WAC-App: West African Coastline App

Call for Innovation: Impacts of Port Development on West Africa's Coastal Areas

Client

The World Bank – West African Coastal Areas Management Program (WACA)

WAC-App: West African Coastline App

Call for Innovation: Impacts of Port Development on West Africa's Coastal Areas

Final report

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Summary

This report describes a proposed tool 'WAC-App: West African Coastline App' that was awarded first prize in WACA's 2020 Call for Innovation.

WAC-App is an easy-to-use tool that rapidly calculates and visualizes coastal evolution and the impacts of coastal interventions. Results are presented in a way that is easy to interpret and allows users to optimize interventions. The proposed application aims to bring a positive change to the practice in coastal planning and help solve some of the specific challenges that West-African countries are facing, such as combating coastal erosion while implementing (port) development plans.

Key features of the proposed WAC-App are:

- WAC-App shows how a proposed intervention impacts its surroundings under selected conditions (including climate change impacts) and, because of its quick results, can be an effective tool in (early stages of) coastal planning activities.
- WAC-App will be available to everyone. It will be open source and free-of-charge to its users.
- WAC-App bridges the knowledge and communication gap between scientists, decision makers and the public and can be easily used in stakeholder engagement sessions.

We present the initial idea for the innovation, a demonstrator case, a market demand analysis and a business plan. The table below indicates in which chapters the required deliverables from the Terms of Reference can be found.

Deliverable	In this Report
1. Basic test version of App	Chapter 2
2.1. Presentation of test version of App at the WACA Marketplace	Chapter 3
2.2. Report/proceedings from the Marketplace consultation & lessons learned	Chapter 3
3.1. Market Demand Analysis, including data availability and gap analysis	Chapter 3
3.2. Pilot product delivery	Chapter 3
4.1. Technical workshop, including app demonstration	Chapter 3
4.2. Report – lessons learned from the technical workshop	Chapter 3
5.1. Business Plan	Chapter 4
5.2. High level webinar (PMAWCA meeting)	Annex B

Glossary of terms

GEE	Google Earth Engine
MSEPO	Maritime Security Environmental Protections and Operations
PMAWCA	Port Management Association of West and Central Africa
WACA	West Africa Coastal Areas Management Program
WAC-App	West African Coastline Application
WARCO	West Africa Regional Coastal Observatory
CSE	Centre de Suivi Ecologique (Ecological Monitoring Centre)

Table of contents

1 Introduction

1.1 The challenge

The West-African coast suffers from coastal erosion, causing flood threats and harming local economies, livelihoods and ecosystems. Among the aspects that have accelerated the coastal erosion process are developments of ports, other coastal and riverine infrastructures and impacts due to climate change. Key challenges for the future are to find effective solutions to mitigate or even reverse on-going erosion problems, and to make sure that new developments are designed and implemented in harmony with the geomorphological coastal processes.

With our current understanding of coastal geomorphology, it is feasible to anticipate on future coastal changes, either with or without interventions along the coast. However, this knowledge is typically reserved to a rather select group of coastal experts and is not readily available to the much wider range of stakeholders that are involved in - or impacted by - coastal processes and coastal developments in West Africa. Our ambition is to make this knowledge available to a wider audience, by offering an easy-to-use tool that allows to learn from past interventions and to explore suitable strategies for future coastal developments.

WACA's 2020 Call for Innovation
In 2020 the World Bank (WB) launched a Call for Innovation for the WACA program with the objective to identify and leverage ideas and technology solutions to fight coastal erosion and flooding issues associated with the development of coastal infrastructures, mainly ports, with limited planning and consideration of potential impacts to downstream communities.

Our proposal in this Call for Innovation addressed the specific challenge of bringing specialized knowledge on coastal morphology closer to decision makers and other stakeholders. The goal is to achieve a generally better understanding of coastal processes among a wide range of stakeholders, which would have a positive impact on coastal planning projects and on identifying possible hazards. With the proposed easy-to-use tool WAC-App, it would be easier to consider morphological effects early in planning processes.

The call for innovation jury recognized that the proposed approach of WAC-App, which would assist communication

between decision makers, technical experts, and other stakeholders, could be relevant for many countries in West Africa and could be easily and rapidly implemented. Subsequently, WAC-App has been selected as first place winner and has also been included in the WACA Innovation Book[1].

1.2 Our proposed innovation

Our proposed innovation 'WAC-App' is an open-access easy-to-use online application that gives insight into the effects of coastal evolution and possible coastal interventions. The application is built upon a validated coastline evolution model 'ShorelineS'[2], which allows quick evaluation of coastal response over different spatial scales of ~10-100km. In WAC-App, interventions can be drawn onto a map and, next, a new coastline as it will develop over time is calculated. The position of the new coastline in relation to the existing coastline immediately shows where erosion problems would occur and where sedimentation is expected. The application will be set up in the cloud, making use of its remote computational power and available global data sets. A "mobile first philosophy" will be followed, such that it can be run from laptop, tablet or even smartphone.

WAC-App combines the functionalities of the innovative coastline evolution model 'ShorelineS' with online interactive geoprocessing and mapping functionalities. The tool provides insights in long-term coastal development and through its simple and user-friendly user-interface promotes the inclusion of a wide range of stakeholders in participatory planning. WAC-App will be open access and free of charge to its users.

WAC-App is operated along the following steps (see Figure 1):

1. Select an area of interest from the map of West Africa. Choose from predefined coastal sections of length ~100 km.
2. To allow assessment of past and future coastal changes, in the selected area a baseline shoreline may be selected from one of the past ~25 years. The user may manually adjust the selected shorelines.
3. The user can choose and locate interventions in the map. The interventions need to be connected to the shore and can be of different types and different magnitude:
    a. Nourishment / dredging (an area can be defined where sediment with a chosen volume is deposited or extracted).
    b. Generic hard structure (an intervention fixing a selected section of the local shoreline can be chosen or draw on the map a new hard structure).

[1] https://storymaps.arcgis.com/stories/09a08140ebc947168ce9fa3ea63b05f0
[2] https://www.slideshare.net/Delft_Software_Days/dsdint-2019-shorelines-and-future-coastline-modelling-roelvink
https://www.frontiersin.org/articles/10.3389/fmars.2020.00535/full

c. Permeable structure (similar to b, but permeable)

4. A new coastline is calculated based on the drawn interventions and chosen evolution horizon (1 to 10 years). Also, in this step a preferred climate /wave scenario may be selected (from ~5 pre-defined options). The coastal evolution model 'ShorelineS' is used to calculate a new equilibrium coastline. ShorelineS uses the existing coastline, the predefined offshore wave conditions as well as input data from the planned intervention. The model operates online and gives near-immediate results.
5. Re-adjust the interventions or baseline data to explore the effects of other scenarios or design configurations.
6. Re-calculate the coastline to explore cause-and–effects or optimize interventions until a desired equilibrium situation is achieved.

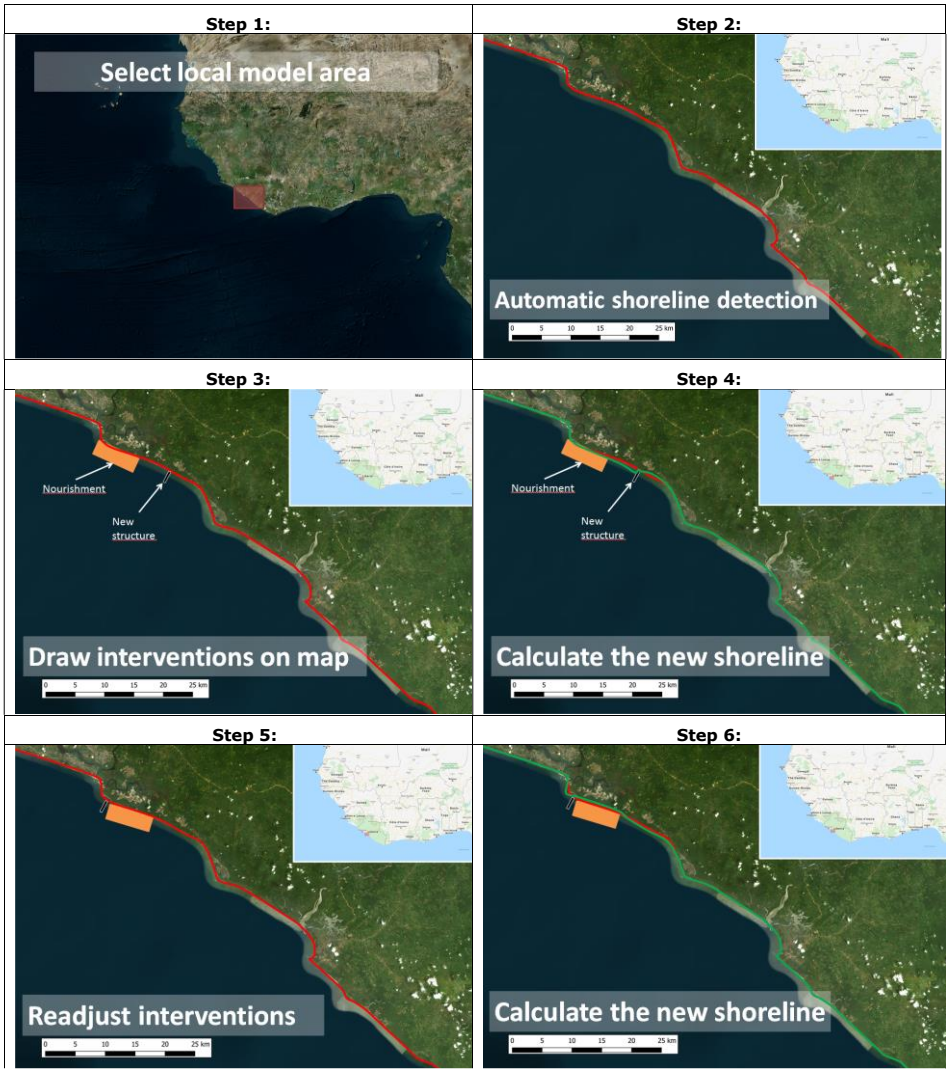


Figure 1 Step-by-step impression of WAC-App operation

1.3 Our team

Our team is a combination of experts from private research and consulting firm HKV and IHE Delft Institute for Water education. Both organizations are

from the Netherlands, with complementary expertise in the broad subject of water management and engineering.

HKV (lead firm)

HKV is a privately owned company that was established 25 years ago in the Netherlands. Currently, HKV has about 80 staff members. HKV's core work is research and advice in water management, natural hazard assessments, system behaviour of fluvial zones and (geo-, hydro-)data analysis and modelling of rivers coasts and delta's. Through its specialized IT department, HKV develops and implements a variety of information systems and applications in the fields of water management. These products and services include web applications, Early Warning systems, and data management and dissemination tools to inform a variety of potential stakeholders. HKV's experience in West-Africa has grown rapidly over the past decade, where activities have focused on flood risk studies in Ghana and neighbouring countries.

IHE Delft Institute for Water Education

IHE Delft is the largest international graduate water education facility in the world. IHE Delft carries out educational, research and institutional strengthening activities that complement and reinforce each other in the broad fields of water engineering, water management, environment, sanitation, and governance. The Institute offers a unique combination of applied, scientific and participatory research in water engineering combined with natural sciences, social sciences and management and governance. Since its establishment, the Institute has played an instrumental role in developing the capacities of water sector organizations around the world. The Chair group of Coastal Systems and Engineering and Port Development has for several years been actively involved in coastal erosion studies in West Africa.

1.4 This report

This report gives an overview of initial developments for WAC-App (prototype version, see Chapter 2) and describes a Market Demand Analysis (Chapter 3) to support the path towards implementation of an operational version of WAC-App. The Market Demand Analysis is based on interviews with stakeholders and a brief analysis of how to align WAC-App with on-going projects and activities. Next, a business plan including financing needs is presented (Chapter 4).

2 Demonstrator Case

This chapter explains the main concepts behind WAC-App and demonstrates a prototype version (i.e. "alpha version").

2.1 Prototype design of WAC-App

For a prototype of the WAC-App we combine two tools that capture the key functionalities of WAC-App:

1. Coastline detection via Google Earth Engine
2. Coastline development via ShorelineS

In this prototype of the WAC-App, the user first defines the coastline for an area of interest in a specific year, using an existing automated coastline detection tool in Google Earth Engine. The resulting coastline is then transferred to ShorelineS where interventions can be chosen, and a new shoreline is calculated. Next, in ShorelineS adjustments can be made to the interventions and their locations to explore impacts on coastal morphology.

2.1.1 Coastline detection

The coastline is detected from satellite imagery using Google Earth Engine. Google Earth Engine is an open geospatial data platform that provides access to a wealth of satellite-derived and GIS data. It offers easy and fast processing and mapping of satellite data online.

Within Google Earth Engine we use a toolkit to extract shorelines from satellite imagery called CoastSat[3]. The used satellite imagery are the publicly available Landsat and Sentinel-2 images. Cloudy pixels are removed in the pre-processing phase and the spatial resolution is enhanced. Next, a shoreline detection algorithm is used to detect the shoreline with an accuracy of ~10 m at sandy beaches. This procedure allows extraction of over 30 years of satellite-derived coastlines.

For a later operational version of WAC-App, the coastline detection will not be repeated for each new simulation. Instead, we will prepare and store within WAC-App coastlines from the past ~25 years for the entire West-African coast. A user may then select in WAC-App one of these coastlines as a starting point for the simulation. If needed, the user can make manual adjustment to the selected coastline.

[3] Vos, K et. al. (2019). CoastSat: A Google Earth Engine-enabled Python toolkit to extract shorelines from publicly available satellite imagery. Environmental modelling and software, 122. https://doi.org/10.1016/j.envsoft.2019.104528

2.1.2 ShorelineS model

The model that we use to calculate coastline development is called 'ShorelineS'. ShorelineS (Roelvink et. al, 2020[4]) is a coastline evolution model that is capable to describe coastline transformation based on relatively simple principles borrowed from general coastline theory (Pelnard-Considere, 1956[5]) and the Coastal Evolution Model (Ashton et al., 2001[6]). ShorelineS can be used to simulate the coastline evolution for different spatial scale (1km-100km) at monthly to century timescales. It was developed at IHE Delft and has been validated and applied for several real-world cases (Elghandour 2018[7], Roelvink et al. 2018[8], Mudde 2019[9]). ShorelineS is an open-source model of which the whole code is available freely to all the developers and can be used by anyone interested in modelling evolutions of coastlines.

ShorelineS describes the coastline as a freely moving string of grid points. It allows for an arbitrary number of coast sections, which can interact with each other by merging or splitting. This way, ShorelineS overcomes the limitations of existing models that are based on a fixed reference coastline, while avoiding the complexities of grid-based approaches and geometrically complex volume reconstructions. As a result, ShorelineS allows for diverse realistic dynamic behavior, including shoreline undulations and formation of spits, migrating islands and merging of coastal shapes.

ShorelineS accounts for the effect of "wave shadowing" when complex coastal shapes influence wave propagation towards the shore. It can consider the effect of natural obstacles (e.g., rocky headlands) or existing structures (e.g., ports) and include new/planned interventions (e.g., nourishment, new coastal protection structures) in the simulations in a pre-defined or interactive manner. It also treats the behaviour of river mouths and tidal inlets, interrupting the sandy coasts, through simple algorithms that keep a mouth open at a specified width depending on the discharge, redistribute sediment locally or add the sediment discharge of the river to the adjacent coastal areas.

[4] Roelvink, D et. al,. (2020). Efficient Modeling of Complex Sandy Coastal Evolution at Monthly to Century Time Scales. Frontiers in Marine Science, 7(535). doi:10.3389/fmars.2020.00535

[5] Pelnard-Considere, R., (1956). Essai de theorie de l'Evolution des Formes de Rivages en Plage de Sable et de Galets, 4emes Journées de l'Hydraulique, les Énergies de la Mer, Question III, Rapport No. 1, pp. 289-298.

[6] Ashton, A., Murray, A.B., Arnoult, O., (2001). Formation of coastline features by large-scale instabilities induced by high-angle waves. Nature 414, 296-300.

[7] Elghandour, A.M. (2018). Efficient modelling of coastal evolution : development, verification and validation of ShorelineS. IHE Delft. MSC Thesis. https://cdm21063.contentdm.oclc.org/digital/collection/masters2/id/81532

[8] Roelvink, D. et al. (2018). Efficient modelling of complex coastal evolution at monthly to century time scales https://github.com/danoroelvink/shorelines/blob/master/doc/ICEC2018_Paper_Roelvink_final_14-8.pdf

[9] Mudde, C. (2019). Development and verification of ShorelineS on longshore sediment transport and spit formation. TU Delft. MSC Thesis. http://resolver.tudelft.nl/uuid:b5845e73-c410-4145-8b1b-cad843d9a107

An example validation case for ShorelineS in West Africa is shown in Figure 2, where a complex section of the coast near St Louis (Senegal) was modelled. The two images under "T=13 years" show the observed coastline in 2016 (left, labelled "obs") and the modelled coastline using ShorelineS (right, labelled "sim"). The Shorelines simulations started from the coastline as observed 13 years earlier (in 2003, see images under "T=0 years"). It shows that the coastline changes over this 13 period are accurately reproduced by the model.

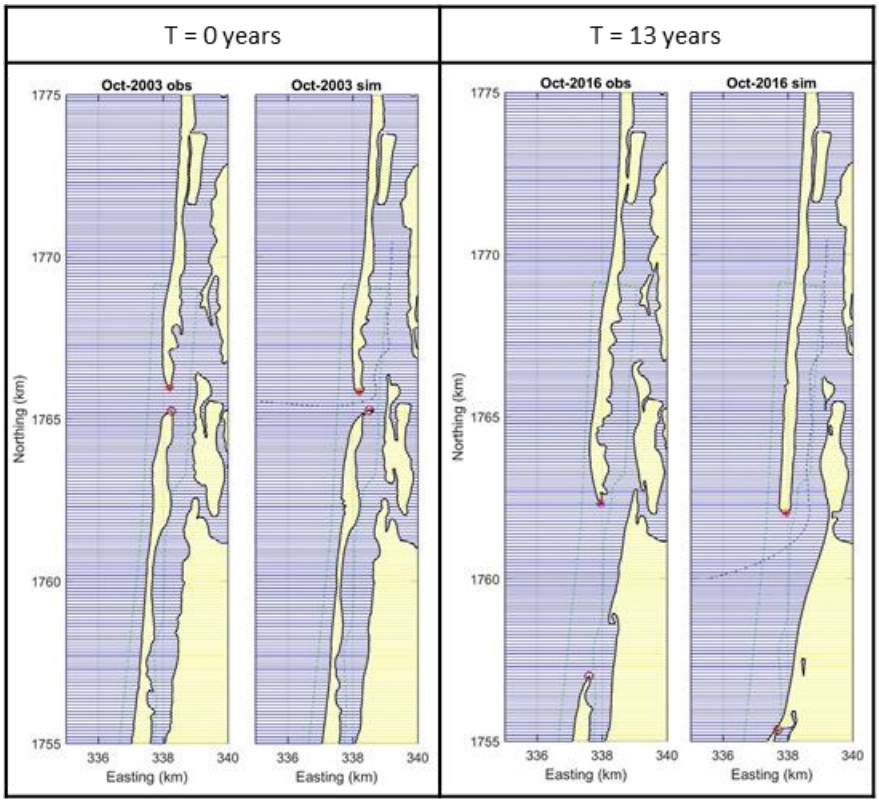


Figure 2 Validation of model Shorelines using the case of St Louis, Senegal. Left images: observations and model results for situation in 2003, Right images: observations and model output in 2016.

2.2 Prototype application

In applying the prototype as described in Section 2.1, several manual steps are needed to feed the output of the coastline detection from CoastSat as input into ShorelineS. In Appendix A we describe step-by-step how to work with the WAC-App prototype. An accompanying demonstration of the prototype of WAC-App is also available as YouTube video[10].

[10] See demonstration video of WAC-app prototype at: https://youtu.be/rb6MoVKukrg

3 Market-demand Analysis

This chapter covers a market demand analysis, which includes summaries from meetings with stakeholders and a gap analysis. Next, key features for an operational version of WAC-App are proposed (or "WAC-App beta version"). Also, options are listed for possible future expansions.

3.1 Stakeholder meetings

To understand the needs of potential users of WAC-App various meetings were held with different stakeholders. Below a summary is given of these meetings, highlighting key requests and suggestions from the stakeholders.

3.1.1 Kick-off meeting with client

On 22 March 2021 a kick-off meeting was held with experts form the WACA World Bank team (Figure 3).

Figure 3 Presenting the team and WACA-App during the kick-off meeting.

During the meeting the intended functionalities of the WAC-App were discussed, which led to the following points of attention (response from HKV in *italics*):

- The timescale of morphodynamical forecasts is a crucial aspect for this App. Will the user be able to select the time scale? Or are pre-defined timescales offered?
  - *We propose a time horizon of up to 10 years.*
- Regarding the baseline data for the app (wave and wind field, infrastructures) be conscious of the most widely accepted data set, and allow (manual) adjustments if needed (including river mouths and islands)
  - *The app will include a standard baseline data set, and this will be agreed upon with the West-Africa Regional Coastal Observatory (see section 3.1.4). The user can manually adjust the Baseline data if needed.*
- The computation time should be acceptable because the tool is meant to support planning and allow for exploration of various options.
  - *Yes, we consider this a key functionality of the App and this will be the limiting factor for spatial resolution and size of the area that can be considered. Also, for this reason a time horizon of around 10 years is considered.*
- Case studies should show the possible range of application. Consider diverse cases such as St Louis (Senegal), Togo/Benin, and having port developments.
  - *As initial case we include St Louis, Senegal. Other cases will be included in the future.*

3.1.2 Stakeholder meeting with Royal IHC

On 25 May 2021 a meeting was held with Royal IHC to discuss purpose and specific needs of WAC-App for their business. Royal IHC was represented by their Africa sales manager, who has extensive experience in Africa's port sector and understands the governance and partnerships required to implement trans-boundary solutions for sustainable ports in West Africa. Main commentaries on the use of WAC-App were (response from HKV and IHE Delft in *italics*):

- For many stakeholders in coastal erosion and port developments there is little understanding on the opportunities and impacts of dredging. This tool could increase that understanding and help in wider and more targeted and effective use of dredging activities. Therefore, it would be valuable if the App allows definition of a dredging scheme.
  - *This will be a standard option in the definition of the nourishment interventions. We are aware of the importance that the tool should be able to be operated by a wide range of stakeholders.*
- The tool could lead to better understanding on the relation between repositioned sediments (nourishments/dredging and tracking of volumes) and intended impact.
  - *We agree that this is an important functionality, making the tool useful for explorations in the dredging sector.*
- The tool could be a valuable in the operations of IHC, both in exploring effective interventions as by communicating these to potential clients.

- *Good to know that the dredging sector is a potential client.*

3.1.3 WACA/World Bank meeting

On 25 May 2021 after the meeting with Royal IHC a follow-up meeting was held with the WACA World Bank Team. Further comments from that meeting were (response from HKV and IHE Delft in *italics*):

- There are already existing applications that built on Google Earth Engine, such as the Aqua Monitor[11] and the Shoreline monitor[12] (and more[13]). Would it be a good idea, and possible, to align with those?
  - *The mentioned applications show geographical changes as derived from satellite observations, but they do not include morphological modelling to anticipate on future (man or climate induced) changes. Therefore, WAC-App goes beyond existing applications. Some functions of existing applications may be relevant, and we will use similar interactive functionalities as available in those tools (e.g. selecting start and end years). We think it is better to keep the application separate, to avoid that too much user functionality with different objectives makes the tool difficult to understand for a wide range of users.*
- To achieve wider attention for the App, it is included in the 2021 Book of Innovations[14].
  - *We appreciate this help from the WACA team.*
- It is important to include learning resources to support usage of the App (webinar, tutorial). Show how the App can support decisions.
  - *The app will indeed have such material included. We also propose a launch event whenever the operational version is available.*
- The app is envisioned as a "responsive website" and initially not as an app to operate on mobile phone. For the mobile phone the user-interactions on a map would possibly not work very well. Would exclusion of a phone App limit its use?
  - *We feel that for the first version simplicity and user-friendliness of the App is key to achieve a wide user-base. If user experiences show that a mobile phone version is desired, and if we believe that can be achieved without compromising user experience, we will consider this option. However, we see a higher priority in making sure the App functions well on laptop or tablet.*
- The main two purposes of the tool are (1) to obtain quick insight on longer term coastline impacts and (2) to easily explore interventions options. Together, these would enhance accountability of coastal interventions and plans (inexpensive assessment of options).

[11] https://aqua-monitor.appspot.com/
[12] https://aqua-monitor.appspot.com/?datasets=shoreline
[13] See:
https://gena.users.earthengine.app/view/global-hand
https://dmmangrove.hkvservices.nl/hydropc/
[14] https://storymaps.arcgis.com/stories/09a08140ebc947168ce9fa3ea63b05f0

- *We agree that the tool may be used to support accountability of coastal planning. This, once again, underlines that a wide user-base should be considered, and that user friendliness of the App is very important.*

- Baseline data should be possible to be changed by the user such that performance of the App improves as better data becomes available. Include in the business plan data improvement opportunities (bathymetry, waves, …).
  - *We agree that this is important. The app will include standard baseline data, but a user may modify these if needed.*
- The West Africa Regional Coastal Observatory (WARCO) could be considered as "owner" of the App, thereby assuring that the App is used consistently and available to interested users. Alternatively, it could be hosted on a WACA-platform.
  - *We welcome those possibilities.*
- The App could be included in "sustainable port development" as best practice (standard tool).
  - *We welcome that possibility.*
- Possible stakeholder groups include governments, port associations, development investors, civil societies.
  - *We agree that these are possible stakeholders, and there may even be more. This, once again, underlines the importance of simplicity and user friendliness of the App, such that stakeholders with various (technical) backgrounds and various purposes of application can make use of the App.*
- The App can also provide valuable insight on interventions from the past and how these impacted the present. Therefore, it is important to allow users to select as starting point of the simulation a moment in the past. This can also function as validation (compare simulated and existing coastal erosion).
  - *We agree that this is important, and we will include that functionality (select available coastline from past ~25 years).*

3.1.4 West-Africa Regional Coastal Observatory

On 10 June 2021 a virtual meeting was held with the West Africa Regional Coastal Observatory (WARCO) to discuss needs, data availability and possible synergies between activities of the WARCO and the ambitions for WAC-App. Specific questions that were considered are:

- Which existing data can be used/exchanged?
- Which functions are desired?
- How can the App be used for impact assessments of coastal measures?
- Which accuracy can be obtained and for which users?

Of particular interest to the participants were (response from HKV and IHE Delft in *italics*):

- The accuracy of the starting coastline and the subsequent simulation result. The size of the area to be explored. For which spatial size is the resulting computation time still acceptable?
  - *We will aim for areas up to about 100 km with the highest possible accuracy that still gives acceptable calculation durations.*
- The App will detect the coastline from satellite imagery, but manual adjustments are possible.
  - *Yes, that will be the case.*
- Inclusion of vegetation (mangroves, other Nature Based Solutions)
  - *The first version will not yet include the option to impose vegetation-based interventions, because it requires still dedicated research. This aspect will be addressed in parallel research projects and be prioritized for future expansion of the WAC-App.*

During the meeting, the prototype of WAC-App was demonstrated (see Figure 4). After the meeting the demonstrated test-software was shared with the WARCO (deliverable "pilot product").

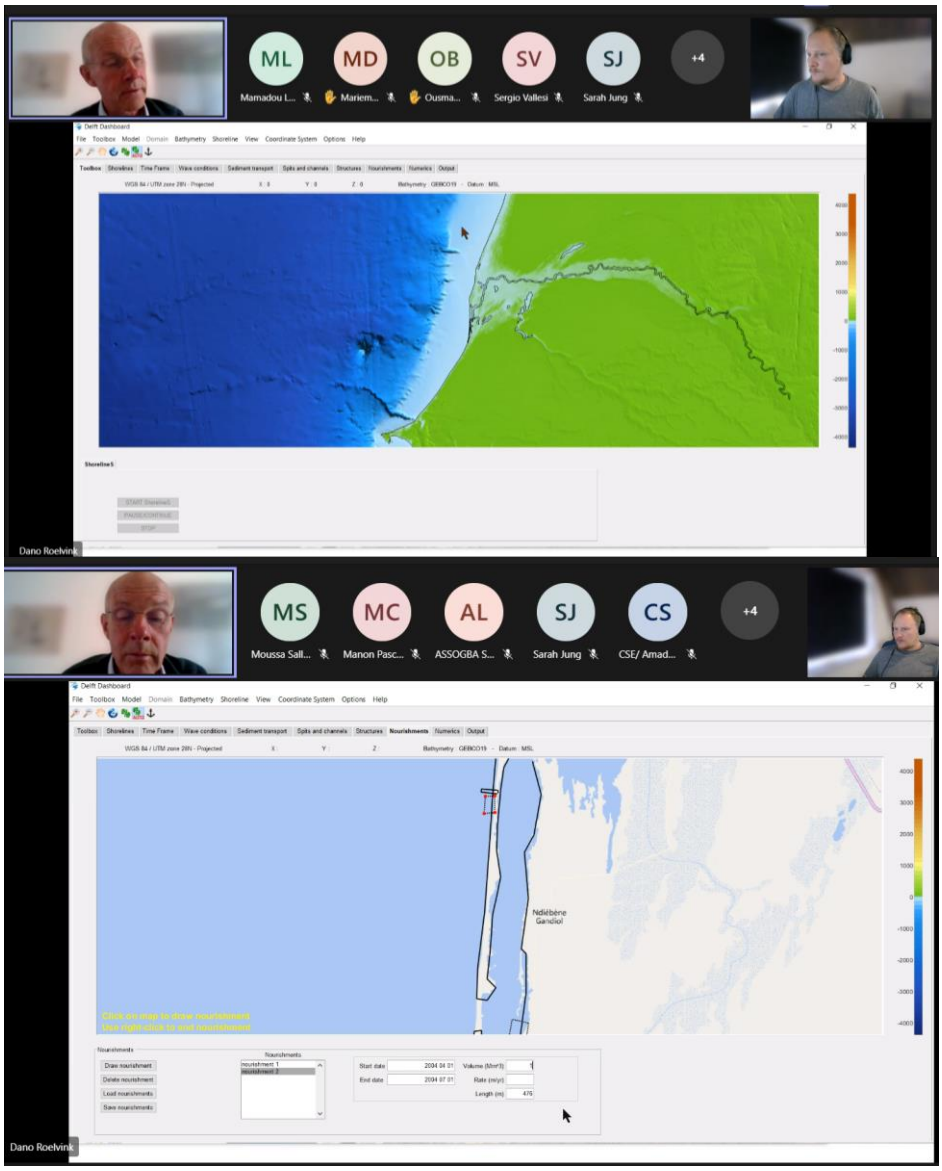


Figure 4 Demonstration of WAC-App alpha functionalities for the WARCO

3.1.5 Port authorities (PMAWCA)

On June 16th 2021, we presented WAC-App alpha version (prototype) during the annual gathering of the members of the Maritime Security Environmental Protections and Operations (MSEPO) technical committee of the Ports Management Association for West and Central Africa (PMAWCA). The meeting tackled different challenges encountered by the Ports Members in their domains. The ports have a long-standing collaboration to develop a Sustainable Ports Partnership supported by the World Bank, and the engagement with private actors to develop sustainable solutions to their social and environmental challenges is an active part of this effort. The agenda of the meeting is included in Annex A.

Participants expressed interest in the App because it offered a simple way of anticipating on coastal erosion and would be pleased to use the App once it becomes available. Through a follow-up questionnaire, feedback was provided by PMAWCA. Four questions were included in the questionnaire, and responses came back from port authorities in Congo, Ivory Coast and Cameroun (responses of PMAWCA in *italics*):

1. What are your main challenges that could be addressed by WAC-App?
   - *Trace the impacts (on coastal lay-out)*
   - *Identify sources of impacts (on coastal lay-out)*
   - *Real-time environmental monitoring of infrastructures*
   - *simulation and modelling of environmental impacts*
   - *Restoration of degraded coastal areas*
   - *Reducing inundations by restoring lagoons and drainage systems and improving basin management.*
   - *Improve City-Port exchanges;*
   - *Target areas at risk for coastal erosion;*
   - *Facilitate the monitoring of mangrove areas that may have a direct impact on port activities*

2. In which way do you see a purpose for Wac-App as communication tool?
   - *by the open access to the parties interested in the information*
   - *contact tool with the interested parties of our management system by giving them environmental status at a moment's notice*
   - *WAC-App is the tool that centralizes information related to the degradation of our coasts and their impact on the various ports*
   - *On the fact that this application can provide real, accessible and reliable information that may be available online*

3. In which way do you see a purpose for Wac-App as design/planning tool?
   - *Through visualization of impacts on ports and other structures*
   - *Useful in drawing up environmental, safety, health & social requirements for calls for tenders*
   - *It is a design and planning tool because it allows us to give the situation of our coasts and the associated impacts. This will make it possible to plan useful actions depending on the state of degradation.*

- *WAC-App can present an initial diagnosis whether a targeted area is suitable for development planning.*

4. Do you have suggestions on the functioning on the App?
   - *it would be wise for the application to propose solutions to be undertaken according to the nature of the visualized impacts*
   - *compatibility with GIS*
   - *We support the current operation*
   - *There are concerns that opening WAC-App to anyone could pose security risks to ports*[15]*.*
   - *Priority features: overview of the entire port area and areas bordering the Port, the type of impact (pollution, erosion, etc.)*

Based on these answers we conclude that WAC-App could serve a variety of challenges that port authorities are facing, mostly in relation to (initial stages in) planning of port development and anticipation on hazards or environmental impacts related to coastline changes.

3.2 Gap analysis

Based on the discussions with stakeholders from section 3.1 we made a gap analysis to set up a business plan for WAC-App. Table 1 gives an overview of objectives, identified gaps and associated actions. In summary, the gap analysis reveals the following key aspects that the WAC-App tool should have:

- WAC-App should be further tested and validated in the WACA context and show short- and long-term impacts at spatial scales and resolution that are useful for coastal planning (coastal erosion, port development).
- WAC-App should be web-based, freely available, intuitive, and easy-to-use, such that a wide range of stakeholders can make use of it.
- WAC-App should include a well-described baseline data set (coastlines, wave and wind field, sediment transport), and offer the possibility for making (manual) adjustments based on local knowledge (such as coastal features, river mouths, islands). Also, it should allow different morphological evolution scenarios, e.g. under impact of climate change.

These are the features that we feel have highest priority for WAC-App and should be included in the first operational version (WAC-App beta version). We feel that a beta version should still be kept relatively simple to make sure that a wide user base can be achieved. Additional functionalities, some of which mentioned by stakeholders in section 3.1 and actions associated with gaps in Table 1, we consider important options for a later updated version (see also next section).

[15] This comment is not considered in the development of the App. The starting premise is that information should be shared widely.

Table 1
Gap analysis

Objective	Current state	Desired State	Gap description	Action/target
For purposes as combating coastal erosion associated with port development: explore options for coastal interventions for short- and long-term impacts	- Various tools exist for professional use. - Existing tools are computationally demanding	Have validated instruments that give quick results to allow exploration of various options (at useful spatial resolution). Consider the impacts of climate change.	Computational demand is often too high for exploration of many options	- Develop a tool to easily explore interventions and that quickly gives results for short- and long-term - Use validated technologies - Assure useful spatial scale and spatial resolution - Include climate change scenarios
Improve understanding of coastal impacts of interventions for a wider audience	Knowledge is with experts on coastal processes	Make more stakeholders aware of basic principles of coastal processes	Technical knowledge is complex and hard to access for non-experts	- Make knowledge on coastal processes and cause-effect relationships of coastal interventions more accessible - Show lessons from practical cases
Stimulate stakeholder engagement in all phases of coastal planning	- Planning considerations by experts on coastal processes are shared with a wider audience at a late stage in the planning process. - Accountability for coastal interventions is low - Licensing of Professional software is too expensive for potential users	- Develop instrument(s) to include non-experts in different phases of coastal planning - Avoid high user costs - Assure local institutional anchorage	- Existing tools are too technical for non-experts - Existing tools are inaccessible to non-experts - Some tools are too expensive - Local institutions are faced with the challenge to decide between various technologically-demanding tools	- Develop an intuitive and easy-to-use tool for non-expert users - Make the tool freely available online – Assure that tool is locally embraced institutionally.

Objective	Current state	Desired State	Gap description	Action/target
Make use of local knowledge in coastal planning	Planning tools are operated by technical experts that sometimes lack local knowledge and choose sub-optimal standard settings.	Have flexible planning tools that are accessible to non-expert users and invite inclusion of local knowledge.	Technical tools and their settings are only used and understood by experts. It is unclear how to incorporate local knowledge.	- Include clearly described default settings in coastal planning tools and invite for their adjustment based on local knowledge. - Make the tool accessible to a wide audience
Take into account, or make use of, forces of nature in coastal planning	- Natural coastal processes are well-understood by experts - State-of-the-art coastal planning tools include options for Nature Based Solutions - Experts more commonly suggest Nature Based Solutions as viable and effective options	- Bring options for 'Nature Based Solutions' more to the forefront to a wide range of stakeholders - More easily show the impacts and benefits of Nature Based Solutions	Natural coastal processes are under-used in coastal planning because various stakeholders are unaware of potential benefits	Provide non-expert tools for coastal planning where interventions make use or are evaluated in the context of the forces of nature

3.3 Expansion possibilities

Expanding on the actions from the gap analysis, possible future expansions of WAC-App functionality are (see also Figure 5):

- Extension to include additional geographical areas. These can be remaining West-African countries or even other coastal areas around the world.
- In the initial stage, WAC-App analyses the effects of dredging/nourishments and hard structures with different degrees of permeability. A key expansion for WAC-App will be an elaborated intervention database. This database may contain additional coastal interventions, such as (semi-) submerged structures and vegetation-based interventions (e.g. mangroves).
- Introduction of re-occurring nourishment/dredging or sequential interventions to allow long term planning and analysis, including maintenance of measures.
- As additional feature to interventions, more elaborate characteristics of Nature Based Solutions (NBS) can be included. NBS are typically characterized by a "spin-up time" that is needed before the interventions

fully function as intended (e.g., time needed for natural development, such as growing of mangroves). This type of intervention thus incorporates a timescale over which the impact of the intervention gradually increases.

- In the intervention database the costs of interventions can be implemented as well. The estimated costs depend on the local depth and on the unit price (per m^3 or m of coastline) at the time of the intervention.
- The calculated change in coastline will have an impact on assets and livelihoods along the coast. A possible expansion to WAC-App is to include impact indicators:
  - Detection of buildings and other infrastructure from satellite imagery can be implemented to see which of these will be impacted by a change in coastline. In Google Earth Engine (GGE) algorithms are already available for automatic building detection.
  - Classification of land use and value within WAC-App will show the economic cost of the coastal erosion, this will help to allow for cost-benefits analyses with WAC-App.
  - Countrywide demographics can be added to WAC-App. This will allow the tool to show the number of affected people.
- Expanded incorporation of local knowledge: the baseline data in WAC-App are pre-defined (wave fields, sea level) or detected automatically (land/sea boundary, infrastructures). In the beta version, these can be adjusted locally by expert users of the system. For easier implementation, local knowledge can be incorporated via an expanded user-friendly interface.
- Methods to derive cross-shore profiles and/or sediment types/properties from satellite data (and other available data sources) can be included in the WAC-App, thus improving the quality of the input of the model that makes coastline predictions for the app. In this component the tidal conditions will be linked to the satellite imagery, allowing for a vertical reference of the satellite-derived coastlines. The result will be an overview of the inter-tidal beach bathymetry along the coastline. Based on the sediment, also an estimation of the underwater equilibrium profile shape can be given.
- Predictions of coastline changes are very sensitive to the properties of the nearshore wave conditions. Based on nearshore bathymetry and wave conditions for distant offshore locations a transform of the offshore wave conditions towards the shoreline can be included. These representative conditions can be implemented in ShorelineS within the WAC-App to improve accuracy of coastline evolution.

Figure 5
Possible expansions of WAC-App

4 Business plan

Based on our initial proposition for WAC-App and the results from the gap analysis (Section 3.2), we present in this chapter our vision for WAC-App, a market strategy, a business strategy and financials for developing an operational application.

4.1 Our vision for WAC-App

Making impact with WAC-App

WAC-App is intended as an easy-to-use tool that visualizes coastal evolution and the impacts of coastal interventions, which are presented in a way that is easy to interpret and allows to optimize interventions. This application aims to bring a positive change to the practice in coastal planning and help solve some of the challenges that West-African countries are facing in combating coastal erosion while implementing coastal development plans.

- WAC-App gives **quick results** and **visualizes** how and when a proposed **intervention impacts its surroundings** geomorphologically, and in later expansions possibly also socio-economically, and thereby allows **a more integrated, sustainable, and cost-effective approach to coastal planning**. Also Nature-Based Solutions may be considered. This makes WAC-App suitable for use in various stages of a planning and decision-making process of coastal developments.
- Early sorting and optimization of interventions by using WAC-App helps to **avoid negative side-effects of coastal interventions** (erosion, impacted livelihoods and environment).
- WAC-app will allow **increased engagement of stakeholders.** Engineers, scientists, decision makers and the general public and the private sector can use the tool and explore for themselves impacts of coastal interventions and thereby **communicate better** and help reach consensus on effective yet balanced coastal management plans.
- WAC-App will be **open source**, **easy to use** and **available for everyone**. WAC-App may be given **"ownership" to local authorities**, and be embedded institutionally to assure that it enters in local coastal planning procedures.

Development requirements for WAC-App

In the prototype phase of WAC-App as described in this report two technical tools were combined that include the key functionalities of WAC-App:

1. The coastline detection tool CoastSat in Google Earth Engine (GEE)
2. The coastline evolution model ShorelineS in DelftDashboard

Together, these two tools have the basic functionalities that are proposed for an operational version of WAC-App, namely automated coastline detection, the ability to draw interventions on a map and, next, to calculate and visualize coastal impact of the interventions. However, what is still missing is that these functionalities are absorbed into one cohesive (online) tool, such that a user does not need to manually carry out the data-transfer and visualization steps. Also, a simple-to use, intuitive and visually attractive user interface needs to be developed to make the application suitable for a wide range of users. The merging of technologies, online hosting and interface development are proposed for a next phase in the development of WAC-App, leading to a first operational version (beta version). A more detailed outline of the proposed architecture for a beta version is included in Annex C.

4.2 Market Strategy

Below key aspects regarding the market strategy are given.

Our target customers

Coastal erosion in West Africa affects many people. Due to the magnitude of the problem interventions need to be planned on a system-wide scale, which involves **communities, and regional and national authorities (including port authorities)**. Also, **scientist, engineers and contractors** are involved to find possible solutions. The WAC-App tool can be used by all these stakeholders to understand the problem and explore initial approaches to mitigating unwanted effects. Also, in areas where coastal erosion is not an existing problem, the WAC-App can help **spatial planners** and **decisions makers** anticipate on impacts that may be caused by coastal development plans, such as related to port development.

Fulfilment of user needs

Because of the wide range of potential customers of the app, also diverse needs exist. We focus on the need to **improve insight to coastal impacts** by offering **a tool for quick and intuitive evaluation of coastal evolution**. This evolution can be assessed under continuation of existing conditions, under climate change and if implementing (basic) coastal interventions (hard structures or nourishments). Essential in the first operational version (beta version) is **user-friendliness** to stimulate a growing user base.

Possible expansions for future versions of WAC-App have been identified to cover an even wider range of user needs. Some of these needs require further research. The WAC-App team at HKV and IHE Delft is setting up parallel **research and development initiatives to realize expansions** and investigate innovations of the app.

Competitors and rival/substitute technologies

Various coastal evolution models exist and are being applied in planning applications. However, these models are made for specialists, require

significant computational power, advanced hard- and software and accurate data input. A **unique computational module** in WAC-App, ShorelineS, allows **quick large-scale results** based on key coastal geographical and marine features, which are readily available for the oceanic coasts around the world. The application can be **hosted on a cloud-based server** and be combined with an **intuitive user interface**, that gives almost immediate simulation results. We follow an **free-of-charge, open access and data sharing** strategy, removing potential barriers for its utilization and stimulating innovation of the application.

Strategy for market introduction

To achieve visibility and to underline credibility of the application, it is important to anchor the application institutionally at (a) locally-respected and influential organisation(s). During the stakeholder meetings it was proposed by the WACA team that the **West Africa Regional Coastal Observatory (WARCO)**, as implemented by the Ecological Monitoring Centre (CSE) under the WACA ResIP (Resilience Investment Project), to be a suitable organisation **to endorse and possibly host[16] WAC-App,** and stimulate its practical use of in West African coastal management projects. The WARCO is also well-positioned to **facilitate collaborations with regional education and research institutes** to expand expert knowledge on WAC-App and work with the WAC-App development team on possible innovations. The WAC-App prototype version has already been delivered to WARCO.

Through formal support by WARCO, the WAC-App could be positioned **as a standard tool** in coastal management projects that fall under the WACA or other related programmes (see text box on next page on ‘’ alignment with the WACA Program). User feedback received within the WACA program, either through WARCO or as part of coastal planning projects, are welcomed by our technical team to inform updates to the application.

For market introduction, we propose that **a launch event** is organized together with WARCO to make the collaboration public, to obtain visibility for WAC-App and, specifically, to show the potential use of WAC-App to a wide potential user base. **Manuals and demonstration cases** (videos) will be prepared and made publicly available to facilitate **easy introduction for new users.** Additionally, use of WAC-App will be shown at relevant future conferences or other costumer events.

Embedding WAC-App in the WACA Program

The West Africa Coastal Management Program (WACA) supports countries’ effort to improve the management of their shared coastal resources and reduce the natural and anthropogenic risks affecting coastal communities.

[16] For flexibility and scalability reasons, we propose to host WAC-App on a cloud-based server and include in the financials the hosting costs and costs for technical updates to the app. Alternatively, WAC-App may be hosted on a local server (at WACA, WARCO or elsewhere) and we can offer a technical training to transfer maintenance responsibilities.

The Program also aims to boost the transfer of knowledge, to foster political dialogue among countries, and to mobilize additional finance to tackle coastal erosion, flooding, pollution, and climate change adaptation.

The WACA Program includes: (1) the WACA Resilience Investment Project (WACA ResIP), a multi-country regional project that supports the strengthening of resilience of coastal communities and assets in six western African countries (Benin, Côte d'Ivoire, Mauritania, São Tomé and Príncipe, Senegal, and Togo), also supporting regional institutions (WAEMU, Abidjan Convention, CSE Centre de Suivi Écologique, IUCN) to strengthen regional integration on coastal management and (2) the WACA Platform, a 5-year programmatic Technical Assistance project.

In particular, the WAC-App innovation fits within project West Africa Coastal Areas High-Level Platform (P166218), an Advisory Services and Analytics (ASA) activity that aims to support WACA partner countries in achieving Coastal Resilience by scaling-up finance with knowledge, expertise and dialogue as enabling conditions. This objective is in line with WB's Maximizing Financing for Development (MFD) approach that seeks to leverages the private sector in sustainable ways to bolster scarce public resources and help reach the goals of reducing poverty and boosting prosperity.

The Platform, which aims to facilitates the mobilization of public, private and civil society partners to support sustainable development and reduce climate risk for millions of people living in West African coastal areas, has three main functions: (1) facilitate and increase access to knowledge, expertise, global good practices, and technical assistance; (2) leverage and crowd-in financing for coastal resilience investments; (3) galvanize and provide a forum for dialogue and facilitate involvement of other key partners, including the private sector.

The innovation also fits within the Regional Component of the WACA ResIP project, as it could be of particular interest to the West Africa Regional Coastal Observatory (WARCO) implemented by the CSE under the WACA ResIP project. The objective of the WARCO is: "Observe to better understand, better understand to better decide", and it relies on a collective effort to improve the practices and the quality of the data produced by the various members.

4.3 Business strategy

Below some key aspects regarding the business strategy are given.

Commercial strategy

HKV and IHE Delft base their commercial services on delivery of expert advice and delivery of tailor-made products and services. The WAC-App is meant to serve the needs of a wide range of stakeholders and thereby gives visibility to our expertise. **We do not plan to obtain direct revenues from the utilisation of WAC-App,** but rather expect to **benefit from strengthening our market position as experts in coastal management** through from visibility and wide application of WAC-App. Our ultimate goal is to make positive impact by delivering good work and try to make things better. WAC-App fits with this philosophy of our organisations.

For the initial development of WAC-App we seek **one-time financial support for development and implementation costs** (from country programmes, regional development programmes, international donors). After that, a modest **yearly maintenance fee** needs to be covered for cloud hosting and maintenance of the application[17]. Innovations in WAC-App will be partly covered by on-going research and development initiatives at our organisations. Clients with specific needs for more elaborate expansions of WAC-App (for example the expansion options listed in Section 3.3), such as dredging companies, port authorities or contractors would have to pay for those services (see indicative costs in Table 3).

Creating partnerships

The key partnership for WAC-App is with the West Africa Regional Coastal Observatory (WARCO). As a first step before developing an operational version of WAC-App it is important that this partnership is well established and that expectations and responsibilities are mutually agreed upon.

The computational core of WAC-App has been developed at IHE Delft in close collaboration with research institute Deltares[18]. Therefore we propose to add **Deltares as partner to the WAC-App development team**. Even today, developments are still on-going at IHE Delft and Deltares, with various researchers involved in optimizing the computational speed, and incorporating new processes and options in the software. By adding Deltares to the development team, lessons from developing WAC-App can inform the Shorelines research and development team at Deltares and vice-versa. Further research and development collaborations will be sought through the **ownership of WAC-App at WARCO**.

As part of the WAC-App development process we propose to set-up two test cases to be carried out by external parties. This will provide **feedback to the development team from potential users**, who will also already become acquainted with the application. The test cases will be applied to real situation in West Africa and offer practical feedback to help fine-tune the tool.

[17] Alternatively, one-time costs are needed for transferring the application to a local hosted server, and to offer training for maintenance of WAC-App.
[18] https://www.deltares.nl/en/

The considered external parties are chosen from the other (long-listed) participants in the WACA Innovation challenge.

Synergies with on-going initiatives at HKV and IHE Delft

HKV and IHE Delft have a strong focus on research, educational and capacity building activities, including initiatives for beneficiaries in Africa. WAC-App is intended as a key component in such activities for the future.

A joint industry project is being set up by IHE Delft and Deltares to further develop the ShorelineS engine and test real-life applications (2022-2024). Several organisations that were also longlisted in the 2020 WACA Innovation challenge are among the partners.

4.4 Financials

Table 2 gives an indication of the costs for development and continued operation of WAC-App (recurring costs), also showing the relative contribution of development partners HKV, IHE Delft and Deltares. The total development costs amount to approximately 190.000 EUR and the yearly recurring costs are about 15.000 EUR/yr. The development costs include the optional activity (in blue) of sub-contracting two external parties to carry out tests with WAC-App for feedback. For this purpose, we propose to ask two organizations that were longlisted in the 2020 WACA Call for Innovation. It is estimated that the technical development of WAC-App requires about seven months.

Table 2 Approximate costs of online WAC-App (beta version)

Activity	HKV	IHE Delft	Deltares	Indicative costs
1. Set up frontend/backend architecture	56%	33%	11%	EUR 9.000
2. Set up server environment	100%	0%	0%	EUR 3.000
3. Develop interface design (user friendly)	70%	20%	10%	EUR 10.000
4. Prepare baseline data	59%	35%	6%	EUR 17.000
5. Develop manual adjustment module	56%	44%	0%	EUR 9.000
6. Develop intervention module	56%	44%	0%	EUR 9.000
7. Develop climate scenarios module	56%	44%	0%	EUR 9.000
8. Optimize ShorelineS for online use	0%	67%	33%	EUR 18.000
9. Develop "Mobile first" functionalities	83%	17%	0%	EUR 6.000
10. Develop training modules	20%	70%	10%	EUR 10.000
11. Internal testing	45%	45%	9%	EUR 11.000
12. External testing by potential users	0%	0%	0%	EUR 14.000
13. Refine interface and functionalities	50%	38%	13%	EUR 16.000
14. Implement tool at WARCO (+ training)	43%	43%	14%	EUR 14.000
15. Reporting (manual)	43%	43%	14%	EUR 14.000
16. Online launch event	50%	33%	17%	EUR 6.000
17. Project management + meetings	53%	33%	13%	EUR 15.000
Development costs				**EUR 190.000**
18. Yearly maintenance				EUR 10.000/yr

19. Online hosting				EUR 5.000/yr
Recurring costs[19]				**EUR 15.000/yr**

Table 3 gives an overview of possible expansions to make WAC-App a more versatile tool with a wider range of application and added functionalities. Some of the expansion options listed in Table 3 still require further in-depth study to improve implementation in WAC-App. These will be incorporated in on-going research activities at our organizations (for example through MSc or PhD projects) or at institutions linked to WARCO.

Table 3 Approximate costs of WAC-App expansion options

Possible expansions	Indicative costs
1. Expand intervention database	EUR 15.000
2. Include functionality for re-occurring interventions	EUR 15.000
3. Include Nature Based Solutions (vegetation interaction)	EUR 20.000
4. Include costs of interventions	EUR 15.000
5. Expand with impact indicators	EUR 25.000
6. Develop expanded interface for incorporation of local knowledge	EUR 25.000
7. Develop specialist module: a) Derivation of cross-shore profiles and beach properties b) Accurate/representative nearshore (wave) forcing conditions	EUR 30.000

4.5 Next steps

Towards realization and sustainable operation of WAC-App the following steps are proposed:

1. Agree with the WACA-team on implementation of WAC-App, including financials.
2. Establish and formalize collaboration with WARCO.
3. Development of WAC-App (~7 months).
4. Set up a procedure for continued operation and maintenance of WAC-App, and a structure for user-feedback.
5. Set up parallel research and development activities supporting WAC-App, including new collaborations.
6. Launch event of WAC-App with WARCO
7. Operation of WAC-App (beta version)

[19] Or costs for one-time knowledge transfer for local hosting of WAC-App

Appendices

A Step-by-step prototype application

The WAC-App prototype (or "WAC-App alpha version") is for the time being built into the DelftDashboard free software[20]. For the future a separate web-based version of the WAC-App will be developed, to be hosted on a cloud-based server.

In this prototype, the coastline detection in GEE is separate from the simulation of coastline evolution within DelftDashboard. Within GEE we use the tool 'CoastSat' to detect the coastline. To use CoastSat the user first defines an area of interest along the coast and choses a year in which she/he wants to obtain the coastline. CoastSat defines the coastline based on the available satellite images for this year depending on available satellite images. The user can then extract the detected coastline by clicking the 'Coastline to ShorelineS' button (see Figure 6). A 'kml-file' with information on the coastline is downloaded and can now be transferred to ShorelineS in DelftDashboard.

For a future operational version of WAC-App, the coastline-detection steps are avoided by preparing baseline coastline data for ~25 years for the entire West-African coast.

Figure 6 Coastline detection via Google Earth Engine. At the bottom right the user can choose a year in which to extract the coastline. In red the detected coastline. The download button can be found at the top of the screen.

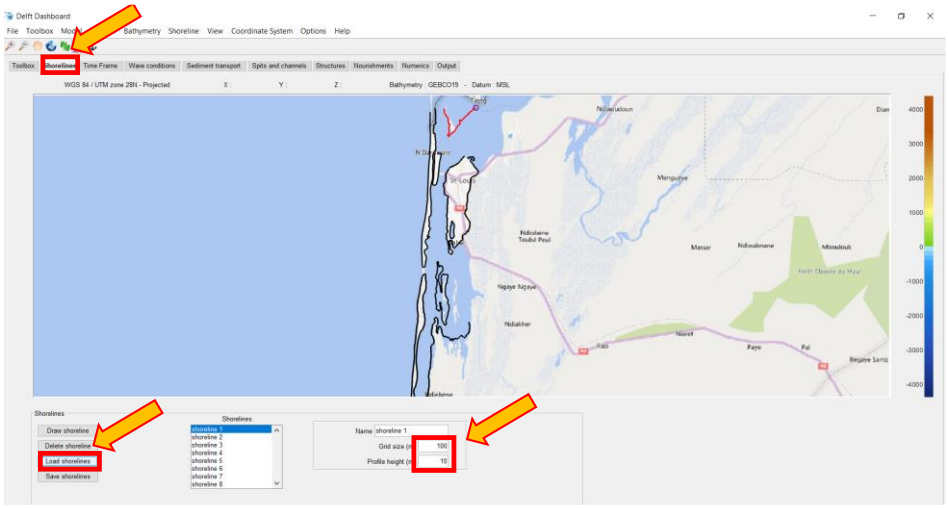
Next, we demonstrate the WAC-App prototype within DelftDashboard, starting from the detected coastline.

When the WAC-App is launched, the user will see the window shown in Figure 7. The example case is in Senegal at the complex coastal zone of St. Louis, where the Senegal river reaches the Atlantic Ocean. The current prototype

[20] See: https://iwaponline.com/jh/article/22/3/510/72480/Delft-Dashboard-a-quick-set-up-tool-for

can be used for other coastal sections of West Africa as well, but these are not shown here. The coastline, which was detected in a previous step using CoastSat in GEE, can be loaded to the app by using the "Shorelines" tab and clicking on the button "load shoreline" (Figure 7).

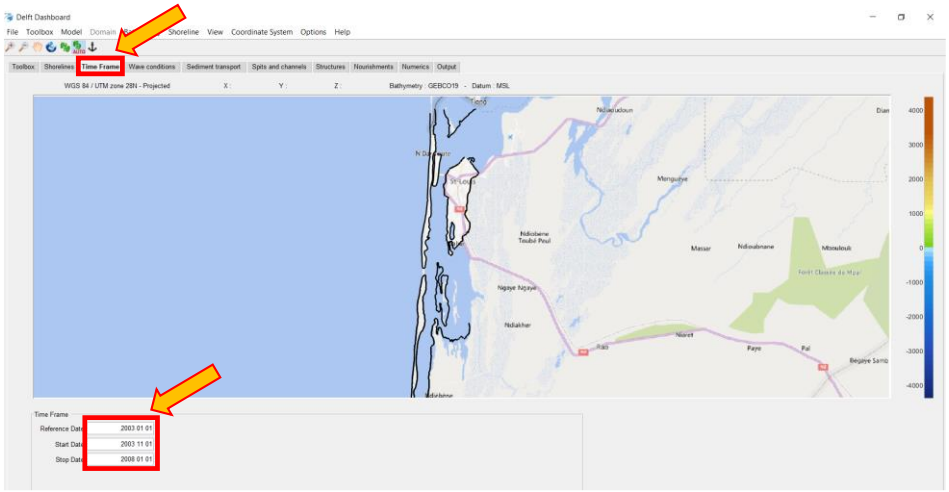
Figure 7
Adding the detected shoreline in WAC-app prototype



Next, in the "Time Frame" field a reference date, start date and stop date of the simulation, is defined (Figure 8). In this case, the model is set up for a hindcast simulation starting in 2003 and running for 5 years.

In a future operational version of WAC-App, the start date follows automatically from the year of selected coastline. A stop date can then be selected up to a horizon of 10 years.

Figure 8
Setting the time frame of simulations in WAC-app prototype

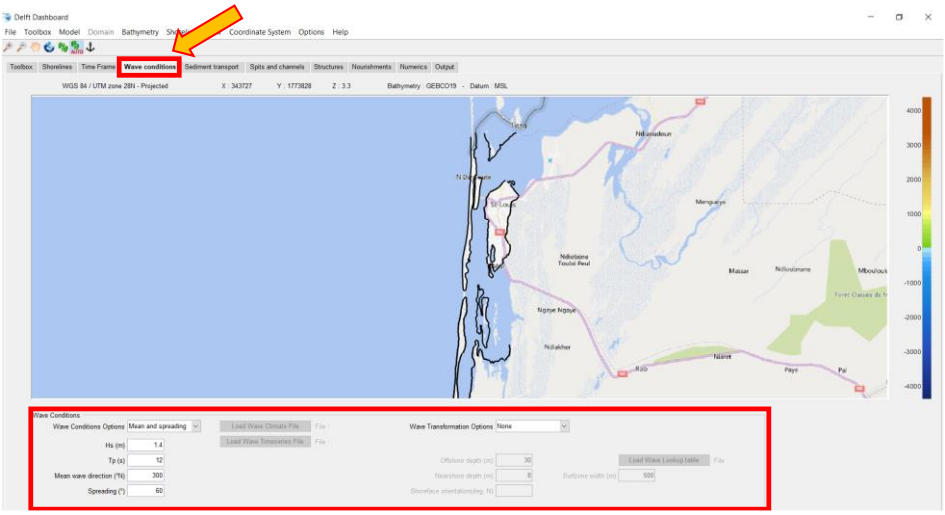


The next step is to impose the wave condition(s) in the model by using the "Wave condition" tab. In this tab, three different options for inputing the wave forcing are available (Figure 9):

- Mean and spreading (constant wave);
- wave climate;
- wave time serries.

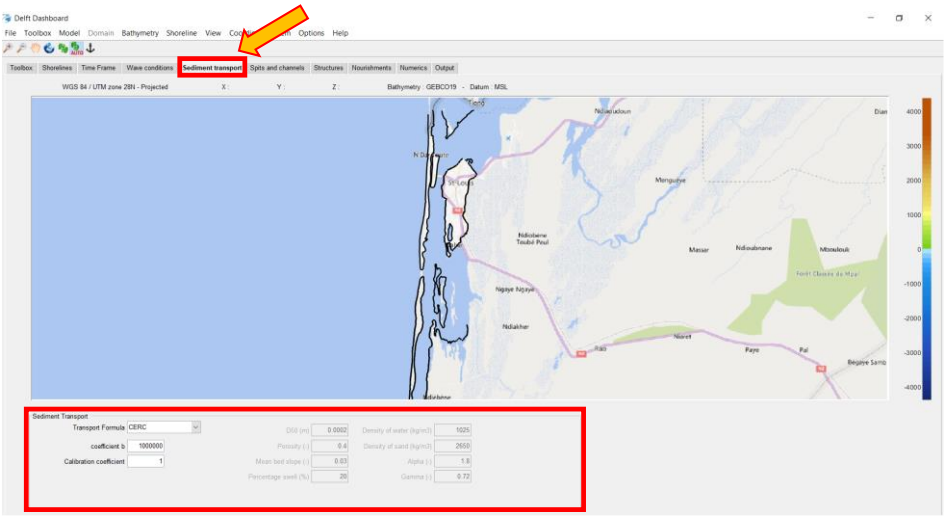
In this case the first option, a constant wave condition of 1.4 m height with period of 12 seconds coming from northwest (300-degree N), is used in the model.

Figure 9 Applying the wave forcing in WAC-App prototype



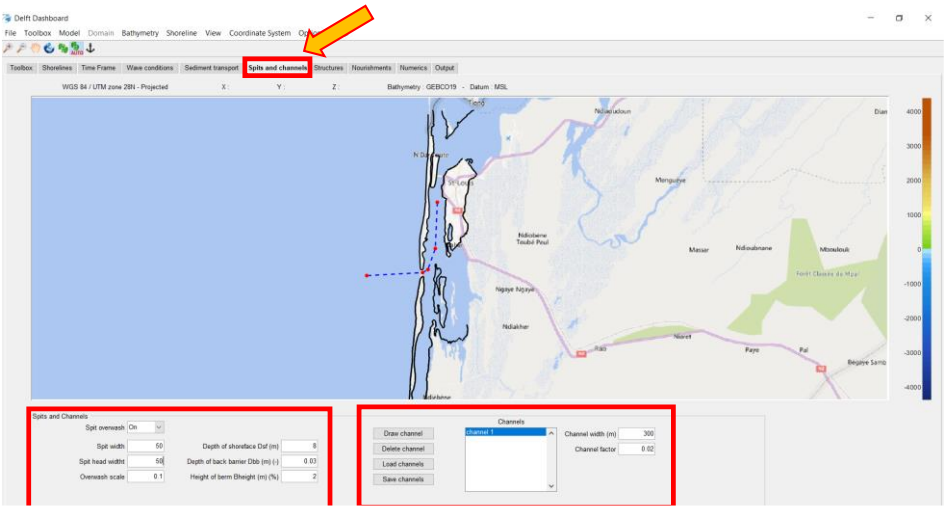
Next, sediment transport formulation and its resepective parameters can be chosen in the tab of "sediment transport" (Figure 10). In this case the CERC formulation is used.

Figure 10 Choosing the sediment transport formulation in WAC-App prototype



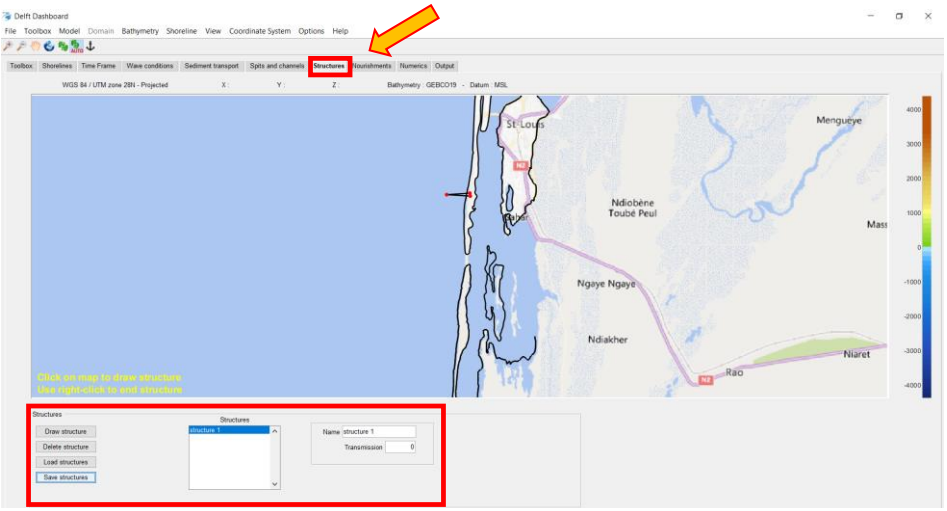
As mentioned in section 2.1.2, complicated coastal features such as river mouth, inlets and spits can be simulated in this app and for that purpose the tab "Spits and Channels" is developed. This tab can be used for inputting the characteristics of these features (Figure 11). In this case, a spit width is assumed to be 50 meters which means that in case the width of spits during the simulation becomes smaller than this threshold, the spit will be over-washed and move landward. The Senegal river mouth is a very important feature of this area and keeps the inlet open. It is identified by the centreline of the channel and the width of the inlet. The model will keep this inlet always wider than the selected "spit width" value.

Figure 11
Adding river mouth, spits and inlets to the shoreline ("Spits and Channels") in WAC-App prototype



Next, the tabs of "Structure" and "Nourishment" are used to impose existing or planned interventions. In the simulation shown in the snapshots two interventions are added to the system (one structure and one nourishment). Note that these interventions have in reality not been implemented in the area of interest and are used here solely for demonstrating the capabilities of the WAC-App prototype. Figure 12 and Figure 13 show how those interventions can be added to the app. Structures are added by drawing their layout in the map and adjusting their sediment transmission (by-passing) in terms of percentage (reflecting permeability). The nourishment is added to the simulation by drawing the area of nourishment on the map and determining the duration of the nourishment and the amount in millions cubic meters. The associated constant rate of sediment input is calculated automatically by the app.

Figure 12
Adding interventions – structures in WAC-App prototype



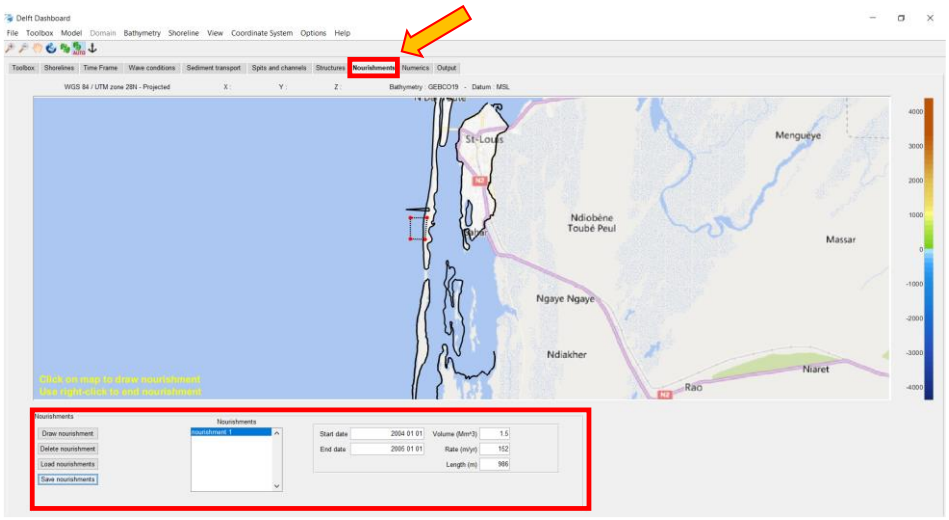


Figure 13 Adding interventions – nourishments in WAC-App prototype

The tab "Numerics" is used for adjusting the numerical parameters for advanced users (Figure 14). The "output" tab is used to choose the interval of showing the results of coastal evolution simulation as well as interval of saving the results for future reference (Figure 15).

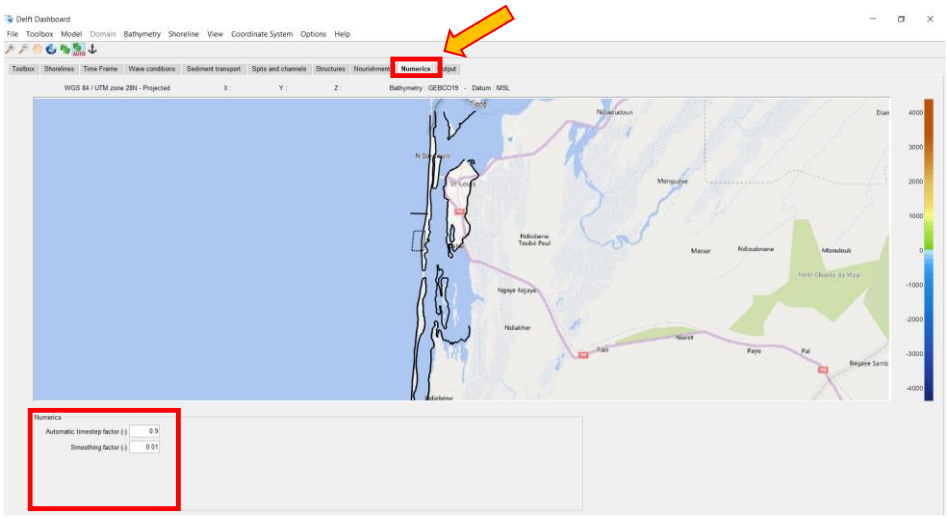


Figure 14 Changing the numerical parameters of the simulations for advance users in WAC-App prototype

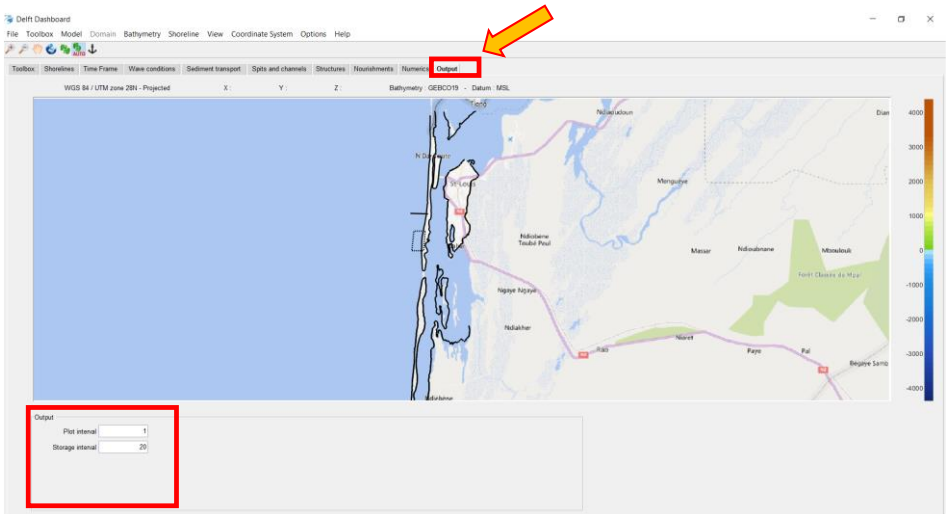


Figure 15 Adjusting the output temporal intervals in WAC-App prototype

When the model is ready, it is saved by selecting “File” in the menu bar (Figure 16). The simulation is started by pressing the “Start ShorelineS” in the “Toolbox” tab, see Figure 17.

Figure 16 Saving the model in WAC-App prototype

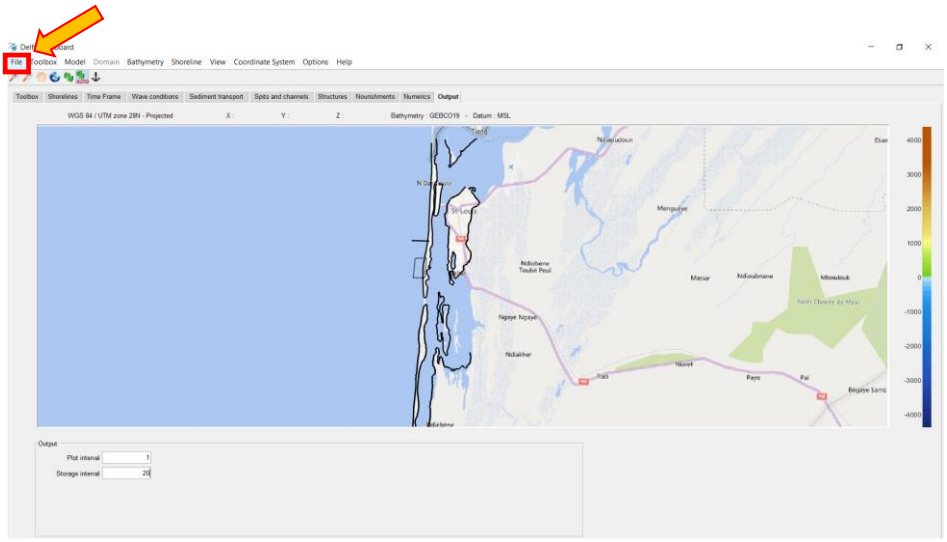
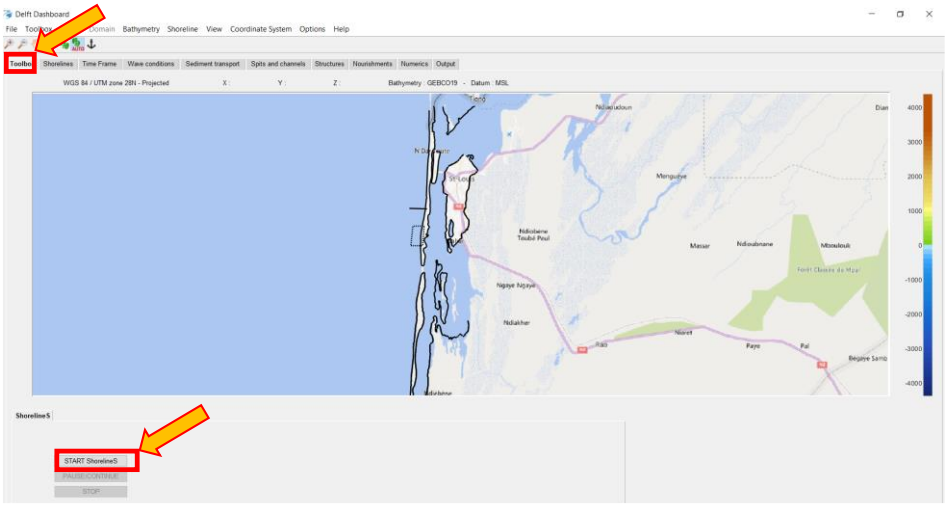


Figure 17 Starting the simulation in WAC-App prototype



While the simulation is running, the coastal evolution and the corresponding date is shown in the app. The initial coastline is shown in black, and the simulated coastline is shown in blue (Figure 18).

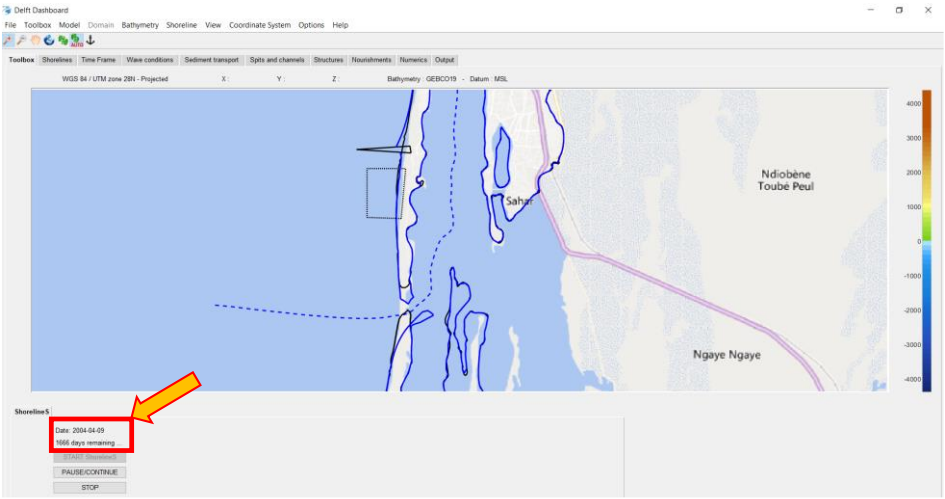


Figure 18
Live visualization of the coastal evolution during the simulation in WAC-App prototype, Black line : initial coastline, Blue line : simulated coastline at the time indicated in red rectangle

This completes the demonstration of the WAC-App prototype. If the simulated coastline gives an undesired impact, then the starting conditions can be adjusted (structure and nourishment) and the simulation repeated until the result is as wanted. Through this iterative process the user can obtain a better understanding of cause-and-effect of coastal interventions.

In a future operational version of the WAC-App, suitable default settings will be included for sediment transport and numerical definitions to facilitate easy operability. Expert users may still adjust these settings if needed.

B Agenda of PMAWCA meeting

Wednesday June 16, 2021, Session 2 – 9:30 am to 11:00 am GMT

Background

In West Africa, coastal erosion and flooding caused 135 casualties and affected 1.4 million people in 2020. Coastal environmental degradation costs $3.8 billion, or 5.3% of four countries' GDP in 2017 (Benin, Côte d'Ivoire, Senegal, and Togo). Challenging the status quo is imperative. The 2020 WACA C4I focused on the specific development challenge of how West Africa countries can manage port infrastructure sustainably to reduce exposure of local households to coastal erosion and flooding.

In the last decade, most African ports have undergone a restructuring and reform process in order to not only improve and update their infrastructural capacities, but to also improve productivity, efficiency and quality of service delivery. By doing so, this has successfully attracted private sector investment in the ports. This additional private sector capital has resulted in substantially improved port operational performance. These improvements and economic growth often did not, however, incorporate mechanisms for addressing environmental sustainability issues. In the WACA program framework, the World Bank is working with the Port Management Association of West and Central Africa (PMAWCA) to establish a Sustainable Ports Partnership, in order to develop a self-sustaining process of continuous improvement in environmental and social sustainability among the port authorities and associated actors in the port sector for the region.

The issue of coastal degradation in West Africa is significant, and one that cannot be addressed by one institution, by one country or by traditional approaches alone. The scale and complexity of the issue require a regional approach that is multi-disciplinary and is on a level of financing that requires the coordination of all stakeholders and their partners.

To find proper solutions for this large challenge, a first-rate medium is to look for innovative solutions. The WACA Call for Innovation provided promising, viable paths for countries and communities to address these longstanding issues, and to seek shared prosperity through a development of port infrastructure that does not degrade the region's vibrant coastal areas.

Twenty-two consortia of innovators participated, representing just under 100 groups from Africa, Europe and Asia. Innovative ideas were submitted through the dedicated web-based entry form on the WACA Website. Ideas were subject to a screening by an Innovation Engineer followed by a multi-disciplinary Technical Committee. On the Innovation Demonstration Day, a

Jury of six recognized leaders from World Bank and its partners selected the three winners:

- 1st Place: WAC-APP: App to Explore the Impacts of Coastal Interventions, by HKV-UNESCO-DELFT Institute.
- 2nd Place: Trans-Sand: Transnational Bypass Scheme Funded by a Public-Private Dredging Fund, by Egis-Deltares-FinanceForImpact.
- 3rd Place: SA-POD: Systems Approach for Port Development, by WITTEVEEN, CDR, BOSKALIS, PENAF, WETLANDS.

Over the past month, the three innovators have been working in advancing their innovation, developing road maps that identify opportunities, challenges and realistic finance and technical next steps to bring the innovation to the implementation stage.

This objective of this event will be to provide a first exposure of these innovation to ranging ports' stakeholders in West Africa. This will be critical to refine the demand and interest for these projects to finalize the road maps.

Agenda		
Introduction	C4I Team	5 Min
WAC-APP Presentation WAC-APP is an online based application assessing the effects of coastal interventions and enabling communication between decision makers and stakeholders. About WAC-APP	HKV & UNESCO IHE Team	10 Min
Q&A		15 Min
TRANS-SAND Presentation Proposed Regional Public-Private dredging consortium to provide dredging capacity for all partner's countries and implement a transboundary sand by-passing scheme. About TRANS-SAND	EGIS & DELTARES Team	10 Min
Q&A		15 Min
SA-POD Presentation Stakeholder inclusive approach to shift the focus of port development, from business and engineering to an integrated environmental economic and social perspective, and promote sustainable development About SA-POD	Witteveen + BOS Team	10 Min
Q&A		15 Min
Discussion – Wrap up - Buffer		10 Min

C Draft architecture for WAC-App (beta version)

For the development of the online WAC-App Tool, we choose an architecture based on the following principles:

- Include baseline data to avoid the need for data pre-processing in the WAC-App tool.
- (re)use of open source components & standards. All components of the architecture will be open source in order to stimulate innovations from a future user base. This approach also avoid potential vendor lock-in of the application.
- application of a cloud native strategy. By building and running the applications in the cloud, we ensure low-maintenance, flexibility, scalability, and resilience of the application.
- Create an intuitive user-interface.

New API

Instead of using Google Earth Engine environment for coastline detection and as a frontend for WAC-App's user interface, we will develop a new API (Application Programming Interface) that is specifically tailored to achieve smooth communication with the backend computational module ShorelineS. The new API (Application Programming Interface) loads relevant geographical and marine baseline data, it allows definition of various scenarios (interventions and surrounding conditions), it sends computation commands to ShorelineS and visualizes the obtained results from ShorelineS. Specific attention is directed towards making the API intuitive and user-friendly, for which the GEE environment would offer more limited options. Also, we will follow a "mobile first philosophy" to facilitate use of WAC-App in mobile devices such as laptops, tablets and mobile phones.

Prepare baseline data

As baseline data for WAC-App we will prepare:

- Historical coastlines from the past ~25 years that may be used as starting point for a simulation. These coastlines may also be manually adjusted by the user,
- Marine conditions for ~5 (wave and climate) scenarios.
- Computational settings to allow morphological modelling along the entire West-African coast.
- Settings to impose a variety of coastal interventions, including hard structures (such as port infrastructure) and Nature-based Solutions (vegetation, nourishments).

Frontend -backend architecture

To support App functionalities, we develop a REST API (Representational State Transfer Application Programming Interface), as an interface between the Web Client and/or scripts and client applications on the one hand and

Python modules on the other. We define this API in accordance with the Open API Specification (OAS3). We develop the API with a widely used, modern and open source web framework (FastAPI). This framework supports asynchronous processing of validation requests, allowing multiple users (concurrent users) to use the application at the same time.

The WAC-App back-end modules are standalone modules that we develop in Python. We choose Python as an open source development language because we believe it increases the chances of sharing, maintaining, further developing, and transferring our solution. The back-end modules can be extended and adapted by third parties, without having to adjust the API framework.

We place the API and Python back-end in the Docker container. We place this container in a Kubernetes platform that can be hosted by any cloud service provider. This fits within our multi-cloud strategy, allowing us to avoid a possible vendor lock-in, reduce costs and minimize risks. In this offer we have assumed the use of the Google Cloud Platform.

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