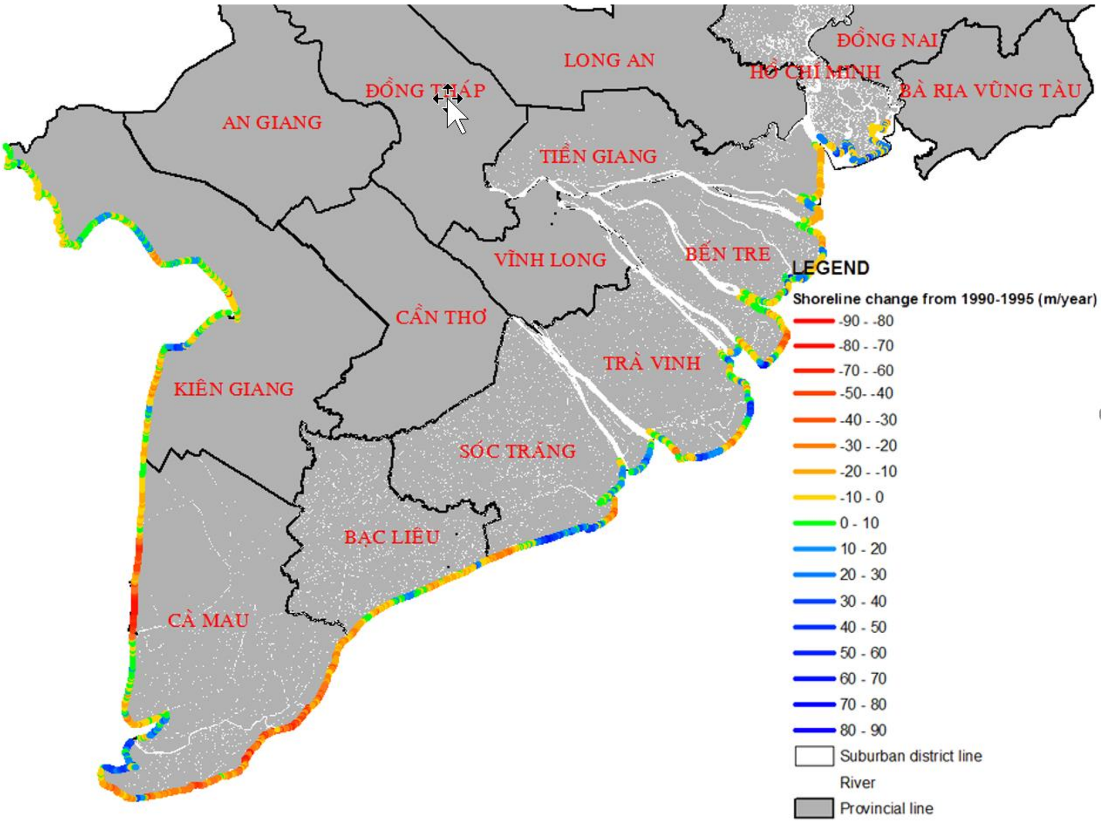
AGENCE FRANÇAISE DE DÉVELOPPEMENT (AFD) & EUROPEAN UNION (EU)
SOUTHERN INSTITUTE OF WATER RESOURCES RESEARCH (SIWRR)

Contract No: AFD-SIWRR 2016

PROJECT
"Erosion processes in the Lower Mekong Delta Coastal Zones (LMDCZ) and measures for protecting Go-Cong and U-Minh from coastal erosion"

FINAL IMPLEMENTATION REPORT



Ho Chi Minh City – January 2018

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FINAL IMPLEMENTATION REPORT

Team Leader **Dr. Patrick. Marchesiello**

Coordinator **Dr. Dinh Cong San**

SIWRR DIRECTOR

Dr. Tran Ba Hoang

1. Summary and context of the Action

The Lower Mekong Delta Coastal Zone (LMDCZ) is emblematic of the coastal erosion problem in tropical delta regions. It is strongly influenced by very large sedimentary fluxes reaching the ocean (about 50 million tons per year), but also by waves and currents, which, in combination, redistribute the river intake to the southwest. This process has formed the Ca Mau peninsula for the last 3500 years. But now, in addition to natural forces, the LMDCZ is affected by local human activity, including possible reduction of river fluxes due to damming and sand mining, as well as a reduction of protective coastal mangroves in favor of agriculture and aquaculture. Coastal erosion is observed in many places, with a rate of up to 50 m per year in some areas. Global warming is not a factor in the current situation because its impact remains low in the face of tectonic subsidence (4 and 16 mm/y for eustatic and isostatic variations respectively), due to groundwater depletion, but the expected increase in sea level will undoubtedly contribute to its aggravation.

The LMD has prograded for thousands of years during the Holocene, advancing southeastward following the river flow direction (16 m/y) and southwestward even faster due to redistribution by coastal currents (26 m/y). However since the middle of the 20th century, progradation has shown signs of weakening, while land use is accelerating. It should be noted that the general tendency of the system is not a settled matter. From satellite investigations of shoreline change rates, the general tendency for the whole LMDCZ is not so clear and shows large interannual variations. However, the system can be separated into subregions of common dynamics, which have a much clearer signature in their evolution. Within these subregions, local processes can also occur. Erosion can thus occur in generally accretive zones, and we will see that it may be the case for our study sites (Phu Tan and Go Cong). Clearly, regional and local scales need to be distinguished as they hold different types of processes.

The objectives of the LMDCZ Project are:

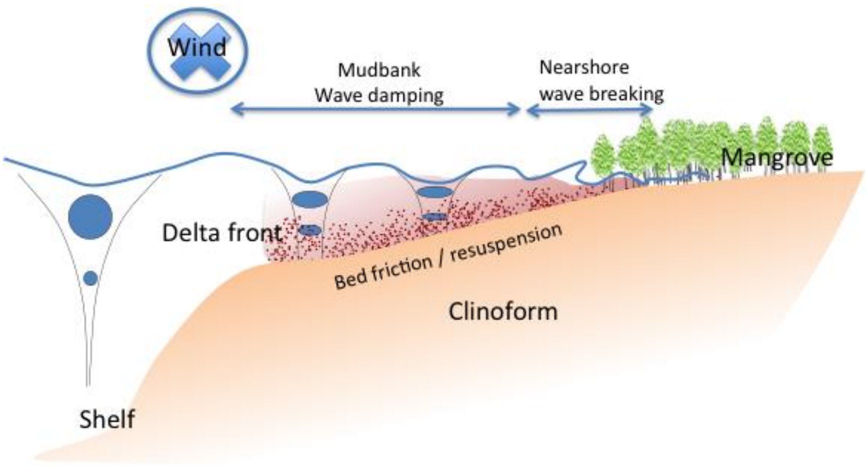
- Understanding the mechanisms responsible for the erosion/accretion process of the LMDCZ, particularly in Go-Cong and U-Minh, and determining the main causes responsible for this erosion process;
- Determining the integrated measures to sustainably protect the Go-Cong and U-Minh coastal zones from erosion while preserving the natural coastal landscape;
- Building a solid scientific basis for Integrated Coastal Zone Management (ICZM) of LMD in the future.

In this project, we provide arguments to separate local from regional phenomena and natural redistribution by currents from actual remote deficit of sediment supply. This investigation is first conducted at regional scale to assess system-wide sediment budgets using in-situ (WP1) and remote observations (WP3), combined with regional numerical modeling (WP2). We then assess the local sediment budgets in two selected sites: Go Cong (Tieng Giang Province) and Phu Tan (West coast of Ca Mau Province). Based on regional and local sediment budget understanding, we test soft and hard measures of protection using the SIWRR plume (physical model) and local numerical models. Model assessments are also confronted to on-site observation and remote sensing of actual protection measures implemented along the LMDCZ (particularly U Minh and Go Cong). All these elements will be finally assembled to provide the necessary arguments to propose protection measures in the selected sites.

The team assembled to carry out the investigation is composed of Vietnamese units with large experience of the Mekong delta region and international experts on coastal dynamics. The study has a particular focus on erosion processes, as opposed to many previous studies that were more focused on monitoring. Therefore, modeling has an important role although the project also utilizes a large set of observational tools to complement our general knowledge and validate the models, from in-situ to satellite observations and coastal video cameras in Go Cong. Laboratory studies are also used for analyzing sediment behavior (CARE lab) and to test protection measures (SIWRR plume).

Erosion processes

Based on observations and model solutions, we revisited some of the important processes of erosion. In some cases, we contributed important results to previous studies, and in others, we reviewed the current state of knowledge.



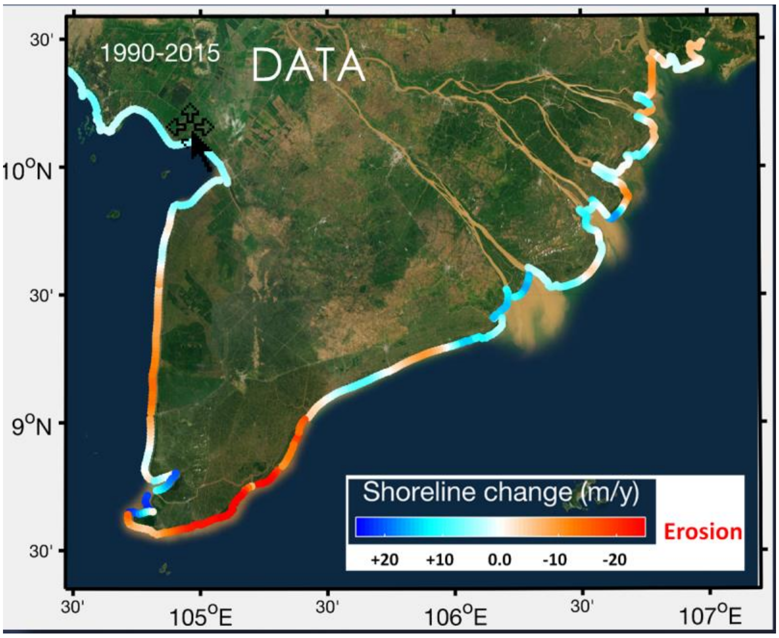
Schematic view of coastal regions and main driving forces in the LMDCZ

Natural redistribution

Deltas are coupled hydro-morphodynamic systems, which are generally unstable and vary following cycles of advance and retreat with time-scales from intra-seasonal to multi-decadal (Winterwerp, 2005). These natural processes certainly explain part of observed erosion in the LMDCZ. In Europe, almost all mudflats are in estuaries or tidal inlets, mainly because the exposure to waves on the open coast is too great to allow any significant amount of mud to accumulate (Roberts et al., 2000). In the tropical zone, there are situations where open coast mudflats exist. These are usually associated with areas having a very large fluvial source of muddy sediments, e.g., the Mekong delta system. In this case, mud and sand are transferred from the river to the coastal zone, but the displacement of mud is much faster than that of sand, so that mud keeps accumulating in southern shores, forming the Ca Mau peninsula. Western shores of the peninsula are less exposed from waves than eastern muddy shores and thus naturally experience less erosive attacks.

Owing to the project results, the regional picture of sediment transport and budget is now substantially improved. It is based on an ensemble of data from in-situ and satellite observation, laboratory analysis and modeling. These comparisons allows us to estimate the part of shoreline changes that results from a natural redistribution of sediments by waves and currents, and the part from other sources (river supply deficit, coastal squeeze, subsidence…). We find that our models can reproduce essential regional patterns of erosion and deposition, featuring three dynamically consistent coastal zones: Estuary zone, East coast and West coast. These patterns thus appear to be largely a result of redistribution processes by waves and currents. The largest subregional erosion is in the southern shores of Ca Mau.

It is important to note that our numerical models suggest erosion to be primarily a result of wave-driven re-suspension and wind-driven transport occurring over a particularly shallow clinoform[1] along the LMDCZ (about 10-km wide across-shore), rather than strictly over the nearshore zone (less than 1 km). Therefore, simpler nearshore models, which only deal with wave-driven longshore drift, cannot explain the observed regional phenomenon. These so-called one-line models or associated paradigm of littoral dynamics (e.g., Albers et al, 2013) were sometimes applied to the LMDCZ; they are inherited from sandy littoral applications where they provide reliable answers, but shallow muddy environments have different dynamics. Our study provided a better-suited paradigm for LMDCZ processes.



Map of shoreline change rates in m/y estimated from satellite images. Red/blue colors are erosive/accretive shores.

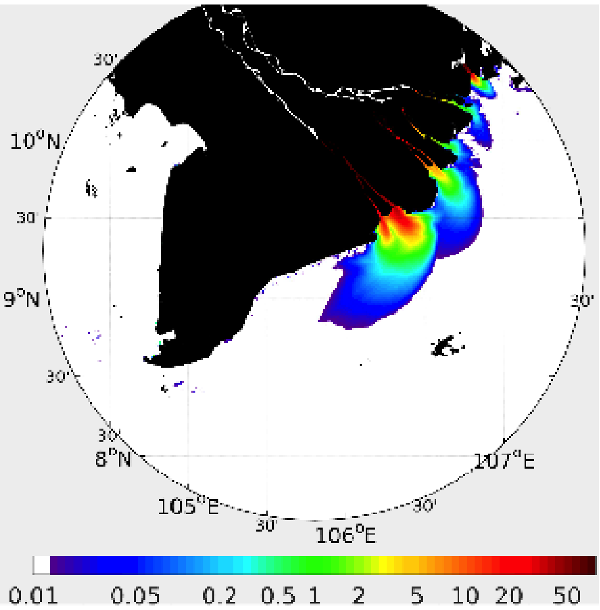
However, looking more closely (particularly in our two study sites), we notice that some patterns cannot be explained by natural redistribution of subaqueous sediments. For example, the models do not predict the recently observed strong erosion at U-Minh and the fact that our bathymetry survey shows little erosion in waters deeper than 2 m suggests that other processes might be involved, including subsidence and/or coastal squeeze. On the contrary, the Go Cong area shows the most consistent erosion of the whole Estuary zone (seen both in satellite-based shoreline analysis and comparison of bathymetric surveys at a 6-year interval). A likely candidate for that severe erosion is a deficit in river supply from the Saigon-Dong-Nai River, upstream from Go Cong (see below).

Sediment river supply

[1] Here, we may use indifferently the words mudbank or clinoform to describe the total wedge-shaped package of sediments contained in the subaqueous-delta deposits. Subaqueous clinoforms serve as the marine foundation for subaerial delta progradation. In the Mekong delta, the transition between the broad clinoform topset and steeper foreset is located at about 5 m depth (rollover depth), much shallower than in many large-river deltas (Eidam et al., 2017).

Because sediment river supply is the source of delta progradation, a decrease of this supply would certainly affect the delta's morphology. One objective of the project was to try and estimate the tendency of sediment input into the coastal ocean. Our estimation of sediment flux in the lower Mekong River**Error! Bookmark not defined.** is on the lower end of previous estimates. Whether this is the expression of a real change or a bias due to low-frequency data used in historical studies, it is hard to conclude**.** The scarcity of in-situ data still precludes us from accurately assessing this tendency. Yet, we can provide answers by indirect methods (through satellite observation and model testing). From our model results, a decrease of river supply about 100km upstream has a rapid decay downstream with significant impact only in the estuary and mouth area (where a fraction of the signal is left). This is consistent with recent observations of sedimentation rates, showing a majority of deposition near the river mouths (DeMaster et al., 2017). Therefore, if sediment is missing from the river, it should first be seen in the estuary zone.

In this sense, the observation by Loisel et al. (2014) of a decrease of suspended particulate concentration off the coast beyond the delta front seems improbably related to the river supply issue. It may take a long time for a sediment deficit originating thousands of kilometers upstream to affect the mouth area. This is due to a compensation process called "hungry waters", in which sediment-depleted waters tend to stimulate erosion as a compensation mechanism (Kondolf, 1997). This process still needs further evaluation for quantification with dedicated projects and data collection. Similarly, current knowledge of the Mekong River sediment fluxes does not help us yet confirm a tendency between pre-dam and post-dam periods (Lu et al., 2006). There is no tendency either during the last decade, based on our own investigation from data collected in My Thuan and Can Tho. Then, and for the same reason of compensation, it would again take a long time for a decrease signal to propagate from the estuary zones to more remote coastal areas such as the West coast of Ca Mau (see also Winterwerp, 2005, for similar conclusions for the gulf of Thailand).



Model sensitivity of coastal surface sediment concentration to river supply. The difference of SSC in mg/l is between two simulations with upstream river SSC fixed at 200 mg/l and 50 mg/l.

Yet, our results also suggest that extreme erosion in Go Cong is likely a result of sediment supply deficit, but from the Saigon-Dong Nai river system rather than the Mekong River. Here follows another novel proposition, which surprisingly was not put forward before. If Go Cong has such a singular behavior in the Estuary zone (which is in general still accretive), it is likely because it is under direct influence of the Saigon Dong Nai river system. Massive dams and reservoirs were built in the 1980s and 1990s: Dau Tieng dam in the Saigon river operated in 1984 and Tri An dam in the Dong Nai river operated in 1991. These dams would modify sediment supply to the coastal zone much faster than those of the Mekong system. Therefore, we need to study more closely the possibility that erosion in Go Cong may result from these dams. **If it were confirmed, then the Go Cong coastal area would be a predictor of the**

Mekong system. It is a relatively small-scale real-world laboratory that will help predict what will probably be the effect of Mekong dams on the LMDCZ.

Coastal mangrove squeeze

A well-known problem in coastal zones is the squeeze of coastal habitats before a dyke, a road or any structure parallel to coastline. Coastal mangrove squeeze is a particular case of coastal squeeze that has been identified as a serious issue for the LMDCZ (Winterwerp, 2013; Phan et al., 2015) because dykes were built all around very close to the shoreline (often less than 500m). Phan et al. (2015) estimated that a critical mangrove width of at least 500m is needed around the LMDCZ to sustain the coastal mangrove belt. Loss of these coastal mangroves is detrimental to shoreline protection because mangroves are a natural protection, i.e., buffer zones acting as barriers to wave energy and in the same time helping nearshore sediment trapping. But, there are still doubts about the correlation between mangrove belt width and its sustainability, which we investigated in this project.

Our study confirms previous findings but with a slightly more complex picture. **A minimum size of mangrove belt of 500-800 m appears as necessary but not sufficient condition for sustainability**. For example, the southern Ca Mau province is so naturally exposed to erosion that no amount of mangrove can stop erosion there. The same may probably be true for Go Cong. On the other hand, the west coast of Ca Mau would more fully profit from mangrove restoration. In erosion-prone areas, the addition of bamboo/melaleuca fences appears as a very efficient complement to mangrove planting, as it promotes sedimentation by flocculation and settling in calmer water.

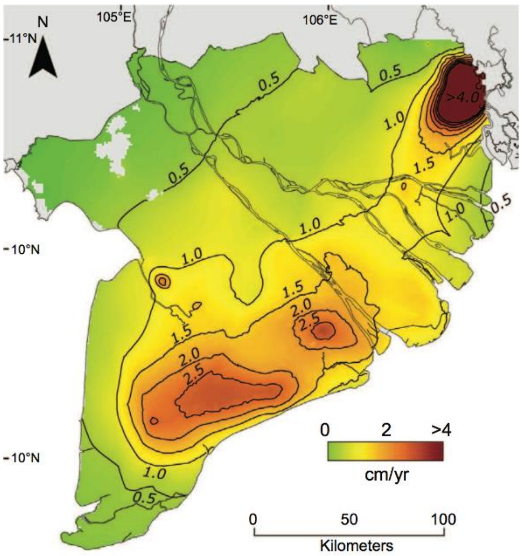
Onshore flow blocking

The cross-shore profiles of mudflats can be classified according to the relative contributions made by waves and tidal currents to the total sediment transport. Traditionally, we see at one end of the range erosional flats dominated by waves, which are characterized by a concave profile; at the other end are tidally dominated flats with a convex profile, which are believed to have a long-term tendency to accrete. Cross-shore tidal flow promotes onshore sediment transport and accretion while waves tend to produce erosion (Le Hir et al., 2000), although there are also wave processes (gravity and infragravity waves) associated with onshore transport (not yet well understood and handled by models, especially for muddy environments). Even though the amount of water flowing towards the coast during rising tides equals that flowing off the coast during falling tide, a net onshore sediment transport is explained by a number of asymmetries in the water movement (tidal asymmetry) and sediment behavior (settling and scour lag; van Straaten, and Kuenen, 1958). Onshore winds can also participate in coastal sediment accretion. The Ekman drift is a process that tends to carry water properties to the right of the wind (less so in shallow water). During winter, northeastern monsoon winds thus provide some ways of accumulating sediments to shore.

In any case, constructing dykes or breakwaters parallel to shore can block the onshore water flux (tidal prism; e.g., Winterwerp, 2013) and associated onshore sediment flux, not only near the wall but also over long distances seaward from it. Our model results seem to confirm the role of tides in onshore sedimentation. Therefore, wherever possible, a submerged or porous barrier would be preferred. The final answer is in the trade-off between reducing detrimental high-energy waves and blocking beneficial currents. Where erosion is severe and waves are high, such as in Go Cong, damping waves is a priority.

Subsidence and sea level rise

Global warming might be significant in the current situation because its impact remains low in the face of tectonic subsidence (1.6 cm/y in average for the LMD and up to 5 cm/y locally**Error! Bookmark not defined.**), due to groundwater depletion, but the expected increase in sea level will undoubtedly contribute to its aggravation in the future. Subsidence is not part of the present study as it involves very different techniques of investigation and would represent an entire new project. However, in present literature, this process is considered a serious risk for flood and shoreline retreat, which should be better evaluated in the future. Right now, subsidence may account for about **10 m/yr** of shoreline retreat along the LMDCZ (based on a foreshore slope of 1/1000), although it has large regional variations and appears to be particularly strong on Vietnam's west coast, i.e. away from the Mekong floodplains. Some of the erosion seen at U-Minh in recent years can possibly be explain by subsidence. It would be consistent with a stable offshore bathymetry, as suggested by our survey.



Anthropogenic subsidence rates from Minderhoud et al. (2017)

Synthesis for Go Cong and Phu Tan

	Shoreline retreat	Subsidence contribution	River supply deficit	Dynamic redistribution	Mangrove squeeze
GO CONG	15 m/y	< 5m/y	**Large sensitivity to Soai Rap river**	Erosive (export south)	NA
PHU TAN	5 m/y	**< 5m/y**	Small	Neutral or accretive (from south)	**Probable**

2. Description of the implemented activities

A- Activities and deliverables

Started from September 2016, the LMDCZ Project has achieved objectives and deliverables, a large part of it are reported in Final Report. For detail, the deliverables are presented in 6 WPs reports. Some evolution and changes were made during the project. These were justified sometimes by the need to clarify issues emerging or, on the contrary, by a need to refocus our efforts on the project's main objectives. This was necessary in the face of difficulties encountered during implementation (e.g., change of team on video cameras) and delays (contracts and payments, etc.). Some tasks were canceled or delayed until the completion of a final report (e.g., "lock-exchange" test case and MIKE-3D modeling), but, more importantly, these activities will not affect the final results, as the main tasks are virtually unchanged. Table 2-1 shows the list of tasks and deliverables.

Table 2-1 List of implemented activities during the reporting period

	Working Package, Tasks and Deliverables	In the Report of
WP1	**Data Collection & In situ measurements**	
T1.1	***Data Collection & Database (Bathymetry, hydro-meteorology, tides, beach geotechnical data, satellite data)***	
D1.1	List of the collected data	WP5-WP6 reports
D1.2	DEM for LMDCZ (scale at 1/2000 for the studied domain and 1/10000 for the local domain, 1/100000 for the regional domain	WP5-WP6 reports
T1.2	**In-situ Measurements**	
D1.3	Reports on the bathymetry survey	WP1_Report LMDCZ Survey Campain
D1.4	Reports on the field surveys (1st and 2nd)	WP1_Report LMDCZ Survey Campain
D1.5	Complete database for the LMDCZ	Available at SIWRR
D1.6	Methodology for estimating SSC by ADCP	WP1_Report _ADCP training
WP2	**3D modelling for coastal flows and sediment transport in the LMDCZ (regional scale)**	
T2.1	***Sediment data collection for model calibration/validation***	
D2.1	Report on SPM satellite data	WP2_Report_Sattelite SPM
	Data collection from previous surveys: VITEL project (June 2014); European CUU-LONG Project (1997-1999);	WP2_Report_Sattelite SPM Hard Copy
D2.2	Report on sediment properties dedicated to LMDCZ modeling	WP3_ Report River Sediment Properties
T2.2	***3D flow computation – Flow structure in ROFI of the LMDCZ***	
D2.3	Report on the computation of 3D coastal flows in the LMDCZ	WP2 _Report_3Dmodeling_CROCO; WP2_Mekong_Delft3d-ver2
D2.4	Report on the computation of 3D sediment transport in the LMDCZ	WP2 _Report_3Dmodeling_CROCO; WP2_Mekong_Delft3d-ver2
T2.3	***Sediment transport computation & Sediment budget in the LMDCZ***	
D2.5	Reports on the sediment budget in the LMDCZ	WP2 _Report_3Dmodeling_CROCO; WP2_Mekong_Delft3d-ver2
WP3	**In-situ and Laboratory studies on erosion process**	
T3.1	***River sediment flux analysis***	
D3.1	Report on sediment flux analysis	WP3_Report River sediment flux analysis
T3.1	***Satellite observation***	
D3.2	Report on LMDCZ morphological change analysis	WP3_Report Shoreline Change
T3.2	***Coastal video camera observation***	
	Installation of video cameras at Go Cong site	WP3_Report Video Analysis

	Working Package, Tasks and Deliverables	In the Report of
	Installation of video cameras at Phu Tan site	Canceled (due to the local conditions)
	Video camera image correction and processing	WP3_Report Video Analysis
D3.3	Report on camera systems monitoring	WP3_Report Video Analysis
D3.4	Map for location of sampling station	WP1_Report LMDCZ Survey Campain
D3.5	Maps of morphological change of LMDCZ issued from analysis approa	WP3_Report Shoreline Change
WP4	**2D computation of waves and coastal currents**	
T4.1	***Wave climate simulation at regional and local scales (TOMAWAC and MIKE 21 SW)***	
T4.2	***2D coastal circulation modeling at regional and local scales***	
D4.1	Model configurations	WP4_ Report Wave Climate; WP4_Report Regional_hydro_Telemac WP4_Report Regional_Local_MIKE
D4.2	Validation of tides, waves and currents	
D4.3	Tidal water elevation, wave field and current fields in the local domain	
D4.4	Radiation stress tensor fields for the local and studied domains	
D4.5	Reports on tides, waves and currents in the studied domains	
WP5	**Sediment transport and LMD morphological change modelling**	
T5.1	***Sediment transport modeling in the study sites (TELEMAC+SYSIPHE, MIKE 21 MT)***	
D5.1	Report on simulations of sediment transport and budgets in the coastal zone of Go-Cong (including sensitivity to sediment supply)	WP5_Report Regional_sediment_Telemac WP5_Report_GoCong_MIKE
D5.2	Report on simulations of sediment transport and budgets in the coastal zones of Phu Tan	WP5_Report Local_sediment_U Minh_Telemac
T5.2	***Understanding LMDCZ morphological changes and erosion processes by analyzing experimental and numerical results with focus on the coastal zones of Go-Cong and Phu Tan***	
D5.3	Report on the understanding of morphological changes of the coastal zones of Go-Cong and Phu-Tan, and on identification of the main causes of erosion/accretion	WP5_Report_GoCong_MIKE WP5_Report Local_sediment_U Minh_Telemac
WP6	**Shoreline protection measures**	
T6.1	***Identifying soft and hard measures for protecting the study sites from erosion***	
D6.1	Report on the identified protection measures and associated scenarios	
T6.2	***Physical models for selecting the best configuration of protection measures***	
	T6.3.1. Test in laboratory channel	
	T6.3.2. Test in laboratory basin	**Canceled**
D6.2	Report on physical model results and recommendation	WP6_Report laboratory protection measures
T6.3	***Testing shoreline protection measures from 2D numerical models of the study sites***	
D6.3	Report on numerical testing of selected protection measures for the study sites	WP6_TELEMAC_GOCONG WP6_GoCong_MIKE WP6_Report_PhuTan_MIKE

	Working Package, Tasks and Deliverables	In the Report of
		WP6-19-1-2018
T6.4	***Impacts of selected coastal protection measures to neighboring coastal zones***	
T6.5	***Assessing the selected shoreline protection measures***	
D6.5	Report on assessment of protection measures and recommendation	WP6-19-1-2018
	The first workshop	*done*
	The second workshop	*done*
	The final workshop	*Done – The minutes of Final workshop*

B. Organizational structure of the project and updated list of experts

B.1 Organizational structure

For implementation of LMDCZ Project, organizational structure was made as shown in Figure 2-1.

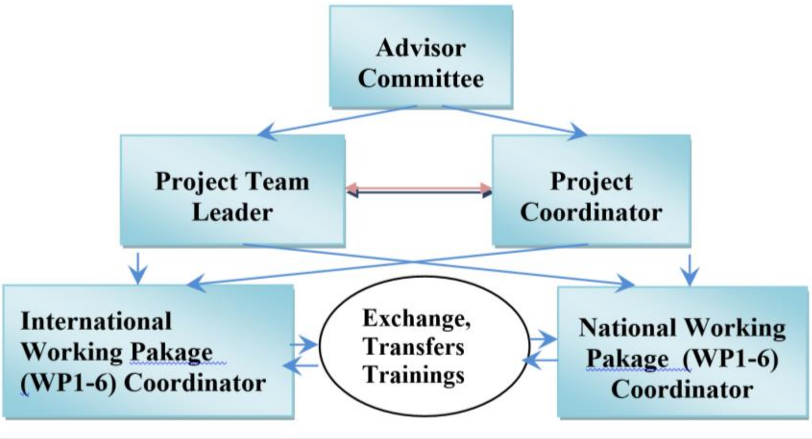


Figure 2-1 Organization of LMDCZ Project

The project was supervized by an Advisory Committee (AC), which was composed of: AFD and its consultant, a SIWRR's representative and two representatives from the People's Committee of Tien-Giang and Ca-Mau Provinces.

The AC has is set up to:
- Define the orientations of the different activities.
- Coordinate the different activities.
- Verify the correct implementation of the project
- Monitor the quality of scientific results
- Advise the Team Leader in decisions relevant to research activities
- Evaluate progress, final reports and findings.

The Project Team Leader:
- Responsible for the quality and the deliverables of the Project.
- Supervision of progress and final reports of each WP.
- Redaction of the progress and final reports of the project as a whole.

The Project Coordinator:

- Coordination with Team Leader and WP Coordinators for all activities of the project.
- Responsibility for the organisation of Workshops, Financial reports, Training courses and dissemination of Project outcomes.

The International Work Package (WP1-6) Coordinators:

- Transfer of advanced knowledge and technologies to Vietnamese colleagues under forms of training courses and experience exchanges.
- Responsible for quality and deliverables of WPi.
- Lead the redaction of the reports in WPi.

National Work Package Coordinators:

- Cooperate with International WP coordinators, Project coordinator and Team Leader for the implementation of WP.
- Supervise all activities of the Vietnamese colleagues in WP.
- Write reports for his WP.

B.2 Updated list of experts with tasks assigned

Due to delays in the project implementation (see section 4) some national and international experts (Prof. H. Tanaka, Dr Nguyen Trung Viet, Dr Damien Pham Van Bang) became no longer available. SIWRR recruited new qualified experts to replace departing ones without cost increase. However, SIWRR have adjusted some of the tasks and budget allocated to the national and international experts (Form Tech 4 of the Contract No. AFD-SIWRR 2016):

- Dr Vo Khac Tri replaced Dr Nguyen Trung Viet for all activities related to video camera installation and images analysis. He was also appointed to be WP3 National Coordinator with the support of Dr. Yves Soufflet and Mr. Clement Mayet. Dr Tri and his team needed training as they had no prior specific experience with coastal video cameras.
- Dr Yves SOUFFLET and Mr Clément MAYET replaced Prof. H. Tanaka in video camera analysis. They also provided a training course to the SIWRR team for installation, configuration and setup, geographical rectification, image processing and analysis.
- Prof. Thieu Quang Tuan with the support of Prof. Holger Schüttrumpf took over from Dr Damien Pham Van Bang. He is responsible for the test of protection measures with SIWRR physical model (flume).
- Prof. Edward Anthony was invited as an international expert to our technical workshop of April 12-14. He has outstanding expertise in the geomorphology of delta system, particularly erosion of the LMDCZ (see for example his article published in Nature in October 2015). His participation to the workshop was an asset to the project by strengthening the discussion and comforting the orientations of the other experts concerning the proposed protection measures. This invitation was financed by the project within available budget resources.
- Dr Dang Thi Ha from School of Maritime Economics and Technology – Vung Tau University and her group were recruised to carry out the main task of Dr. OUILLON Sylvain (as the agreement of OUILLON Sylvain) "Task 2.2 River sediment flux analysis". She also did the same task for Hoi An project.
- The experts of Insitute of Ecology and Works Protection (WIP) were recruised to carry out the "Restoration of mangrove belts near the coast of the studied sites for Identifying mangrove kinds that will be most adapted in the studied sites; and Selecting the technique for a best implantation of mangroves" instead of Dr GRATIOT Nicolas. The reason was

that Dr Nicolas had no experiences in Mangrove Rehabilitation but WIP had dealed with many Mangrove Rehabilitation projects in the LMDCZ.

- As requested by AFD (the discussion held between Ms Sandra Rullier and Project Team Leader, Mr. Patrick Marchesiello), the Project will be reviewed by independent reviewers as follows:

  + Prof. Dr.-Ing. Hocine Oumeraci who works in Department of Hydromechanics and Coastal Engineering - Leichtweiß-Institute for Hydraulic Engineering and Water Resources (https://www.tu-braunschweig.de/lwi/hyku/mitarbeiter/profdroumeraci).

  + Dr Stefan Groenewold, Technical Advisor Integrated Coastal Management Programme Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Vietnam.

These updates are listed and tasks are expressed in Table A.1, A.2 and A.3 in Appendix A.

3. Actual results

In this section, we describe the activities in each work package and summarize the results obtained in more details. This progress report has no final recommendation, but essential findings are exposed in a synthetic way. But before looking at each WP, we can summarize the main findings that this work has provided.

The regional picture of sediment transport and budget is now more robust. It is based on an ensemble of data from in-situ and satellite observation, lab analysis and modeling and in-situ data from this project. These comparisons allowed us to estimate the part of shoreline changes that result from a natural redistribution of sediments by waves and currents, and from other sources (river supply deficit, coastal squeeze, subsidence…). Surprisingly enough, we find that our regional models can reproduce the essential regional patterns of erosion and deposition, with three dynamically consistent coastal zones: Estuary zone, East coast and West coast. These patterns thus appear to be largely a result of redistribution processes by waves and currents (the regional models have no processes of human impact).

However, looking more closely, particularly in our two study sites, we noticed that some patterns cannot be explained that way. For example, the models do not predict the strong erosion in U-Minh and the fact, that the bathymetry survey shows little erosion in waters deeper than 2 m, suggests that other processes might be involved, including subsidence and/or coastal squeeze. On the contrary, the Go Cong area shows the most consistent erosion of the Estuary zone (seen both in satellite-based shoreline analysis and comparison of bathymetric surveys at 6 years interval). A likely candidate for that extreme erosion is a deficit in river supply from the upstream of Go Cong.

Here follows another novel proposition, which surprisingly was not put forward before. If Go Cong has such a singular behavior in the Estuary zone (which is in general still accretive), it is likely because it is under direct influence of the Sai Gon-Dong Nai river system rather than the Mekong. Different dams were built in the 1980s and 1990s (Dau Tieng dam in the Saigon river operated in 1984 and Tri An dam in the Dong Nai river operated in 1991). These dams would modify sediment supply to the coastal zone much faster than the dams of the Mekong system. Therefore, we need to study more closely the possibility that the erosion in Go Cong may result from these dams.

If U-Minh shows erosion, Phu Tan, our study site on the West coast, appears mostly as an accretive zone, receiving sediments from the eroding East Coast. Yet, local zones of erosions are a concern. Anyway, the case of Phu Tan is different from U-Minh and even more so from Go Cong. The SIWRR physical model was used extensively to test hard and soft protection measures (i.e., porous breakwaters and nourished sandbars). Local numerical studies and analysis of recent observations will allow us to conclude. For details on by WP results, see below.

WP1: Data collection and in-situ measurements

Bathymetry Survey (report delivered)

The bathymetry survey was done along the study sites in Go Cong and Phu tan district areas. Bathymetry was measured from the prodelta region to nearshore but was limited to a maximum depth of 2 m, as shallower waters were not accessible by boat. Bathymetry profiles were compared with previous bathymetry surveys by MONRE, which gave us a measure of erosion as seen on the delta front rather than the shoreline. It confirms the large erosion in Go Cong that extends far offshore over the whole mudflat (concave shape). On the other hand, Phu Tan does not show any sign of erosion at least up to 2 m depth, anywhere along the district. If there is local erosion there, then it must be a very shallow process, not related to large-scale alongshore transport (see WP2).

Field surveys for hydrodynamics and sediment concentration data (reports delivered)

2 field surveys were conducted. The first campaign took place in October 2016 when the sediment plume extension of the Mekong estuaries is farthest offshore in the East Sea. That is also the end of the southwest monsoon season when coastal areas of the West Sea are impacted by erosion. The second campaign was in February 2017 – at the peak of the northeast monsoon, which causes severe coastal erosion in the East Sea.

The survey included fixed river and coastal stations and coastal cruises:

- 2 fixed river stations in Mekong (My Thuan) and Bassac (Can Tho) rivers, which coincided with National Hydrology Stations. It provided river discharges (Q) and suspended sediment concentration (SSC) by ADCP. These data were used to force the models.
- 2 fixed coastal stations at Go Cong and U-Minh.
- Marine sampling stations from 2 mobile ships cruising along the East and West seas.

Measured fields at the coastal stations are:
- Water level (hourly at the 2 fixed stations)
- Vertical distribution of velocity
- Vertical distribution of salinity (5 points for each vertical line)
- Vertical distribution of sediments (5 points for each vertical line)
- Waves (height, period and direction)

These data were used particularly for the calibration of the local high-resolution models. For the regional models, satellite imaging specifically processed for this project were used in priority because it provides statistical reliability and synopticity (spatial patterns are coherent, see WP2).

In addition, when checking the possibily of SSC through the concrete pile breakwaters in the West coat of Ca Mau, during the observation, SIWRR team reconized that the SSC in the area were much higher in the nearshore area. Then 2 additional field surveys were conducted to measure the SSC from the shoreline to about 2 km offshore. Analysis results showed that SSC in the SW monsoon at Ca Mau from about 2 km offshore were very high (300 ÷800 mg/l) in comparison to SSC from two survey campaigns of LMDCZ project and other satellite images. There are only a few data in the SW monsoon of 2017 and more data is needed in the near shore area to understand the SSC in the SW monsoon. The same issue is for the NE monsoon in the coastal zone of the East Sea.

WP2: 3D modeling of sediment budget in the LMDCZ (regional scale)

Satellite imaging (report delivered)

Due to high variability of physical and biogeochemical processes in the coastal ocean, traditional approaches based on oceanographic ship surveys and in situ time series, although essential, are time- consuming, expensive and maybe more importantly here of limited use for synoptic patterns. Remote sensing on the other hand is a powerful mean of capturing synoptic or climatological patterns, which is essential to calibrate and validate regional patterns in models. In situ data, such as those gathered in the frame of this project, and also from previous oceanographic surveys performed in the LMDCZ, remain obviously necessary to validate the satellite products. From the study supervised by H. Loisel in this project, monthly means of suspended particulate matter concentration (SPM) were produced using the best available satellite products and specifically designed new algorithms for data inversion.

In-situ analysis and laboratory study of sediment properties (report delivered)

Suspended and deposited sediment were collected during the two coastal surveys of the project (SIWRR), another field survey onboard IRD ALIS vessel (June 2014, VITEL campaign) spanning from the Bassac estuary to the adjacent coastal zone, and from additional surveys conducted in the Bassac estuary by SIWRR (2016). Some of the samples were analyzed at the CARE laboratory (HCMUT), where flocculation properties and settling velocities were estimated. This study was very important for model calibration as it shows that a simple sediment model with two important size classes (flocculi and fine sand) can be used. For these classes, we neglect flocculation processes and consider this model a pseudo-cohesive one, due to the implicit assumption of flocculation in the choice of settling velocities. Using these analyses, the match between model and satellite climatologies is very good in comparison with that previously shown in the literature.

Model solution for sediment transports and budget (report delivered)

We used a regional setup for a full 3D model of the LMDCZ. The sediment model parameters (classes, sizes, settling velocities, critical bed shear stress and erosion rates) were calibrated using in-situ samples, laboratory analysis, and the best satellite climatology specifically generated for the LMDCZ. The model solutions show that, schematically, river sediments are supplied in summer to the estuary area and transported in winter to the Ca Mau peninsula. The coastal circulation is driven by winds, tides and river buoyant plumes, but sediment transport is done through a repetitive cycle of re-suspension and deposition, so that sediment concentration measured along the coast is essentially a result of re-suspension due to wave-induced bed shear stress. Yet, alongshore transports set the patterns of erosion and deposition. In agreement with satellite observation of shoreline evolution, we find that the Mekong deltaic coast is locally non-equilibrated. In other words, it experiences large redistribution of sediments by hydrodynamical processes, and its morphology is in constant evolution with both erosion and accretion zones. It is divided into 3 areas of distinct morphodynamics:

- The estuary zone, from Vung Tau to Soc Trang, has mostly accretion
- The East coast from Soc Trang to Ca Mau is mostly a natural erosion region
- The West coast from Ca Mau to Kien Giang receives the eroded sediments from the East coast in its southern area, otherwise shows signs of erosion (Tran Van Thoi, U-Minh) but of moderate intensity.

The fact that Go Cong, in the estuarine region, has seen strong erosion in the past years suggests a deficit of sediment intake. The most obvious candidate is a large reduction of the Sai Gon - Dong Nai river supply due to upstream damming. This is supported by sensitivity test of the model to river supply.

On the other hand, the model also shows that reduction in river supplies is not likely to affect the downstream Ca Mau peninsula at the same timescale. Therefore, increased erosion in the West coast must be explained by other mechanisms: weakening of mangrove belt protection, subsidence (estimated at 3cm/year) and may be others.

WP3: In-situ and Laboratory studies on erosion process

Satellite remote sensing (report delivered)

Anthony et al. (2015) presented a first synthetic analysis of erosion/accretion along the whole LMDCZ (over 600 km of coast). Graphs of shoreline (m/year) and coastal area (km^2/year) change rates between 2003 and 2012 were analyzed from high-resolution SPOT 5 satellite images. Phan et al. (2017) reproduced this exercise recently for the period of 1973 - 2015 from Landsat images. In the same time, in the course of this project, SIWRR conducted its own investigation for the period 1990-2015, using a combination of Google Earth images, SPOT images and in-situ observations. The three studies show local differences but similar patterns of erosion/accretion at regional scale. These are the same patterns predicted by our regional model (see WP2). The good comparison between all these products is a strong indication of the natural large-scale redistribution process in the LMDCZ. However, at local scales, in Go Cong and U-Minh for example, discrepancies suggest other processes: deficit of river supply, coastal squeeze, and subsidence, etc.

Coastal video-camera (report delivered)

Installation of video cameras was a challenge, and we had to deal with the change of team and recruitment of additional help to train the new team, which had no experience with the video cameras and processing of their images. For installation, the challenge was the lack of coastal structure and logistic (power, internet, permit), as opposed to previous installations done in Nha Trang for example. The solution was to use solar panels for energy and store data locally rather than sending images through Internet. This was conducted for Go Cong, but not for the West coast, even less accessible. Yves Soufflet was recruited to help with installation and train the Vietnamese team for image processing.

Shoreline detection methods are usually based on image color properties. On sandy beach environment (where video cameras are traditionally used), shoreline detection rely on the color difference between sand (high red color value) and sea (high value of blue or green). However, Go Cong is a mixed sand-mud environment. In addition, the shore’s upper limit is protected by concrete (grey) while the water is charged with small sediments, which gives a brown color. As classical methods would not fail in such condition, we implemented a new indicator based on light intensity and its gradient. That probably makes the first method adapted to delta systems. However, another limitation is that most of the detected shoreline here is along the concrete dike, while lines detected at low tides are of coarser resolution. Therefore, averaging over longer periods, i.e., monthly, would improve accuracy on the budget analysis of the intertidal zone. As the video system is now set and working, it will prove a useful monitoring tool and provide accurate shoreline changes.

The results reported here are for the monitoring period of June 1 to September 3 2017 (summer monsoon), and only on camera S1, as it has the longest dataset. Only parts of the video data were collected so there are gaps or missing data for some weeks. Overall, a total of 7 weeks of S1 video data was transferred. From the available recorded video, no swell was detected, as this summer monsoon season was of very calm conditions with no extreme weather in the Go Cong area.

No significant shoreline change was detected either from these images, which suggests that no significant accumulation of sediment occurred during summer 2017. The capacity of sediment supply by the Soai Rap River can be questioned.

During 2017 summer monsoon, no important swell was detected and characterization of wave dynamics from stack images is more limited in this case. Yet, wave period was evaluated and the daily average wave period was found in the 5-7 sec range over the 3-month monitoring period.

Not enough data were yet collected to provide a complete description of various expected parameters. In addition, the monitoring period over which this report is based is very low-energy and no change is observed in beach morphology. However, this is a powerful result on its own because accretion would be expected during the wet season if river supply were to be efficient. It underlines the poor supply capacity of the Soai Rap River (Saigon-Dong Nai river system) at the present time and suggests this as a probable reason for the observed severe erosion in the Go Cong area.

As no incoming swell was detected, wave parameters such as wave height and celerity could not be assessed through classical methods, but new methods were devised to estimate the heights of small wind waves. In addition, the observation system is now set up and running in the Go Cong area and will continue providing data throughout the winter monsoon season to capture seasonal variations of beach and wave parameters. We will be particularly interested in the erosion rate associated with high-energy waves from the northeast monsoon.

WP4-WP5: Wave, coastal current computations, Sediment Transport and Go Cong, U Minh Morphological Change Modelling

A study of regional and local wave climate was conducted using the TOMAWAC wave model. Because waves are the main forcing of sediment re-suspension, a proper assessment was needed, which was used as a general reference to all modeling activity, even though each modeling group used their own data for modeling purpose. It confirms the difference of wave action in the East and West coasts and the dissipation role of mudflats, which need to be well represented in models to avoid overestimating wave energy in the coastal area.

Local models using the coupled TELEMAC and MIKE modeling system (circulation-waves-sediments) were implemented for the Go Cong and Phu Tan districts. The grids have variable mesh size with refinement of a few meters in the coastal zone. The regional models of WP4 were used to force the local models at the offshore boundaries. The models are calibrated and validated using in-situ and satellite observations for waves, currents, and sediment concentrations. It confirms the findings from the 3D regional model (WP2) showing a pathway from the East coast to the West coast around the peninsula head and sediment transported to Phu Tan along this pathway. In general, Phu Tan has less erosion than Go Cong due to weaker wave and tidal forcing and the presence of a pathway around the peninsula's tip that can carry sediments from the East Sea to West Sea.

Local sediment transport behavior seems well simulated by the two-dimensional models (hydrodynamics, waves, sediment transport). Consistency was found with satellite observation and in-situ surveys. During the wet summer season, high sediment concentrations are found in the direct flume of rivers, whereas during the northeast winter monsoon, the turbid plume is stretched eastward with a low level of suspended matter along the West coast. During this period, sediments move from East to West around the peninsula head and could be a contribution to the general deposition balance of the Phu Tan Coast. All simulations show that waves play an important role in coastal erosion. Those results are in agreement with the 3D numerical simulations with non-cohesive sediment provided by WP2 and with the mechanism described by Hein et al. (2013).

Local sediment transport and morphological simulations were done on the West coast (Phu Tan area). The general behavior agrees with observations. It leads to erosion during summer and accretion during winter. Erosion does not seem correlated with wave direction, but rather seems driven by wave energy (re-suspension) and coastal wind direction driving suspended sediment transport. Different models were used but they give overall consistent behavior. During the project a set of sediment transport and morphological modeling was established. Applying non-cohesive sediment modeling was a difficult task but it provided interesting results.

One particularly interesting result for Go Cong, confirming the result of the 3D regional model is the important role of the Saigon-Dong Nai River. A 75% reduction of river supply upstream is translated into more than 50% reduction of accretion in the coastal area of Go Cong.

WP6: Coastal Erosion Protection Measures

Design philosophy

First of all, we realize that coastal protection in the face of structural erosion cannot rely only on creating bigger and stronger dikes; dikes can be built to withstand any undercutting by erosion and increased wave attack, but not against acceptable costs. Therefore the project aims at halting the erosion with measures that maintain a shallow foreshore and viable mangrove areas.

From Schüttrumpf (2017) we may summarize the design considerations as follows. Any coastal protection structure should ensure the following requirements:

- Be porous enough to ensure water exchange, sediment transfer and water quality
- Be as high as possible to reduce wave impacts
- Be able to withstand extreme wave heights

- Be able to trap sand, silt and clay. Especially trapping of silt and clay is a crucial task and not easy to ensure under turbulent hydraulic conditions

FIELD STUDIES (reports delivered)

Erosion in U-Minh area: effects of pile breakwaters

Our survey confirms that erosion stopped at U-Minh, although the mangrove line is constant; there are some evidence of planting but no evidence of expansion of mangroves. The sediment deposited inside the breakwater must have come in by tidal exchange, as the water level inside the breakwater closely follows the level outside. This suggests that as long as the breakwaters are porous enough to allow the tide in, there can be a sufficient exchange of sediment.

Erosion in Go Cong area and geotube effect

Based on bathymetric survey differences, there is huge erosion (>20 Mm^3) in the first 2 km from the shoreline over 6 years. The differences need to be verified for biases between the two periods of measurements. However, the comparison in West coast of Ca Mau does not show such a large difference, which means that there is consistency between satellite analysis of shoreline changes and bathymetric surveys.

The geotubes implemented in Go Cong are so far unconvincing. There is very little evidence of small accretion; no effect of vegetation growth; there are still large waves accessing the shore.

Satellite analysis of shoreline changes

Go Cong: Shoreline analysis (WP3) shows consistent erosion in Go Cong from 1990 to 2015. This is unique within the Estuary zone. Our understanding is that Go Cong shores may be under direct influence from the Saigon Dong Nai river system, rather than the Mekong River.

Phu Tan: Phu Tan is a very different subregion, showing interannual variability between mild erosion and mild accretion as opposed to U-Minh, which has showed consistent erosion in recent years. Consistently, our bathymetric survey compared with a survey performed about 15 years before shows little evolution. If there is local erosion, then it may be due to local causes or interannual climate variability.

Mangrove width and sustainability

The conclusion is that a width of 500 m is a minimum for a healthy mangrove belt, but is not sufficient to prevent erosion (a necessary but not sufficient condition). In addition, protection structures can prevent mangrove seeds from flowing through and thus prevent restoration. Soft fences are more permeable than concrete piles but planting may be required for mangrove restoration even for efficient sedimentation. Exposition time above the sea surface is also a critical factor, i.e., there is a critical height for mangrove seeds to anchor and colonize, which is related to temporal windows permitted by tides. Studies of the LMDCZ on this matter should benefit from experience acquired in other tropical regions (e.g., French Guyana).

LAB STUDIES (reports delivered)

Two methods to reduce wave energy were investigated in the laboratory: a new type of porous breakwaters and wide, shallow sand banks. Details can be found in the report on physical models.

Porous breakwaters

The conclusions of flume experiments for the selected porous breakwater is that it may work as a means to reduce **wave transmission**, but it must be much higher than the still water level: for a zero relative freeboard R_C/H_{m0}[2] (crest level at water level), transmission is more than 50%. In practice this means that the crest level should be well above mean high water (MHW). Also, we note serious reflection, which can produce some amount of scouring on the seaward side of the breakwater.

Preliminary tests with kaolinite sediment showed that sediment is clearly transported through the breakwater, even without any tidal flow. With tidal flow cycles, we expect an easy exchange of sediment through the structure.

Sandbars

For the sand banks investigated, there is a significant reduction of the wave spectrum due to a wide sand bar (50-70 m). Here a negative freeboard (crest level under water level) RC/Hm0 of -0.5 reduces the wave heights to about 30%.

Deformation of the bar can be significant but positive damping effect remains over most tested wave conditions. Overall, the test of nourished sand bars appears positive, but the crest level should be about 0.5 m above mean sea level (MSL) to ensure significant wave damping under most circumstances.

MODELING

Large-scale modeling of sediment plume

As seen before (WP2), regional models can provide (by comparison with data) valuable information for WP6. It shows the strong capacity of LMDCZ in redistributing sediments along shore at regional scales. It also shows that the whole shallow subaqueous delta should be considered for understanding erosion, not only the shoreline. Using sensitivity testing of river supply, the models also helped us reveal how Go Cong appears as a consistently erosive subregion within a generally accretive region (estuary zone). The model results are sensitive to river supply variations from the Sai Gon - Dong Nai river system (as opposed to other local areas of the estuary region influenced by the Mekong River). Phu Tan is essentially a region of alternate mild accretive or erosion, receiving sediments from the East Coast of Ca Mau (naturally erosive). Local erosion there may thus have local causes or be subject to interannual climate variability.

Local 2D model: Phu Tan (reports delivered)

Both MIKE and TELEMAC were applied to the west coast of the LMDCZ. The results of these models were consistent in many aspects. The main difference is quantitative and appears on the amount of sediment accumulation behind protection structures. The use of a cohesive sediment model in MIKE leads to larger sedimentation in calm waters; additionally, MIKE predicted generally higher SSC, which is favorable to accretion behind protections. These results were closer to observations of existing protections at U-minh (although maybe overestimated).

[2] R_C is the free board height, i.e., the difference in height between the top of the structure and mean sea level. H_{m0} is a measure of significant wave height (assumed here equal to H_S).

Nevertheless, TELEMAC showed similar tendencies and sensitivities and we used the tests that it provided to complement our interpretation of results.

Local model testing is done over representative months of high and low energy (Aug-Sep and Jan-Feb). According to the regional model, combined budgets from these months are qualitatively similar to yearly budgets. Confirming the result of the regional model, we show that, contrarily to sandy environments with steep beach profiles or more usual subaqueous delta profiles (deeper profiles; see Eidam et al., 2017), the effect of waves here is not confined to the surf zone, but extend further onto the shallow mud seafloors where bed shear stress is dominated by wave orbital velocities to a depth of about 10m.

Below is a summary of model test results in terms of mean bed thickness evolution for a combination of summer and winter months (Jan/Sep 2014), with comments that follow:

Phu Tan simulations	Baseline	Breakwater	Sandbar
Jan/Sep 2014 Sedimentation (cm) in 2-km nearshore area	-1.8	-1.1	0.1
Jan/Sep 2014 Sedimentation (cm) in area inside structure	**-0.8**	**8.0**	**9.0**
Comments		Scouring Wind contribution to trapping	Sandbar deformation Wind contribution to trapping

MODELED BREAKWATER: The modeled breakwater is a shore-parallel structure 300m from shore, with gaps of 70 m, and has a crest elevation above the highest water level. Our results show that it can efficiently remove inshore wave energy. Because erosion results from wave-enhanced bed friction, the breakwater efficiently controls it. **The sediment budget changes from weak bed erosion to strong accumulation of tens of cm/y. This result tends to confirm the result of our survey on existing breakwater structures in U-Minh**. At U-Minh, Erosion stopped and sediments accumulated inside the breakwater. Interestingly, accretion is much stronger during the SW summer monsoon because SSC is higher due to stronger waves outside of the protected zone, so that a larger sediment load can be brought inside and deposited. Without protection, the same waves would lead to offshore export of mud and erosion. Therefore, some amount of wave energy can be beneficial to accretion, provided that the nearshore area is protected. To confirm this, a model test with double wave height leads to 50% increase of sediment deposition inside the protected area.

If tides are the main mechanism for onshore sediment transport, and we assume complete effectiveness of trapping processes, an upper limit for sedimentation rate can be estimated, depending on SSC. For SSC above 300 mg/l as measured during our nearshore surveys, accumulation of 30 cm/y, as observed in U-Minh and elsewhere (see our report on mangrove restoration; and Cuong et al., 2017) are possible. The present model helped us define the necessary conditions for such effective trapping to occur. We see here that not only waves must be efficiently damped but also tides must be allowed to carry sediments inside structures.

SANDBARS: We also tested the effect of a nourished sand bar. The modeled nourished sand bar is a shore-parallel structure ~500m from shore, 70 or 120 m wide, with gaps of 200m and height at minimum sea level. The damping of waves by the bar was also an efficient process, provided that the bar width is in the order of a wavelength (120m is more efficient than 70m in our simulations but with bar height at mean sea level, the difference is not important). Sandbars are a bit less efficient for wave blocking than a shore-parallel breakwater and has lower peak accretion inside the structure, but it has the **advantage of avoiding scouring at the breakwater foot and within the gaps, which leads to better overall trapping**. Finally, the addition of simulated mangrove effect on wave and flow dissipation showed to be a good complement to nourished sand bar as it carries wave damping further inshore and allows a more positive nearshore sediment budget in the model. As this is a preliminary experiment, the results remain qualitative.

Local 2D model: Go Cong (reports delivered)

Local modeling of the Go Cong area (both MIKE and TELEMAC) are also done over two representative months of high and low energy (Jan and Sep). It shows a clear impact of the T-groyne schemes on the flow velocities and a significant reduction of the wave heights. It also shows that the schemes are capable of enhancing sedimentation and reducing erosion in both monsoons. However, sand bank testing was not successful as no significant effect was seen on sedimentation and erosion rates. We believe that simulated sand banks were too low (MSL -2m) and narrow for this area, defined by large waves and deeper bathymetry than in Phu Tan.

MODELED BREAKWATER: The modeled breakwater is a T-groyne structure 300m from shore, and has a crest elevation above the highest water level (2.2m). It is composed of sections 600m wide with gaps of 30-50-70m (3 scenarios). The model testing of protection measures shows that the breakwater has the capacity of allowing some inshore accretion, reversing the erosive tendency of the simulation without protection measures. Gaps between shore-parallel breakwaters were tested as well. It turns out that the smaller the gap is, the more effective is accretion, due to reduction of wave effect. Therefore, damping waves appears as a priority for Go Cong. It will not prevent erosion occurring further offshore, which eventually will affect the nearshore region and wall structures. Without raising again the sediment supply from the Saigon/Dong-Nai River, avoiding this problem will be difficult.

SANDBARS: We also tested the effect of a nourished sand bar. The modeled nourished sandbar is a shore-parallel structure 500m from shore, 50 or 70 m wide, with gaps of 300 m and crest level at mean sea level (deeper crest level proved inefficient in this high-energy environment). The model was first tested for sandbar integrity under high-energy NE monsoon waves. The results confirmed that of the physical model in producing only mild morphological changes on the outer slope of the bar. The damping of waves by the bar was less efficient than with breakwaters. Even though accretion inside the protection structure is lower, scouring is much reduced for sandbars compared with breakwaters. **The overall accretion with sandbars (over a section of 2km from shore) is higher by 30%**. Interestingly, during the low-energy season (SW monsoon), sandbars are more effective for accretion inside the protection structure, which adds to the overall efficiency. Finally, sandbar nourishment can also be useful as sediment storage in this sediment starved area. However, how helpful this might be for mangrove rehabilitation is an open question.

SEDIMENT SUPPLY: A test of sediment supply from the Saigon/Dong-Nai River was also performed. When sediment input is reduced by **75%** (100 km upstream), the net erosion increases along the coast of Go Cong.

There is a **60%** deficit of sediment deposition in the coastal area (mostly in the wet season). The rest is deposited offshore or compensated by river erosion ("hungry water" process that limits the effective reduction of supply for downstream areas). Because in the reference simulation, erosion is almost balanced by accretion[3], the deficit of accretion in the river supply experiment results in a large increase of net erosion over the combined two months of simulation (Jan and Sep): **0.67 Mm^3 erosion instead of 0.08 Mm^3** (an order of magnitude). This result confirms previous suggestions from the regional model, indicating that erosion in Go Cong is highly sensitive to the river supply by the Saigon Dong Nai river system. This is also confirmed by SIWRR surveys in recent years showing only thin layers of mud deposition during the low-energy season (summer), contrasting with thicker layers that are deposited further south in the mouths of Mekong branches (albeit with interannual variability).

Interestingly, using breakwaters, river deficit cannot be fully balanced by reduction of erosion and only half of net erosion is mitigated. This underline the fact that a full recovery of sediment in such a sediment starved area will require either local nourishment or modification of dam operations upstream on the Saigon and Dong Nai rivers.

Below is a summary of model test results in terms of mean bed thickness evolution for various scenarios and combination of summer and winter months (Jan/Sep 2014).

Go Cong simulations	Baseline	Baseline -75% supply	Breakwater	Breakwater -75% supply	Sandbar	Sandbar -75% supply
Jan/Sep 2014 Sedimentation in 2-km coastal area (cm)	0.4	-1.2	0.8	-0.6	1.1	-0.3
Jan/Sep 2014 Sedimentation inside structure (cm)	**-2.8**	**-3.6**	**4.0**	**3.7**	**2.7**	**1.6**
Comments			Scouring		No scouring Small bar deformation	

Below is summary of recommended protection measures at Phu Tan and Go Cong.

	Options	Measures	Crest level (m)	Width (m)	Distance from shore (m)	Unit Length (m)	Gap between units (m)	Initial Cost ($/m)	Damage (%/year)
Phu Tan	1	Sandbars; L=7km; V= 0.7 Mm^3	0	70	500	1000	200	500	15
		T-fences (GIZ type)	Scale of fences are smaller than GIZ’s					50	50
	2	Porous breakwaters	1.1	N/A	300	600	70	N/A	N/A
		T-fences (GIZ type)	Scale of fences are smaller than GIZ’s					50	50
	3	Concrete pile breakwater porosity >=20%	1.1	N/A	300	600	70	N/A	N/A
		T fences (GIZ type)	Fence scale smaller than GIZ’s					50	50

[3] The Soai Rap River sediment flux is probably excessive in the reference simulation. The exact numbers are uncertain but recent studies of the Saigon Dong Nai river indicate low values associated with low SSC (J. Nemery, personal communication). This would need to be settled.

	Options	Measures	Crest level (m)	Width (m)	Distance from shore (m)	Unit Length (m)	Gap between units (m)	Initial Cost ($/m)	Damage (%/year)
Go Cong	1	Sandbars;L=15.5km V= 2.56 Mm^3	0	70	500	1000	200	800	20
		T fences (GIZ type)	Fence scale smaller than GIZ's					50	50
	2	Porous breakwaters	2.2	N/A	300	600	70	N/A	N/A
		T-fences (GIZ type)	Fence scale smaller than GIZ's					50	50

4. Information on the difficulties encountered and measures taken to overcome problems and eventual changes introduced

The delay in funding from EU resulted in a delay for conducting field surveys and subsequently in the departure of project members. We needed to recruit a new Vietnamese team for camera monitoring, resulting in more delay. The new international expert (Yves Soufflet) and national experts (SIWRR team) started to work on the Go Cong site last April. However, in August, the Ca Mau province informed us that they could not grant us a permit to install video cameras at the selected site due to internal reasons. This issue is objective and unforeseen, thus the task cannot be done in Ca Mau.

More generally, the delays encountered have leaded us to focus on the essential objectives of the project, removing tasks that were more peripheral (which could be done in a later stage). There was also a need for clearer separation between regional and local modeling. We asked the experts of WP4-WP5 on 2D high-resolution local studies to concentrate on their respective study site with less emphasis on regional simulation analysis, which were done carefully by 3D modelers in WP2. Also, additional field trips to the study sites were conducted to better assess the effects of existing breakwaters (geotubes in Go Cong; concrete pile breakwaters in U-Minh).

Computing power for long-term numerical simulations: this is not a priority. Our computing facility was designed for short-term, high-resolution simulations (a few hundred meters for regional models and a few meters for local ones). We put more emphasis on high resolution of coastal processes than long-term evolution because there is a lack of understanding of these processes. Short simulations (1 or 2 months) can reproduce dominant coastal processes during key periods of erosion and deposition. There are also adapted to testing protection measures by looking at differences between simulations with and without protections. For the regional sediment budget, the 3D models were run for a full year and thus provided a full seasonal budget that could be compared with long-term data and check the validity of short-term simulations. For complementary local multi-year simulations of the study areas, computer rental should be considered, but probably after the final report.

For international experts (Sylvain Guillou and Michel Benoit) who have late signed their contracts with AFD lead to a delay in performing tasks that they are assigned to. Nevertheless, these two experts have participated to our kick-off meeting (11/2016) and technical workshop (04/2017) and they have been working with the national experts since then.

Remote working environment: different time zones, long distance working relationships, and summer holiday (particularly in Europe) should be factored into the delay.

Finally, some difficulties are inherent to the natural evolution of a project in the face of knowledge gained with the various experts during the course of it. For example, the TOR was very optimistic on Task 3.1 stating that the tendency of sediment river fluxes over the years could be calculated based on in-situ measurements. It is now obvious that it was overstated, as the temporal and spatial resolution needed is not available.

5. Information on the implementation of the Visibility and Communication

Project Workshop

The LMDCZ project has organized 3 workshops so far as listed below:

1- Kick-off workshop 12-13/11/2016 in Ho Chi Minh City at the cost of 8,150 €
2- Midterm workshop 24-16/5/2017 in Hoi An at the cost of 17,766 €
3- Final worskhop 26/1/2018 in Ho Chi Minh City (at SIWRR) cost of 11,500 €

The workshops attracted many international and national experts who eagerly contributed to the study, the decision makers at the central, provincial and local levels, various organizations and media as presented in Table 5.1.

Table 5.1 Number of participants to the workshops

Name of Workshops / Participants attended	Kick-off	The international (Hoi An) workshop	The Final workshop
International Organizations (AFD, EU, GIZ Vietnam, IUCN Vietnam, the WB, SECO, IFAD, WFF, UNDP, etc.)	8	7	18
Managers of from Ministries (MARD, MONRE, MOST, MOF, MPI)	3	6	10
Institutes, University and other science Organizations	7	12	15
Local governments (Quang Nam, Tien Giang and Ca Mau provinces	3	10	11
International technical experts	5	3	6
National experts and others	47	10	25
Total	**73**	**48**	**85**

During the kick-off meeting, field trips were organized for many of the team experts. The technical workshop then assembled most of the experts to share findings and experiences in an informal way. This was very helpful before presenting preliminary results to mid-term workshop in Hoi-An. During that workshop, very interesting exchanges occurred between scientist and decision makers.

The final workshop was held on January 26, 2018 once the final report and project findings are submitted to AFD and 3 reviewers by early December 2017. The reviewers sent comments to AFD and they were sharing among project members. After taking into account the reviewers comments, the reports that had been sent to AFD and reviewers updated with new findings. The robust results of protection measures proposed have been integrated in the Final Report.

Project Website: http://lmdcz.siwrr.org.vn/?lang=e

A website was set up for the LMDCZ project, linked to SIWRR's website, EU COMMISSION - INTERNATIONAL COOPERATION AND DEVELOPMENT (https://ec.europa.eu/europeaid/index_en.htm) and AGENCE FRANCAISE DE DEVELOPPMENT (www.afd.fr) at the cost of 1,000 € for 2 years (2016, 2017).

In the LMDCZ project website, readers can freely download data, reports from the three above workshops and project technical workshop (12-14/4/2017) for their purposes. Midterm and final reports are also upload in the website of the project, SIWRR's website and related local governments' websites (Tien Giang and Ca Mau provinces).

Translation

Although the official language for the project is English, a large audience is local people, especially provincial people; therefore it is essential to translate some documents/presentations/ reports into Vietnamese.

6. Information on the costs incurred as well as the legal commitments entered into by the organization

Data Surveys

The LMDCZ project has deployed two survey campaigns to measure coastal SSC, bathymetry and hydrodynamics as planned in the TOR: the first one in October 2016 (southwest monsoon) and the second in February 2017 (northeast monsoon). Each survey lasted for 2 weeks and included several stations (2 fixed river stations, 2 fixed coastal stations and almost 200 mobile stations occupied by 2 boats cruising along the East and West coasts). In addition, cross-sections of bathymetry were measured along the study sites: Go-Cong (along 21 km) and Phu Tan (25 km); the cross-shore extension is about 8 km at both sites with a sampling resolution of 1.25 km (in average).

The results of these campaigns were uploaded to the project's website to share among project members.

Actually, coastal surveys, including the present ones and those of previous projects (national and international) generally pay little attention to nearshore SSC, i.e., in water shallower than about 2 m (roughly the surf zone). Nearshore SSC may be an important parameter to assess for predicting the effect of protection measures. After discussing with Prof. Kim Dan Nguyen (AFD's project supervisor), SIWRR proposed two additional field surveys in August and September 2017 with a period of a few days each. The same additional survey for the East coast in December 2017 was proposed. The purpose of additional surveys is to determine nearshore SSC within 2-3 km of the coast during the SW monsoon (at U Minh) and NE monsoon at Go Cong.

These additional campaigns (called 3rd, 4th and 5th) have cost 18,216 € and the task was as follows:

- The 3rd campaign was to examine the exchange of SSC through the U-Minh concrete pile breakwater. This campaign revealed high SSC near the breakwaters, where the water was also more agitated.

- The 4th campaign was planned by the end of August but failed due to rough weather. It was thus postponed to September 12-14, 2017.

- The 5th campaign was planned by the end of December 2017.

Workshop

The midterm workshop in Hoi An and Final workshop in Ho Chi Minh City (not yet in the financial proposal) mentioned in section 5 was costly (about 29,000 €) because we invited a wide range of participants from the central Government decision makers to local ones, as well as foreign diplomats and representatives of various international research institutes involved in Mekong studies.

Independent reviewers

As requested by AFD (the discussion held between Ms Sandra Rullier and Project Team Leader, Mr. Patrick Marchesiello), the Project will be reviewed by independent reviewers as follows:

+ Prof. Dr.-Ing. Hocine Oumeraci who works in Department of Hydromechanics and Coastal Engineering - Leichtweiß-Institute for Hydraulic Engineering and Water Resources (https://www.tu-braunschweig.de/lwi/hyku/mitarbeiter/profdroumeraci).

+ Dr Stefan Groenewold, Technical Advisor Integrated Coastal Management Programme Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Vietnam.

The cost for this activity is about €13,000 in which €7,500 is for the first reviewer and €5,500 for the second reviewer

Film

A film has been realized with IRD on the Study as part of the communication and visibility plan. The cost for the film is 2,500 €.

Cancel tasks/activities

The Lock-exchange (density-induced flows) test, the Computing River and coastal flows in the LMDCZ by MIKE3D, the 3D wave basin modeling and the installation of cameras in Ca Mau Province are waived from the Study. Total cost for cancel activities/tasks is about -59,500 €

7. Summary of controls and audit measures carried out

To this point, the project's financial budget has been adequately managed. We followed rules and regulations required by the Vietnamese Government as well as AFD/EU. During implementation, some concerns were raised, some resolved, some remained as question marks for the next phase:

- The contracts of international experts were to be signed between these experts and AFD due to tax issues. This is not what was planned at first. It turned out that if the international experts signed their contracts with SIWRR directly, the contracts would have been subject to the Vietnam law. It means 10% VAT and 20% personal income tax would have been directly retained from the consultation fees. To avoid this issue, an amendment between AFD and SIWRR was issued allowing contracts between the international experts and AFD. However, this took significant time and effort to resolve.

- We were also concerned with the VAT issue due to the late and unclear response from the Tax Department of Ho Chi Minh City (HTD) regarding the VAT tax issue applied to the research contract between AFD and SIWRR. A meeting between HTD and SIWRR was held on the 21st and 22nd November 2017. After the meeting, HDT responded to SIWRR by a letter dated 23/11/2017 in which it confirms that the research contract signed between AFD and SIWRR is not subject to a VAT tax rate provided that SIWRR would transfer all research results to AFD. In addition, SIWRR is informed that because there are no international consultant subcontracts, which are subject to a VAT tax and personal income tax, signed by SIWRR, therefore SIWRR would not be taxed on these subcontracts. Based on the HTD official letter ref. N011429/CT-TTHT dated 23/11/2017 (attached) we understand that the costs associated with the activities carried out by SIWRR and the national experts are not subject to a VAT tax. However, SIWRR would like to clarify that the research results which will be transferred to AFD as mentioned in the HDT document are the deliverables only. The contract signed between AFD and SIWRR is a research collaboration and both parties have financially contributed to the project budget, hence both SIWRR and AFD equally hold the intellectual property rights for all deliverables.

  Finally, SIWRR had to confirm with AFD that SIWRR will be responsible for VAT issue if it incurred after the project finish.

8. Summary of cost of the Contract

(to be updated on 31/1/2018)

Description	Total	AIF	AFD	SIWRR
(1) Remuneration experts	**386 486**	**339 000**	**23 743**	**23 743**
Including overhead cost	47 486	-	23 743	23 743
(2) Perdiem experts	**47 277**	**43 821**	**1 728**	**1 728**
Including overhead cost	3 456	-	1 728	1 728
(4) Travel	**43 564**	**39 044**	**2 260**	**2 260**
Including overhead cost	4 520	-	2 260	2 260
(5) Workshops and communication	**50 020**	**34 075**	**13 831**	**2 114**
Including overhead cost	4 227	-	2 113	2 114
(6) Measurement and technical workshop	**396 209**	**320 724**	**17 964**	**57 521**
Including overhead cost	35 928	-	17 964	17 964
(7) Equipment	**60 015**	**53 337**	**3 339**	**3 339**
Including overhead cost	6 678		3 339	3 339
Total	**983 571**	**830 000**	**62 865**	**90 705**

APPENDIX A

Table A.1: Updated *list of international experts and tasks*

Partner N°	Institution	Name	Tasks assigned
K1	Institut de Recherche pour le Développement (IRD)	Mr. Patrick. Marchesiello (PM)	International expert, **Team Leader and WP2 Coordinator** : 3D modelling for sediment transport in the LMDCZ
K2	LNHE/EDF (Laboratoire National d'Hydraulique et Environnement), France	Mr. Michel Benoit (MB)	International expert, **WP4 Coordinator** : Wave and Coastal Currents Computations
K3	International laboratory ECLAIRS	Mr. Rafael Almar (RA)	International expert, **WP3 Coordinator**: In Situ Experimental Study on LMD Erosion Process
K4-1	RIVAGES Scop SARL	Yves SOUFFLET	International Expert, WP-3: In Situ Experimental Study on LMD Erosion Process – Videocamera
	RIVAGES Scop SARL	Clément MAYET	International Expert, WP-3: In Situ Experimental Study on LMD Erosion Process – Videocamera
K5-1	Institut de Recherche pour le Développement (IRD) ; Professor at the LOG laboratory; University of Littoral Côte d'Opale	Mr. Hubert Loisel (HL)	International Expert, WP3: In Situ Experimental Study on LMD Erosion Process; Task 3.3 Settelite immage analysis
K5	LUSAC, University of Caen	Mr. Sylvain Guillou	International Expert, **WP5 Coordinator** : Sediment Transport and Go-Cong U-Minh Morphological Change Modelling
K6	UNESCO-IHENetherlands	Mr. Dano Roelvink (DR)	International Expert, **WP6 Coordinator**: Shoreline protection measures
K7	RWTH Aachen University, Germany	Mr. Holger Schüttrumpf (HS)	International Expert, WP6 : Shoreline protection measures
K8	Laboratory for Hydraulic Saint- Venant, France	Mr. Damien Pham Van Bang (DPVB)	WP1: Data Collection & In situ measurements Task 1.3 : Training course (calibration of turbidity measurement by ADCP; calibration in laboratory)
K10	Institut de Recherche pour le Développement (IRD)	Mr. GRATIOT Nicolas (GN)	International Expert, WP3: In Situ Experimental Study on LMD Erosion Process; WP6: Task 6-1: Identifying soft and hard measures for protecting the studied sites from erosion
K11	Institut de Recherche pour le Développement (IRD)	Mr. OUILLON Sylvain (OS)	International Expert; WP2: 3D modelling for sediment transport in the LMDCZ; WP3: In Situ Experimental Study on LMD Erosion Process

Table A-0-1 : Updated List of national key experts and tasks

Partner N°	Institution	Name	Tasks assigned
K13	Southern Institute of Water Resources Research (SIWRR)	Mr. Dinh Cong San (DCS)	National expert, Project coordinator; WP 6: Shoreline protection measures
K14	SIWRR	Mr. Nguyen Duy Khang (NDK)	National Expert; WP2 Coordinator : 3D modelling for sediment transport in the LMDCZ; WP3: In Situ Experimental Study; WP4: Wave and Coastal Currents Computations; WP5 : Sediment Transport and Go-Cong U-Minh Morphological Change Modelling; WP6 : Shoreline protection measures
K16	Ho Chi Minh City University of Technology	Mr.Nguyen Thong (NT)	National Expert; WP4: Wave and Coastal Currents Computations; WP5 : Sediment Transport and Go-Cong U-Minh Morphological Change Modelling;
K17	Ho Chi Minh City University of Technology	Mr. Huynh Cong Hoai (HCH)	National Expert; WP4: Wave and Coastal Currents Computations WP5 Coordinator: Sediment Transport and Go-Cong U-Minh Morphological Change Modelling;
K18	University of Sciences and Technologies of Hanoi (USTH)	Ms. Nguyen Nguyet Minh (NMN)	National Expert; WP2: 3D modelling for sediment transport in the LMDCZ;
K19	INSTITUTE OF VIETNAMESE STUDIES AND DEVELOPMENT SCIENCE & CATHOLIC UNIVERSITY OF LEUVEN (KUL) – BELGIUM	Ms. Nguyen Thi Lan Anh (NTLA)	National Expert; WP2: 3D modelling for sediment transport in the LMDCZ; WP4: Wave and Coastal Currents Computations;
K20	University of Science, National University of Ho Chi Minh City	Mr Nguyen Cong Thanh	National Expert; WP1 Coordinator: Data Collection & In situ measurements
K21	SIWRR	Mr. Nguyen Tuan Long	National Expert; WP1: Data Collection & In situ measurements
K22	SIWRR	Mr. Le Manh Hung	National Expert; WP6 : Shoreline protection measures
K23	ICOE	Mr. Nguyen Anh Tien	National Expert; WP6 : Shoreline protection measures

Partner N°	Institution	Name	Tasks assigned
K24	SIWRR	Mr. To Quang Toan	National Expert; WP6 : Shoreline protection measures
K25	SIWRR	Mr. Le Van Kiem	National Expert; WP6 : Shoreline protection measures
K26	SIWRR	Mr. Vo Khac Tri	National Expert; WP1: Data Collection & In situ measurements; WP3 : In Situ Experimental Study on LMD Erosion Process
K27	SIWRR	Mr. Pham Trung	National Expert; WP-4: Wave and Coastal Currents Computations;
K28	SIWRR	Mr.Le Thanh Chuong	National Expert; WP3 : In Situ Experimental Study on LMD Erosion Process; WP6: Shoreline protection measures
K29	SIWRR	Mr. Tang Duc Thang	National Expert; WP4 Coordinator: Wave and Coastal Currents Computations;
K30	SIWRR	Mr. Nguyen Nghia Hung	National Expert; WP5 : Sediment Transport and Go-Cong U-Minh
K31	SIWRR	Mr. Pham The Vinh	National Expert; WP5 : Sediment Transport and Go-Cong U-Minh
K32	SIWRR	Mr. Nguyen Binh Duong	National Expert; WP4 Wave and Coastal Currents Computations; WP5 Coordinator: Sediment Transport and Go-Cong U-Minh;
K33	Institute of Marine Environment and Resources (Vietnam Academy of Science and Technology)	Mr. Vu Duy Vinh	National Expert; WP2: 3D modelling for sediment transport in the LMDCZ; Task 2.4 Simulation by Delft 3D sediment transport according to three situations: Northeast, Southwest winds, and inter-monsoon season and comparion with ROM3D
	Thuyloi University (Ha Noi Water Resources University)	Mr. Thieu Quang Tuan	National expert ; WP 6: Shoreline protection measures Task 6.3 Physical models for selecting the best configuration of groins, breakwaters and mixed systems
	School of Maritime Economics and Technology – Vung Tau University	Ms Dang Thi Ha	Task 2.2 River sediment flux analysis
	Institute of Ecology and Works Protection (WIP)	Group	Task 6.2.1 "Restoration of mangrove belts near the coast of the studied sites for: - Identifying mangrove kinds that will be most adapted in the studied sites; - Selecting the technique for a best implantation of mangroves"

Partner N°	Institution	Name	Tasks assigned
	Technical Advisor Integrated Coastal Management Programme Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Vietnam.	Stefan Groenewold	Independent review of the project results
	Department of Hydromechanics and Coastal Engineering - Leichtweiß-Institute for Hydraulic Engineering and Water Resources	Hocine Oumeraci	Independent review of the project results

Table A-0-2 : Updated List of national non-key experts and tasks

Partner N°	Institution	Name	Tasks assigned
NK-35	SIWRR	Mr. Nguyen Minh Trung	WP3 : In Situ Experimental Study on LMD Erosion Process
NK-36	SIWRR	Mr. Nguyen Cong Phong	WP4: Wave and Coastal Currents Computations; WP5 : Sediment Transport and Go-Cong U-Minh; WP6 : Shoreline protection measures
NK-37	SIWRR	Mr. Pham Van Hiep	WP1: Data Collection & In situ measurements; WP6 : Shoreline protection measures
NK-38	SIWRR	Ms. Le Thi Hien	WP2: 3D modelling for sediment transport in the LMDCZ; Task 2.5 Simulation by MIKE3 sediment transport according to three situations: Northeast, Southwest winds, and inter-monsoon season and comparion with ROMS3D