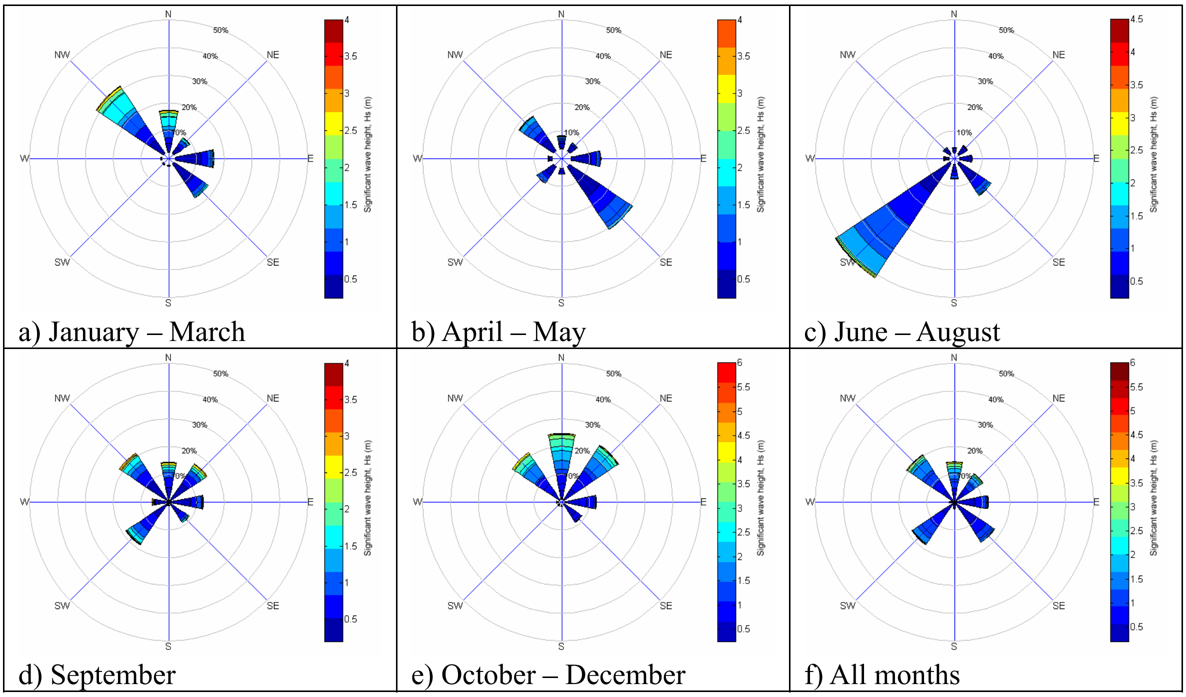
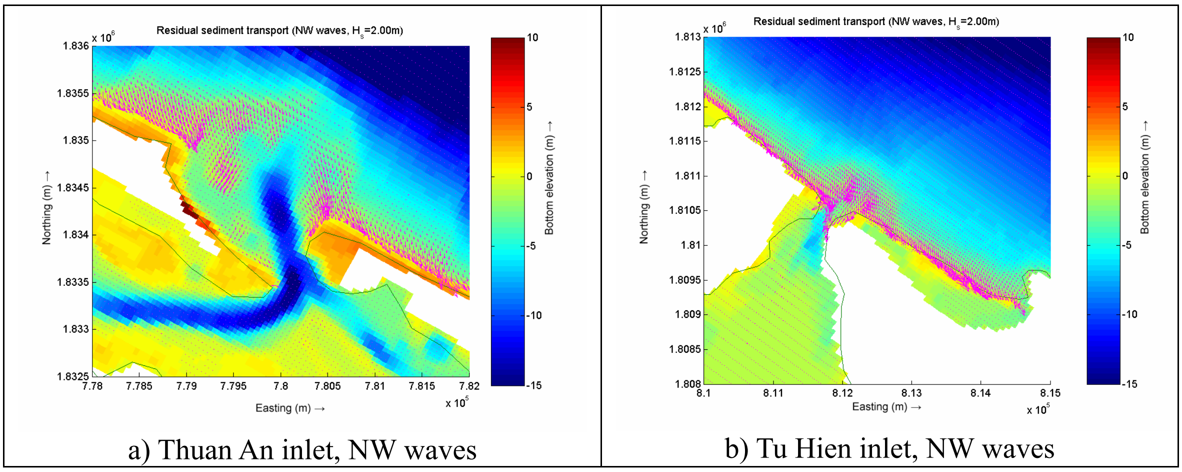
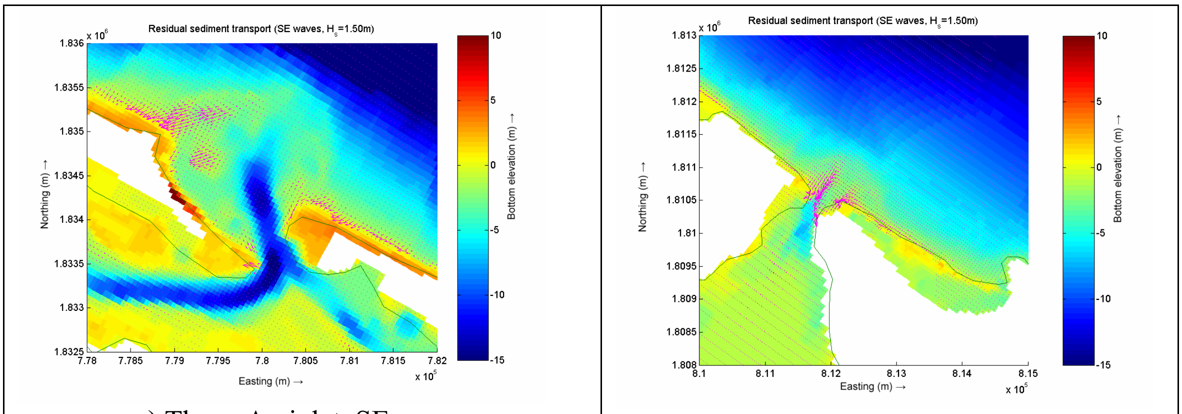


Figure 9 Wave roses at Con Co Island based on 1992-2001 observations

In beginning months of summer from April to May, the sea is rather calm with small dominant SE wave of less than 1 m high (Figure 9b). The combination of the shoreline direction and the wave direction creates the strongest longshore sediment transport in the north-westward direction by the summer monsoon. Because the southern coast of the Tu Hien inlet is blocked by a rocky headland at Loc Thuy so the longshore sediment transported to the inlet is limited (Figure 10c,d). On this coast, the sediment transported by waves is mainly to build up the small sand barrier. During the most active months of the southwest monsoon winds from June to August, the offshore waves at Con Co come dominantly from SW direction (Figure 9c). In the nearshore areas the waves which are mainly swell waves, are quite calm and rework the beaches and the ebb deltas.





c) Thuan An inlet, SE waves

d) Tu Hien inlet, SE waves

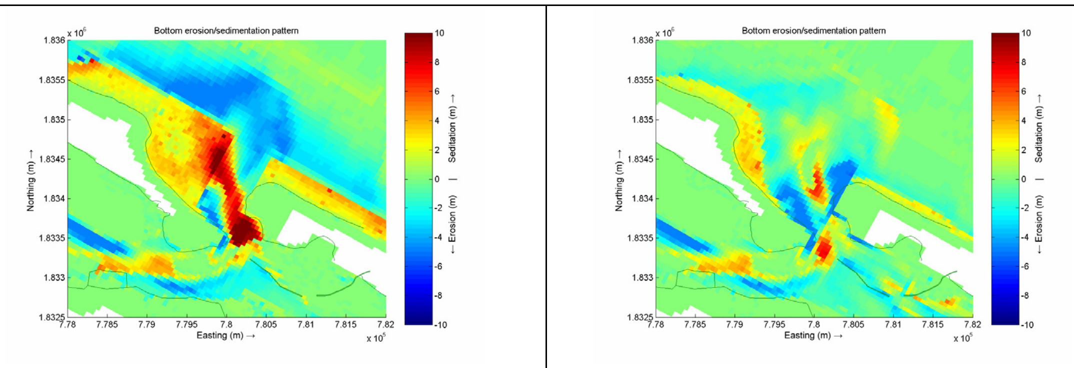
Figure 10 Residual sediment transport in the inlets

Small waves and swell in the summer months rework the sediment and transport it onshore. The beaches are restored by onshore sediment transport. The ebb tidal deltas are moved back and become smaller in size. The tidal channels are filled up and the bars in the deltas develop. These developments continue until the system getting the equilibrium state. If the equilibrium is reached then sand by passing in the ebb deltas and the migration of updrift sand spits and sand bars in the ebb deltas will happen. After some severe river floods it may take the Thuan An nearly 10 years to regain the equilibrium state (Lam, 2005). When it reaches the equilibrium state, the maximum growing speed of the southern sand spit at the Thuan An inlet can be at the order of about 15m/year as has been observed (Hoi et e., 2001).

3.4. *Multiple-inlet influences*

Simulations on the influence of multiple inlet configurations have been carried out. There is a scenario of the third inlet opened at Hoa Duan like it happened in reality during the flood event of November 1999. The simulated morphodynamic results confirm the conclusion made by Lam (2002) based hydrodynamic analysis that the changes in the Thuan An inlet and the open or closure of the Hoa Duan inlet have only small influences on the Tu Hien inlet. There are not much changes in the flow velocity, sediment transport and morphology of the Tu Hien inlet due to the changes at the Thuan An and Hoa Duan inlets. The reason of this can be found by looking at the Thuy Tu lagoon – the connection between the two locations: the Tu Hien inlet and the Thuan An – Hoa Duan inlets. This lagoon is 24 km long but is rather shallow and narrow. It has the average width of 1 km and the mean water depth of 2 m. The southern end of the lagoon is constricted with a system of bars as of the ancient ebb tidal delta. Tidal waves which enter from the inlets dissipate too much energy when approaching to this location.

In contrary, because the Hoa Duan inlet is located just 4 km south of the Thuan An inlet so its presence have much influence on the Thuan An inlet. In a long-term simulation when the Hoa Duan inlet is present, the Thuan An inlet then declines due to the sedimentation in its channel. Its ebb delta is almost disappeared and the beaches are accreted due to wave reworking (Figure 11).



a) with Hoa Duan inlet present | b) with Hoa Duan inlet closed

Figure 11 Influence of Hoa Duan inlet on the erosion/sedimentation pattern at Thuan An inlet

4. Conclusions

With the help of the numerical models, morphodynamics of Hue tidal inlets system has been simulated and described. The numerical models have also helped to overcome the problem of the data availability by using available observations from other locations, interpolated and transferred them numerically into necessary information in the inlet areas. The behaviour of the inlet system under the influence of governing processes such as tides, waves, river flows, and system configuration has been described. For Hue tidal inlets located in a micro-tidal coast and controlled by the tropical monsoon climatic regime, the influences of river flows and ocean waves are important and dominant. The episodic influences of river flow and wave climate follow the tropical monsoon regime and make the tidal inlet morphology also seasonally varying and highly dynamic.

Acknowledgements

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References

Bruun, P., (1968). *Tidal Inlets and Littoral Drift*, Oslo: University Book Company.

Bruun, P., Mehta, A.J., Johnsson, I.G., (1978). *Stability of Tidal Inlets – Theory and Engineering*, Developments In Geotechnical Engineering Vol. 23, Elsevier Scientific Publishing Co., Amsterdam – Oxford – New York.

Bruun, P., (1986). Morphological and Navigational Aspects of Tidal Inlets on Littoral Drift Shores, *Journal of Coastal Research*, Winter Issue.

Eanes, R., and Bettadpur, S. 1995. *The CSR 3.0 Global Ocean Tide Model*. CSR-TM-95-06, Center for Space Research, UT Austin.

Egbert, G. D. and Erofeeva, L., (2002). Efficient inverse modeling of barotropic ocean tides. *Journal of Atmospheric and Oceanic Technolgy*, Vol. 19.

Elwany, M.H.S., Flick, R.E., Aijaz, S., 1998. Opening and closure of a marginal Southern California Lagoon Inlet. *Estuaries* 21 (2), 246-254.

Escoffier, F.F, 1940. The stability of tidal inlets. Shore and Beach, 8(4): 114-115.

FitzGerald, D.M., (2005). Tidal Inlets. In: M. Schwartz (Ed.), *Encyclopedia of Coastal Science*. Springer, Dordrecht. pp. 958-964.

Hoi, T.D., Cu, N.V., and Phu, H.N., (2001) Summary report. *Rehabilitative and adaptive alternatives for the coastal area from Thuan An to Tu Hien and the Tam Giang-Cau Hai lagoon system*, Hanoi.

Huynh, L.B., Thi, N.V., Long, B.D., and Mai, D.T., (1999). *Flood Disaster Study*, Disaster Management Unit, UNDP Project VIE/97/002

Lam, N.T., (2002). A Preliminary Study on Hydrodynamics of the Tam Giang – Cau Hai Lagoon and Tidal Inlet System in Thua Thien-Hue Province, Vietnam. M.Sc. Thesis H.E. 105, IHE, Delft

Lam, N.T., (2005). Simulation of long term morphological development in the Thuan An inlet, *Journal of Water Resources and Environmental Engineering*, Vol. 8, Feb 2005. pp58-62 (in Vietnamese)

Lam, N.T, Stive, M.J.F., Verhagen, H.J., and Wang, Z.B., (2006). Morphodynamic modelling for Thuan An Inlet, Vietnam. *Proceedings of the Second International Conference on Estuaries and Coasts (ICEC-2006)*. Guangzhou, China. 28-30 November 2006.

Lorentz, H.A., 1926. Verslag Staatscommissie Zuiderzee 1918-1926. 's-Gravenhage - Algemene Landsdrukkerij.

Matsumoto, K., T. Takanezawa, and M. Ooe, (2000). Ocean Tide Models Developed by Assimilating TOPEX/POSEIDON Altimeter Data into Hydrodynamical Model: A Global Model and a Regional Model Around Japan, *Journal of Oceanography*, 56, 567-581.

O'Brien, M.P., 1931, Estuary Tidal Prisms Related to Entrance Areas, *Civil Engineering*, 1(8), pp 738-739.

Ranasinghe, R. and Pattiaratchi, C., (1999). The seasonal closure of tidal inlets: Wilson Inlet--a case study. *Coastal Engineering*, 37(1): 37-56

Ray, R.,1999. *A global ocean tide model from Topex/Poseidon altimetry: GOT99.2*, NASA Tech Memo 209478, 58 pages.

Roelvink, J.A., (2006). Coastal morphodynamic evolution techniques. *Coastal Engineering*, 53(2-3): 277-287.

Schrama, E.J.O. and Ray, R.,1994. A preliminary tidal analysis of OPEX/POSEIDON altimetry. *Journal of Geophysical Research*, v99-24, 24799.

Schwartz, M.L. (Editor), (1973). Barrier Islands. *Benchmark Papers in Geology* 9. Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pa., 451 pp.

Tanaka, H., Lee, H.-S., 2001 Relationship between river mouth morphology and wave set-up height at Shiribetsu River, Japan. *Proceedings of the 2nd IAHR Symposium of River Coastal and Estuarine Morphodynamics*, Obihiro, Japan, pp. 495-504.

Thanh, T.D., Cu, N.H., Huan, P.V., Huy, D.V. and Lan, T.D., (2000). Theme Report "The evolutionary processes and the dynamics of the Tam Giang–Cau Hai lagoon", *Rehabilitative and adaptive alternatives for the coastal area from Thuan An to Tu Hien and the Tam Giang-Cau Hai lagoon system*, Hanoi.

Tuan, N.D. et al., (2001). Theme Report "Floods and Numerical Models", *Rehabilitative and adaptive alternatives for the coastal area from Thuan An to Tu Hien and the Tam Giang-Cau Hai lagoon system*, Hanoi.

WL | Delft Hydraulics, (2006). Delft3D-FLOW User Manual Version 3.13, Delft.