EUROPEAN PROJECT MAREMED
"Maritime Regions Cooperation for the Mediterranean"

Adaptation to Climate Change on Coastal Area
Book 4: Shoreline Management Program.
A methodology for the monitoring and maintenance of Sustainable Project Shoreline

Direzione Regionale Infrastrutture, Ambiente e Politiche Abitative

Centro di Monitoraggio per la Gestione Integrata della Zona Costiera

MAREMED Project
MAritime REgions cooperation for the MEDiterranean

Adaptation to Climate Change on Coastal Area

Book 4
Shoreline Management Program.
A methodology for the monitoring and maintenance of the Sustainable Project Shoreline

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Summary

1. Introduction

The European project MAREMED "Maritime Regions Cooperation for the Mediterranean" was approved in the MED SPACE program (2010-2013) and gathers Region PACA (lead partner) and other 13 Mediterranean regions. It includes 6 thematics of interest:

- Coastal Pollution
- Integrated Coastal Zone Management
- Coastal Adaptation to Climate Change
- Fishery
- Coastal Geo-data management
- Governance

The Lazio Region is in charge of the Coastal Adaptation to Climate Change (ACC) and is responsible for developing four specific issues:

1. Compared analysis between coastal vulnerability maps (Book n.1);
2. Shared tools for the forecast and management of the CC effects along the coast (Book n.2);
3. Implementation of a coastal observatory network in the Mediterranean basin (Book n.3);
4. Shoreline Management Program. A methodology for the monitoring and maintenance of Sustainable Project Shoreline (Book n.4).

This fourth volume concerns the "**Shoreline Management Program. A methodology for the monitoring and maintenance of the Project Shoreline**".

This activity is inspired by the need emerged during the MAREMED ACC diagnosis phase to maintain (or at least not to increase) the current resilience level of the Mediterranean coasts against flooding threats.

The negative consequences of a flood are proportional to its intensity but also to the morphology of the coast and its exposed assets.

In the case of sandy coasts, beaches are the first natural defense system against floods. Hazard models are elaborated based on the hypothesis that extreme events occur with a steady shoreline. If the coast is affected by a significant yearly erosion trend, this condition is not respected over time and the "highest winter water" line (art.8 Protocol ICZM[1]) must be redefined as well as the "set-back" line.

[1] PROTOCOL on Integrated Coastal Zone Management in the Mediterranean - Official Journal of the European Union L 34/19 - 4.2.2009.

Moreover, it is necessary to assume that the shoreline is steady in order for the results obtained by the Risk model evaluations to be reliable. The more the shoreline is unstable, the more evident the uncertainty of the risk model results. The Dutch Government is coping with this problem by using a BASELINE[2] (Basiskustlijn -BKL), established by a specific national law, i.e. a coastal threshold which, if reached by the sea, leads to the implementation of a protecting intervention (usually re-nourishment).

With this integration to ACC Pilot Actions, the Lazio Region proposed the elaboration of a methodology to define an **Intervention Shoreline**, i.e. a shoreline beyond which an intervention is required to re-establish the respect of the hazard/risk plans. That way, the steadiness of the setback zone will be respected, too (see Art. 8 of the ICZM protocol).

The first part of this volume is dedicated to the description of the Shoreline Management Program. A methodology developed by the Maremed Project for the monitoring and management of a Project Shoreline 'PS'.

The second part of this volume is dedicated to the application of this methodology to a pilot site along the Lazio coast. This report describes the maintenance and monitoring costs of the PS as well as a real application on a significant stretch of coast.

Before presenting the explanation of this methodology, here is a series of important morphological definitions of the shoreline:

[2] Ministerie van Verkeer en Waterstaat - Dienst Weg en Waterbouwkunde. HISSchade en Slachtoffer module (2004).

SHORELINE DEFINITIONS:

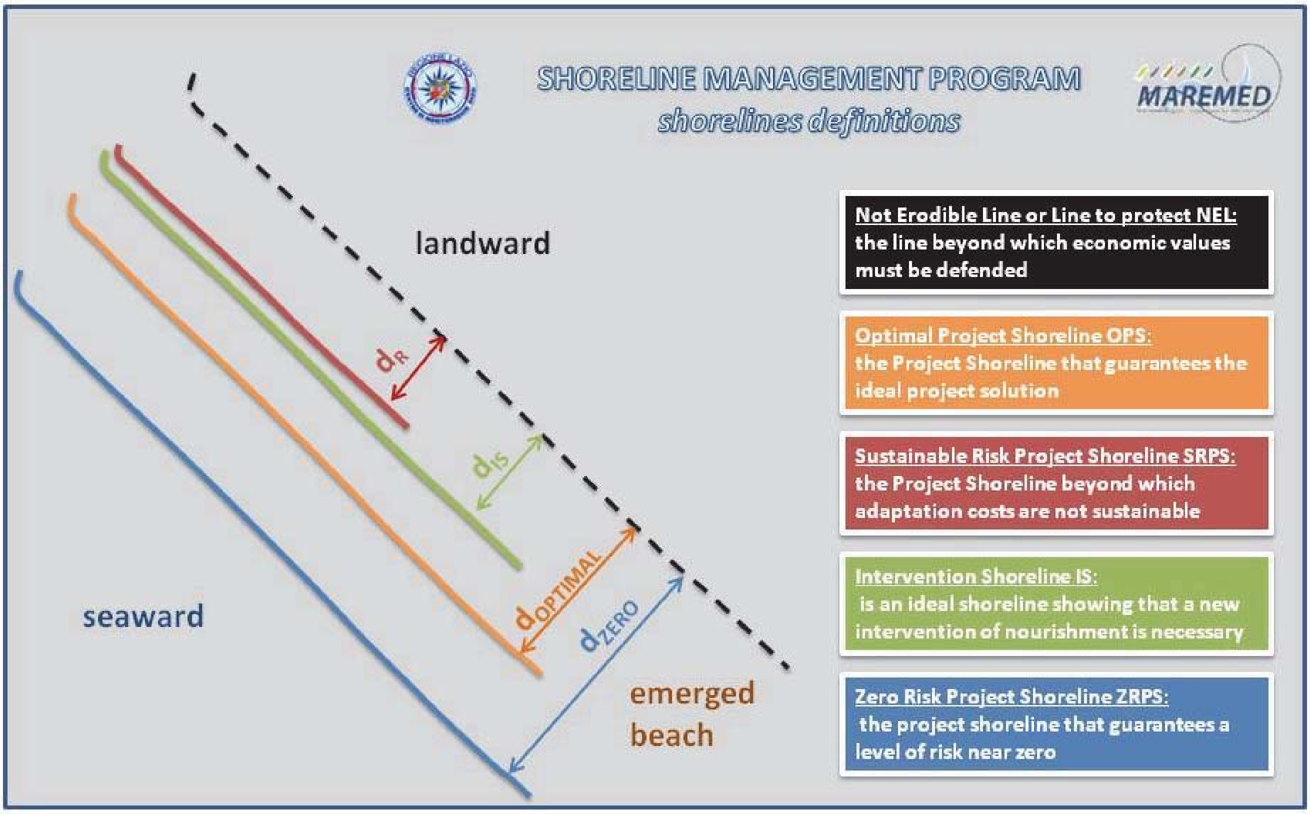
SHORELINE	DEFINITION
Shoreline	A shoreline is the boundary where a Sea Area meets Land. The shoreline shown on charts must therefore have a value for the water level that identifies the tidal state used to define itself[3]. The shoreline extracted by aerial/satellite pictures represents the true line of contact between the land and sea at the moment of its survey (often without a value for its water level).
Coastline	The coastline is used to represent the shoreline at Mean High Water[3]. The coastline shown on charts represents the conventional line of contact between land and a selected water elevation MHW.
Not Erodible Line or Line to Protect 'NEL'	The line that separates the emerged beach from the "high value" land. This is the line beyond which the economic assets must be protected against flood risks and Its position shouldn't be changed. Along anthropized NEL usually corresponds to more exposed infrastructures or residential buildings. On natural zones this line can be identified by the presence of vegetation (e.g.dune foot).
Project Shoreline 'PS'	The shoreline that must be restored and maintained by coastal intervention works, such us beach nourishments. Its position is defined by the the seaward distance 'd' from the NEL and is established by the project manager during the planning phase of beach management.
*Sustainable Risk Project Shoreline 'SRPS'	The Project Shoreline PS that must be kept so that a coastal intervention work is sustainable in terms of risk. Its position d_R (seaward distance from the NEL) is obtained by solving the equation (1): *(Risk with adaptation + implementation and maintenance Costs =Risk without adaptation).*
*Optimal Project Shoreline 'OPS'	The Project Shoreline PS that guarantees the minimum value of the sum *(Risk with adaptation + implementation and maintenance Costs = MIN)*. Its distance $d_{OPTIMAL}$ from the NEL represents the ideal position of Project Shoreline from an economic point of view.
*Zero Risk Project Shoreline 'ZRPS'	The Project Shoreline PS that guarantees that risk is zero with the adaptation measure*(Risk with adaptation = 0)*. Its distance d_{ZERO} from the NEL does not always ensure the optimal project choice from an economic point of view. It depends also on the of coastal defense implementation and maintenance costs.
Laying Shoreline 'LS'	The Shoreline at the implementation of coastal intervention works. Some time after the implementation of the works (beach adaptation), the LS position should be near the Project Shoreline PS.
Momentary Shoreline 'MS'	The shoreline representing the status of the beach in the moment of its acquisition. It is computed with two alternative methods: the volumetric approach and the emerged beach approach (see the description below)
Intervention Shoreline 'IS'	The Momentary Shoreline reaching the SRPS position in the same period of time required to organize and implement the

[3] INSPIRE Directive 2007/2/EC Annex III – D2.8.III.16 Data Specification on Sea regions – Draft GuidelinesSea Regions – Data specifications 2012-07-02

	intervention works (technical requirements). The 'IS' position depends on the beach erosion trend. When SRPS position is reached, the coastal intervention work must begin.

* Position from the NEL is given by the application of Risk Models that take into account the influence of project shoreline position on Risks computation (e.g. COFLERMap & COFLERTools Models).

SHORELINE DEFINITIONS (GRAPHIC REPRESENTATION)



2. Project Shoreline Management Program. A methodology for the maintenance and monitoring of Project Shoreline.

Starting from an idea adopted by Dutch Government for the long-term management of their coasts, the Shoreline Management Program is a tool developed for Coastal Project Managers in order to have a detailed program for shoreline monitoring and a detailed program of shoreline maintenance operations with the objective to make it more stable and economically sustainable over time. The more stable the beach over time, the lesser the level of flooding risk.

Due to the economic approach that COFLERMap and COFLERTools Models (Maremed Books n. 1 and n. 2) adopted for the evaluation of coastal risks, these represent the most suitable way to develop a Shoreline Management Program. The economic value associated to coastal risks will be compared with the implementation and maintenance costs associated to the adaptation measures.

Once established the priority areas of intervention, e.g. at regional scale, and the most convenient and sustainable typology of intervention, the next step for an optimal management and allocation of economic resources could be the evaluation of the area of new beach. So a tool is required to solve the problem of identifying the optimal position of Project Shoreline 'PS' from an economic point of view.

2.1 The computation of Sustainable Risk Project Shoreline position 'd_R'

The choice of the position of the Project Shoreline obviously depends on the implementation and maintenance costs of the intervention work over time, but also on the sustainability of the intervention work in terms of reduction of potential damage that could occur during the lifetime of the work (risks).

The objective of a beach intervention work is to minimize the risk values after its implementation. In other words, the following questions are to be taken into account: which is the most cost-effective choice between either doing nothing or reducing the risks by implementing coastal defense works? In this second case, which is the most cost-effective position of the shoreline that needs to be maintained?

We assume that coastal defense works become economically sustainable when the sum between the risks after the implementation of the intervention work (R_A) and the costs of its implementation and maintenance (C_{RM}) become lower than the risk in case of no intervention (R).

$\boxed{R_A + C_{RM} < R}$ *Sustainable condition for coastal defense work intervention (1)*

Both R_A and C_{RM} values are linked to the project shoreline position 'd' (distance from the Not Erodible Line NEL). The distance 'd' is assumed to be steady on the coastal stretch under examination.

Three important values of the Project Shoreline position 'd' could be defined if we apply the equation $R_A + C_{RM} = R$;

a) the *Sustainable Risk Project Shoreline position* 'd_R', i.e. the value of 'd' that satisfies the equation (1);

b) the *Optimal Project Shoreline position* '$d_{OPTIMAL}$', i.e. the value of 'd' that corresponds to the minimum value of the sum ($R_A + C_{RM}$);

c) the *Zero Risk Project Shoreline position* 'd_{ZERO}', i.e. the value of 'd' for which the risk R_A is zero.

It will be highlighted in the following paragraphs that the solution of equation (1) could be the best methodology to choose the optimal position of the project shoreline 'd' from an economic point of view. The Project Manager can choose between two border values of 'd': a minimum value 'd_R' (which ensures a solution with lower costs, but not a minimum risk) and a maximum value 'd_{ZERO}' (which ensures a total reduction of the risks, but probably a solution that is too expensive).

In order to better understand the equation (1), let us analyze the three elements of the equation separately.

2.1.1 The Risks without adaptation measure (or intervention work) "R"

This element represents the economic value of the Risk in case we do nothing to defend the beach against erosion and floods (extreme events).

We adopt the COFLERMap Model to evaluate the flood risks considering the combined effects of erosion and floods (for more details on this Model, please see Maremed BOOK n.1). It is worth reminding that the COFLERMap model uses morphological, hydrodynamic and socio-economic (land uses and economic values) data as input data, and provides risk values expressed as an economic sum per year. The Risk is assumed to be as the product between the Damages 'D' potentially effected by Hazards 'H' (extreme event) and the probability of occurrence of the extreme events:

$$R = D*H \text{ [euro/year]}$$

In the equation (1) R is also expressed by:

$$R = R_0 + \sum_{j=1}^{T} \frac{R_j}{(1+s)^j} \qquad \text{(Risk without adaptation/coastal intervention)}$$

where 'R_0' is the Risk value in the first year of computation, 's' is the interest rate and 'T' is the lifetime of the intervention work.

'R_j' is the risk in the year 'j'. The model assumes that the erosion or beach advancement values will affect the assessment of 'R_j'. In particular, an eroded beach profile causes a decrease in the beach width and a raising up of the beach slope. Both effects cause an increase of the flood level.

The method to quantify erosion or beach advancement does not fall within the objectives of this work. The method is developed by the ICZM Monitoring Centre of the Lazio Region and is described in detail in the Deliverable "Atlas of Coastal Dynamics", printed for the Maremed project.

2.1.2 The Risks with adaptation measure (or intervention work) "R_A"

The economic sum of the risk is calculated in case of adaptation measures or intervention works. This parameter is calculated by the COFLERTools Model, which simulates the presence of a coastal defense work (nourishment, dikes, barrier, groins, etc.) and re-calculates the risks, taking into account the effects of the defense work on the protection level (risk reduction).

The model re-calculates the risks considering both the positive effect of the stabilization of the beach (beach width and beach slope are maintained constant over time) and the raising-up of the protection level in terms of risk reduction.

The risk values R_A in the case of an adaptation measure is expressed by:

$$R_A = R_{A0} + \sum_{j=1}^{T} \frac{R_{Aj}}{(1+s)^j} \quad \text{(Risk with adaptation typology A)}$$

Where R_{Ai} is the risk value in year j. In this case, the effects of erosion are eliminated by the re-nourishment effect (maintenance of the beach over time by means of nourishment). The nourishment and re-nourishment costs are considered for the computation of parameter C_{RM} of the equation (1), as described in the following section.

Something which is very important is the rule of the parameter 'd' (project shoreline position) that is essential for the definition of the sustainable risk project shoreline 'd_R'. In fact, both the elements R_A and C_{RM} depend on parameter 'd'.

The higher the project shoreline position 'd', the more reduced the Risk value 'R_A'. The increase in the width of the nourishment beach, and the decrease in the slope of the nourishment beach produce dissipation effects, leading to a drop in the flood level. Also, a lower value of 'd' will cause the opposite effect to rising the risks R_A.

The value of 'd' that reduces the risks in case of intervention, as expressed by equation (1), gives us the value of 'd_R'.

The value of 'd_R' is the basis for all the choices concerning the planning of beach nourishment works. Starting from its value, we can consider also other project parameters such us the optimal position of Project Shoreline, and finally the Laying Shoreline (LS), sand volume, grain size, and all the parameters required for the implementation and maintenance of nourishment activities. The following paragraphs present some suggestions to have an optimal shoreline maintenance program based on important choices, such as the volume of recharges, the period of recharges, the position of Intervention Shoreline IS, etc.

2.1.3 Implementation and maintenance costs of coastal defense works "C_{RM}"

This parameter is calculated by the COFLERTool Model and takes into account three other factors: the implementation cost of the intervention work, the maintenance cost of the intervention work, and the cost required for monitoring the beach morphology trend.

The implementation cost is proportional to the project shoreline position, the grain size characteristics of borrow sand and native sand, closure depth, and beach berm quote. We adopt the Dean formula to calculate the project volume. The implementation cost is considered in the first year of investment.

The maintenance and monitoring costs start from the second year and last for the entire lifetime of the work 'T'. They are proportional to the volumes and costs of the sand required for the periodical recharge of the beach (in case of erosion) as well as to all the monitoring operations required to maintain the project beach (aerial photos, bathymetric surveys, analysis computations, ..).

As already showed for the other elements of equation (1), we adopt the compound interest formula actualized at the year zero:

$$C_A = C_{A0} + \sum_{j=1}^{T} \frac{C_{Aj}}{(1+s)^j} \quad \text{(Adaptation measure Costs typology A)}$$

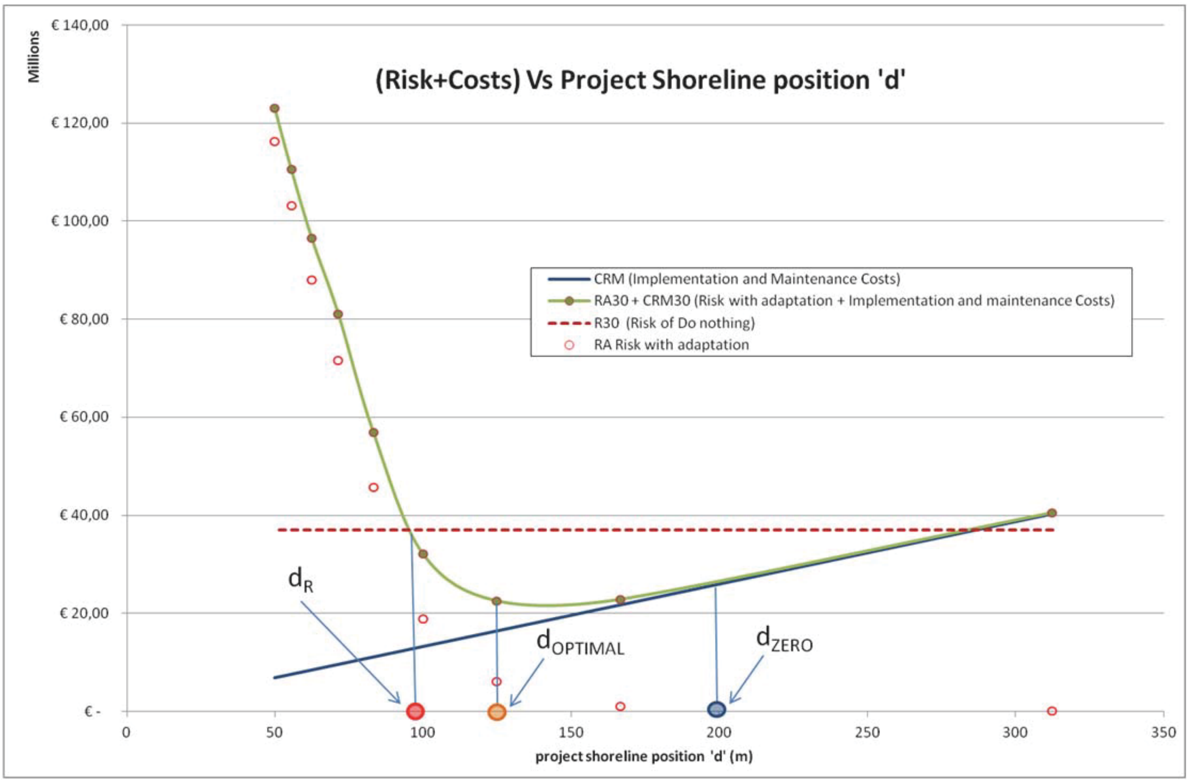
In this case, C_A is directly proportional to the project shoreline position 'd'. It will rise up in proportion to the project shoreline position.

2.2 The choice of the project shoreline position 'd'

Once we have applied the equation (1) and defined the values of sustainable risk project shoreline d_R, zero risk project shoreline d_{ZERO} and optimal project shoreline position $d_{OPTIMAL}$, next choice is the definition of the project beach (project shoreline position). How width should the project beach be in order to satisfy the project manager requirement? Obviously, this depends on the funds that the coastal Administration can spend, and on the risk level it intends to endure.

This methodology could answer these questions by using the economic risk evaluation approach that we adopted (COFLERMap and COFLERTools).

We adopt the graphic representation of '(Risk+Costs)' versus 'd' trend line, i.e. the representation of the sum of risks and costs in case of an adaptation measure (R_A+C_{RM}), which varies depending on the project shoreline position 'd'.



Representation of the Risk-'d' trend line. An cost-effective method to choose the optimal project shoreline position.

This graph shows the trend line of the combination between risks and adaptation costs, as well as the risk value in case of "Do nothing" (red line). The interception between the two lines gives the value of 'd' that solves the equation (1), i.e. the position of *sustainable risk project shoreline* 'd_R'. The minimum value of the green curve (R_A+C_{RM}) indicates the position of *optimal project shoreline*.

The representation of the costs curve (blue line) helps the decision maker (Coastal Administrator/Project Manager) to choose the beach project width, according to the availability of economic resources and the level of risks he/she wants to tolerate. The interception between the green curve and the blue line gives indicates the position of the *zero project shoreline*.

Other considerations on these aspects are included in chapter 4 of this volume, which is dedicated to the description of the pilot action carried out on a pilot site along Lazio Region's coasts.

3. Monitoring and restoration of the Project Shoreline

This chapter is dedicated to the description of two different approaches for the monitoring of the project shoreline. We analyze the volumetric approach and the emerged beach approach.

Both methods have the objective to calculate the position of Intervention Shoreline IS. This is an "alert" shoreline that informs the coastal manager that an intervention of re-nourishment is necessary in order to restore the position of Project Shoreline PS. This position is proportional to the time required to make a new recharge of the beach (technical times). The objective is to intervene before the shoreline reaches the position of the Sustainable Risk Project Shoreline SRPS.

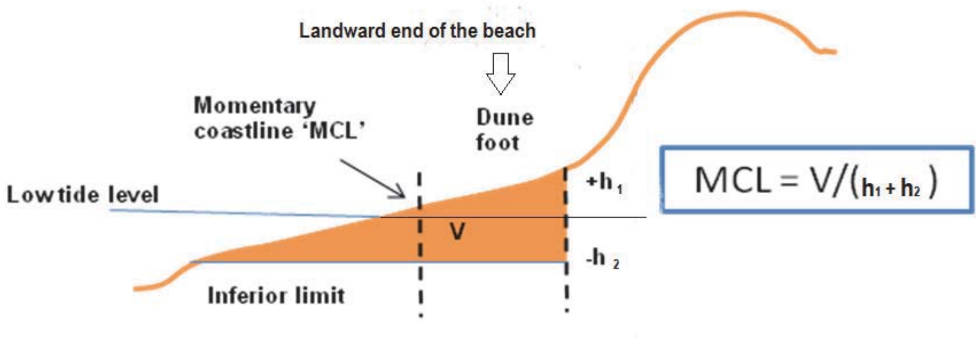
The volumetric approach, stricter and more expensive, consists in the evaluation of sand volumes actually available on the beach profile, starting from the emerged beach to the submerged bar. A method adopted by the Dutch government for the management of their coasts. This helps us to understand how to draw a shoreline that represents the health state of the beach at a given time (see section 3.1).

The emerged beach approach is a simplification of the volumetric approach, but more expeditious and cheaper. It is based on the hypothesis that the area of the emerged beach is representative of the sand volume available on the beach profile. Even if questionable, this hypothesis enables us to trace an evolutionary trend line of the beach position over time (e.g. each year) with simple technical equipment needed and a limited budget.

3.1 Volumetric Approach

This approach is currently utilized by the Dutch Government to monitor the health state of the beach. The most rigorous method to understand the evolution of the beach is to analyze the sand volume both in the emerged beach and in the submerged part of the beach profile.

The Dutch methodology adopted the Momentary Shoreline (MS) monitoring, a theoretical shoreline that represents the state of a beach in a specific moment. The MS is defined by some morphological parameters. Its position is based on the area of the beach profile encompassed between the height of the “landward end of the beach” (e.g. the foot of the dune) at roughly Mean Sea Level +3m, and the bathymetric -4m schematized into a rectangular shape, with the same area as the measured profile.



Momentary Shoreline definition. Volumetric Approach (VNK Project)

In order to evaluate whether an intervention is required to protect the shoreline, a bathymetric survey program is planned at fixed times (each year e.g.). The MS could be extracted on a beach profile with longitudinal distances of 200m each. In case the MS reaches the position of Intervention Shoreline IS, a beach re-nourishment must be planned to restore the current beach in the position of Project Shoreline PS. This operation could be made in different steps, to be defined during the monitoring plan, in proportion to the erosion trends.

Every year, the MS is computed according to the current condition of the beach. Based on the MS of several years in a row, a trend line is determined and the position of the shoreline in the next year is estimated. When bathymetric measures are missing, the shoreline position can be determined by esteeming the following year's position of the real shoreline. Alternatively, we can use the Emerged beach monitoring approach.

3.2 Emerged beach approach

Based on the hypothesis that the emerged beach area is the sand volume of the entire beach profile, this approach could be utilized in case the volumetric monitoring approach represents both a technical and economic obstacle for the application of this shoreline management methodology on the coastal area.

The Lazio Region ICZM Monitoring center carried out some studies in the past, in order to validate this important assumption. A clear relation between emerged beach areas and volumetric sand deposits has not been demonstrated yet in all the analyzed cases; but in specific areas and with some specific assumptions, a correlation between the two parameters was observed. Obviously, the volumetric approach remains more rigorous for the application of this methodology.

Once the images on the emerged beach area (satellite images, aerial photos, etc.) have been acquired, the analysis of emerged beach is obtained by the interpretation of the shoreline and the comparison between shorelines acquired in different periods. A good representation of beach evolution could be obtained with yearly shoreline acquisitions.

The objective is to make a comparison between the Momentary Shoreline (MS) (simply drawn according to the interpretation of the images) and the Intervention Shoreline (IS) (established during the shoreline planning phase). In case the MS is positioned behind the IS, all the intervention operations must get started in order to carry out the re-nourishment before the Sustainable Risk Shoreline is achieved.

This method is also more expeditious if we consider the time needed to draw the momentary shoreline. The knowledge of the erosion trend in the analyzed shoreline will help to define Maintenance Program.

3.3 Shoreline Maintenance program

The Shoreline Maintenance Program consists in the definition of the costs, technical tools and staff required to carry out monitoring activities and interventions. These Programs are developed during the shoreline management planning phase, and must take into account some specific parameters which are essential for the knowledge of coastal evolution.

Morphological parameters such as the erosion trend of the analyzed area are essential to define the periods and costs required for carrying out monitoring campaigns.

If the volumetric approach is applied, bathymetric monitoring campaigns are required in order to understand and design the beach profile of the area. The distances between each beach profile must be defined when defining the Shoreline Management Program. Distances could be chosen according to the regularity of the morphology in the coasts. For example along the coasts of the Emilia-Romagna Region, where the morphology of the shorelines is quite regular, an ongoing monitoring of beach profiles was adopted, with distances of 500m between one monitoring and the following one. Instead, along the coasts of the Lazio Region, where coastal evolution is more irregular, a 100m distance was adopted.

The frequency between each monitoring campaign and the following one should also be defined when defining the Shoreline Management Program, consistently with the erosion trend of the area.

This methodology was applied to a pilot site along the Lazio Region coast to analyze and understand all these aspects.

4. Application of the methodology on a pilot site along the Lazio Region coast.

The area of Montalto di Castro (Viterbo) was chosen because of the availability of good quantitative and qualitative data on the morphology of this area, and also because a risk evaluation had already been carried out in this area using the COFLERMap and COFLERTools models. Risk evaluation results are preparatory for the application of this methodology.

4.1 Morphology

Located in the Municipality of Montalto di Castro (Viterbo) in the northern part of the Lazio Region, this Pilot Area is comprised between the river Fiora in the north, and the Sanguinaro Channel for a total length of the coast of about 1.4 km.

The morphology of the area was characterized by a LiDAR campaign commissioned by the Lazio Region in 2010. Bathymetric surveys were also carried out in 2003 and 2005. This part of the littoral is characterized by a stable trend (Atlas of Lazio Coastal Dynamics, Maremed 2013). We assumed zero erosion in case of 'do nothing', and an erosive trend of 2 m^3/m per year in the case of nourishment. The main slope of the emerged beach is about 2.5% for the stable beach profile. The berm quote, i.e. the maximum quote reached by emerged active beach profile, is Q_b = 2.5m above sea level and we assumed this quote remains constant during beach evolution.

Morphologic parameters that we consider variable over time are the distance 'd' of project shoreline from the Not Erodible Line NEL, and the main slope of the beach. The reference shoreline that we consider at time Zero for all risks computations is the shoreline in 2005, that was registered with a distance of d_{2005} = 100 m from the NEL (mean value of the analyzed coast).

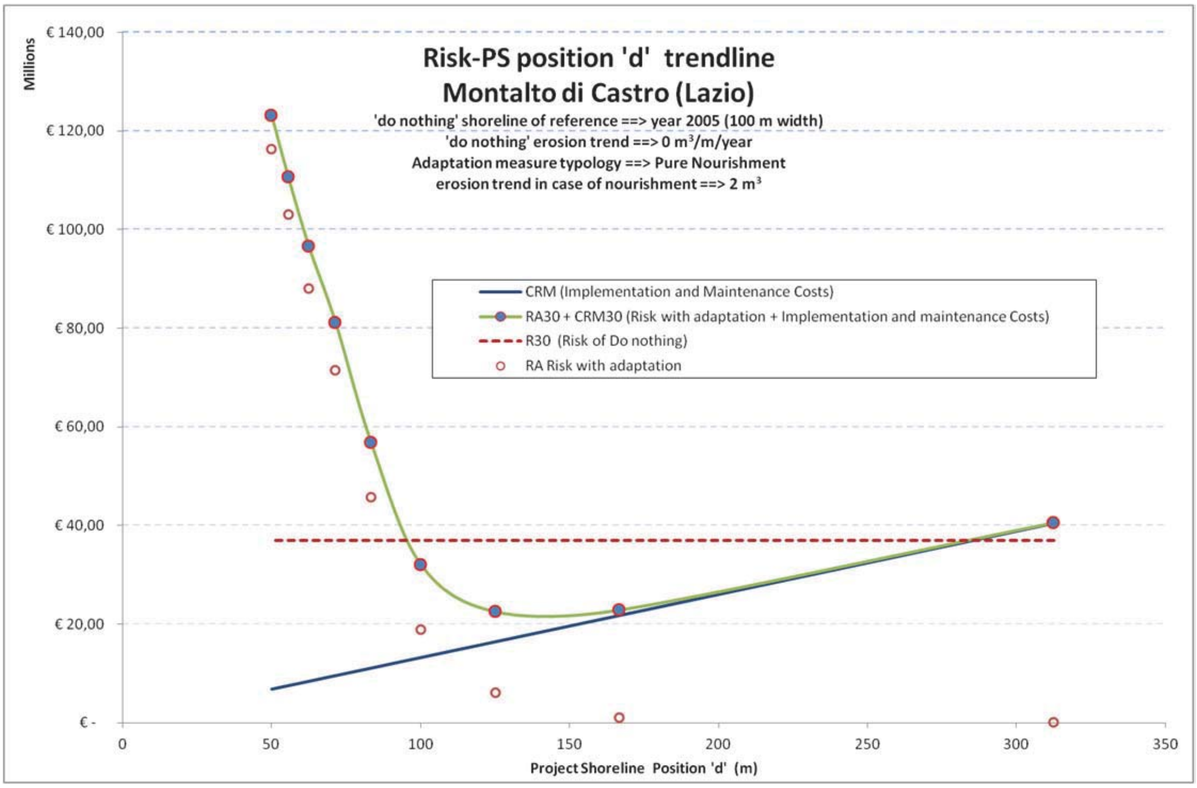
4.2 Computation of risks and costs

We applied the COFLERMap and COFLERTools models in order to evaluate the flooding risks as well as the implementation and maintenance costs for two typologies of interventions: Pure nourishment and Protected nourishment. We calculated the risks both in the case of no adaptation (do nothing) and in the case of the implementation of an adaptation measure. The objective is the application of the equation (1) to find the value of the Sustainable Risk Project Shoreline position 'd_R'.

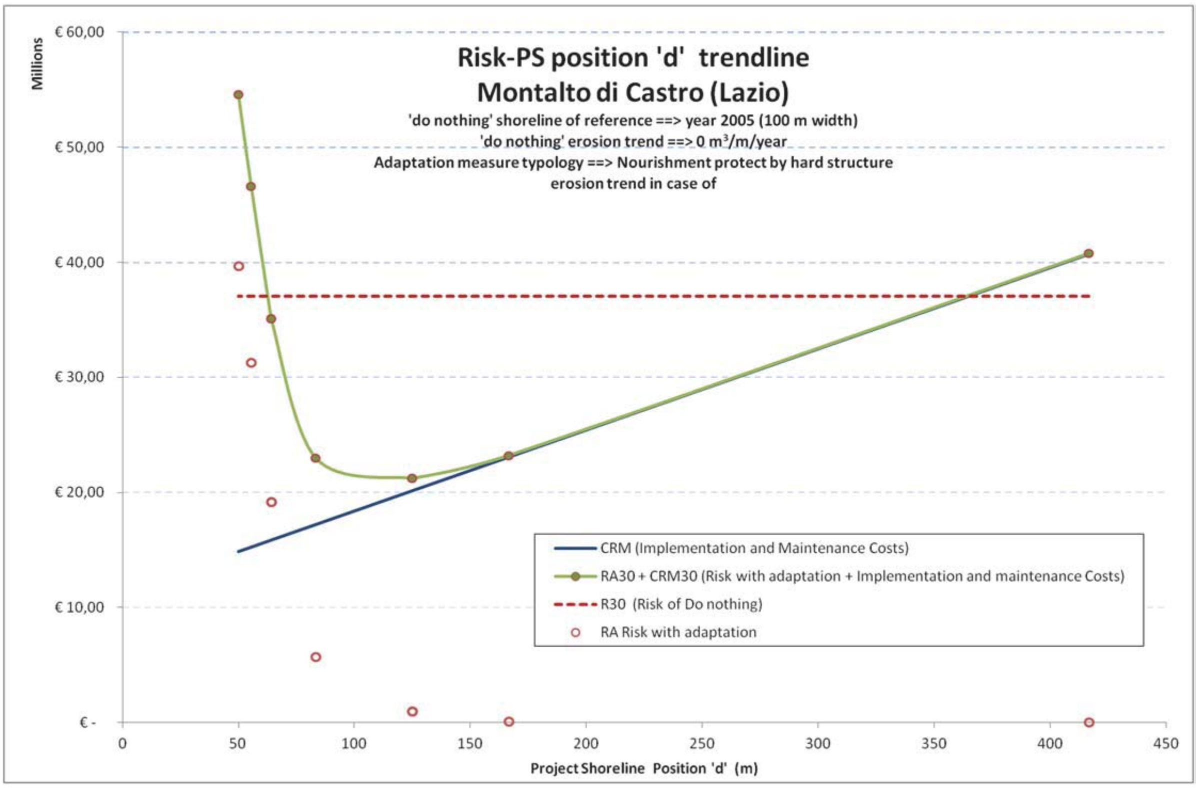
The Risk value in case of no adaptation with a return period of 30 years is R_{30} = 1.5 Million euros/year. Implementation costs are proportional to the project volume and unitary costs of sediments. The Project volume is proportional to the Project Shoreline position 'd' (Dean formula), and unitary costs of sediments are derived from the long experience in nourishment works carried out by the ICZM Monitoring Centre of Lazio Region. We assumed a cost of 7 €/m^3 for the first nourishment (implementation costs) and 15 €/m^3 for the following re-nourishment (maintenance costs).

Risks in the case of nourishment was calculated for different values of Project shoreline positions and reported in a graph for the elaboration of the trend curve. These values summed up to the implementation and maintenance costs, were compared with the risk level without intervention R = 37.1 M€ (Risks without adaptation).

Computations are referred to a time frequency of 30 years.



Curve Risk-PS in the case of pure nourishment



Curve Risk-PS in the case of nourishment protected by hard structures

The value of the Project Shoreline Position that suitably represents the Coastal Administration needs, in terms of sustainable risk level and/or costs, is choice that decision makers should make during the planning phase.

In the case of pure nourishment, the sustainable risk of the project shoreline position d_R is about 100m, while in the case of nourishment protected by hard structures is about 60m. The highest protection level will cause the highest risk reduction, with a higher level of initial investment. This is probably a foregone conclusion, but the quantification of these aspects from an economic point of view could be fundamental for decision makers.

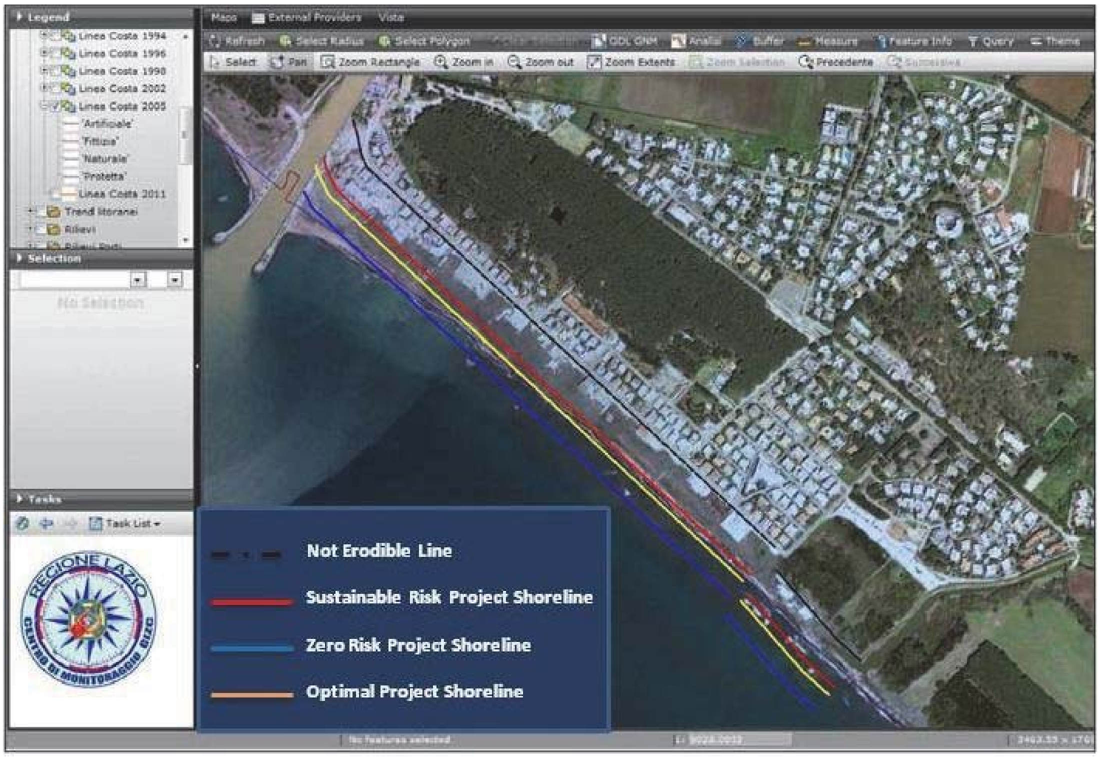
In order to simplify the description of the model application, we reported above the computation results obtained in the case of pure nourishment.

This model provides a range of values between which the Project Shoreline position could be established. The minimum value is characterized by the Sustainable Risk Project Shoreline position 'd_R' and maximum value is characterized by the zero risk project shoreline position 'd_{ZERO}'. As shown in the graph above, d_R = 100m and d_{ZERO} = 180m.

The value of 'd' corresponding to the best cost-effective choice is represented by the minimum value of the curve (R_A+C_{RM}), i.e. the *Optimal Shoreline position* $d_{OPTIMAL}$ = 125m. After 30 years this choice will reduce the risk level from R_{30} = 37.1 M€ (risk without adaptation) to R_{A30} = 6.1 M€ (risk with adaptation), with implementation and maintenance costs equal to C_{RM30} = 22.4 M€ obtaining a Net Benefit of the adaptation of $B_{30} = R_{30} - (R_{A30} + C_{RM30})$ = 37.1 - (22.4 + 6.1) = 8.6 M€.

All the results of the computation are reported in the following table for the case of Adaptation measure with Pure nourishment:

R_{A30} + C_{RM30} (Risk with adaptation + Implementation and maintenance Costs)	R_{30} (Risk of Do nothing)	R_A (Risk with adaptation)	C_{RM} (Implementation and Maintenance Costs)	B_{A30} (Net Benefit after 30 years)	Project Shoreline Position 'd' [m]	Beach Main Slope
€ 43,750,668.49		€ 219,574.66	€ 43,531,093.82	-€ 6,693,671.52	250	1.0%
€ 30,526,154.95		€ 1,093,639.91	€ 29,432,515.04	€ 6,530,842.02	167	1.5%
€ 28,473,130.21		**€ 6,089,904.57**	**€ 22,383,225.64**	**€ 8,583,866.75**	**125**	**2.0%**
€ 37,055,497.82		€ 18,901,845.81	€ 18,153,652.00	€ 1,499.15	100	2.5%
€ 61,103,066.10	€ 37,056,996.97	€ 45,769,129.85	€ 15,333,936.25	-€ 24,046,069.13	83	3.0%
€ 84,899,759.31		€ 71,579,905.75	€ 13,319,853.56	-€ 47,842,762.34	71	3.5%
€ 99,914,234.34		€ 88,104,942.79	€ 11,809,291.55	-€ 62,857,237.37	63	4.0%
€ 113,756,422.59		€ 103,122,012.60	€ 10,634,409.98	-€ 76,699,425.62	56	4.5%
€ 125,992,809.97		€ 116,298,305.24	€ 9,694,504.73	-€ 88,935,813.01	50	5.0%



The results of Project Shoreline computations could be represented on WEBGIS tools.
The shoreline in 2005 is indicated by the black line.

4.3 Monitoring and Maintenance Program

If we assume an adaptation of the beach profile with a regression of about 75 m during the first year of the nourishment, we can calculate the position of Laying Project Shoreline dLS = 175m. After one year the shoreline will probably reach the position of Project Shoreline and after 15 years it will probably reach the position of Sustainable Risk Project Shoreline. However, a yearly shoreline survey with the Emerged beach approach is recommended and a beach nourishment monitoring every 5 years with the Volumetric approach is recommended too, in order to understand the actual steadiness of the beach profile.

The results of the Shoreline Management Program applied to the Pilot area of Montalto di Castro are reported in a schedule which summarizes all the parameters and results adopted during the application of the model.

A sample of the results obtained by the shoreline management program (Montalto di Castro, Lazio)

5. References

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White paper on Adapting to climate change

Med Program

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