Chapter 8
Applying Ecohydrology to Promote a Nature-Based Solution:
To Improve Quality of Life and Ecosystem Health in Luanda Bay, Angola

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ABSTRACT

This chapter aims to develop an ecohydrological modelling approach to propose an environmental engineering solution based on historical nature-based information to alleviate the severe water degradation problem within Luanda Bay, Angola. This solution would improve local communities' ecosystem health and quality of life. The model suggests a simple and practical solution to solving the pollution

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problem by opening a cut from the bay's shallows to the sea. This will essentially reproduce an old bay opening to the sea, which was filled early in the last century. The residence time of water in the shallows of Luanda Bay would be reduced to about one week by excavating the channel over the land is straightforward. This should return the system to a more natural state and improve the water quality for recreational activities, increase the quality of marine food resources, reduce toxic algae blooms, and improve the quality of life of people in the area. Nevertheless, preventing pollutants from reaching Luanda Bay is the only long-term solution to restore a healthy environment in Luanda Bay

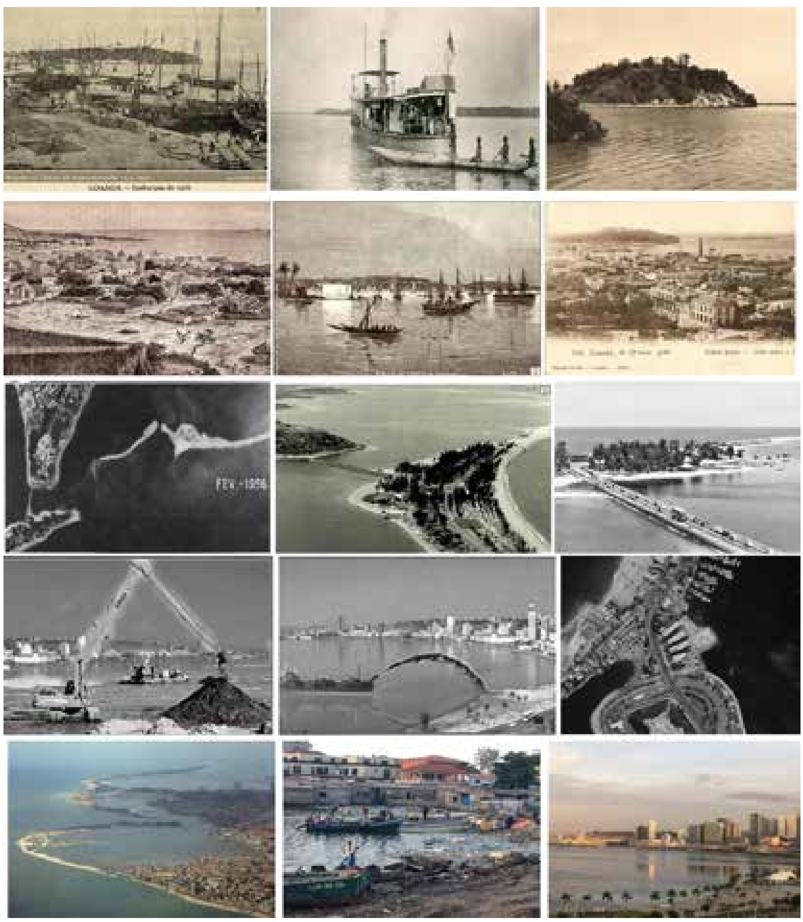
1. INTRODUCTION

Throughout the world, coastal waters have experienced environmental degradation caused by global changes, both climate and direct anthropogenic actions. Significant observed impacts in bays are the increasing eutrophication risk, Harmful Algae Bloom (HAB), muddiness and siltation, and modifications in biodiversity due to overfishing, and invasions. These result in the loss of traditional ecosystem services (coastal fisheries, leisure) and negative socioeconomic impacts (the loss of income and employment for coastal communities). This also hinders sustainable development in coastal areas worldwide, including Angola. In Angola, Luanda Bay (Figure 1) is affected namely by water quality degradation and frequent harmful algal blooms (HABs) events (Rangel et al., 2004, 2006, 2007; Blanco et al., 2010). The Luanda Waterfront Project aimed to provide a biodiversity database and a deeper understanding of the cause underlying poor water quality. The Project found significant pollution in the upper shallows of Luanda Bay, threatening the consumption of marine resources used in subsistence fishing and leisure and recreational activities (Faria et al., 2021). This was linked to runoff from the watershed, mainly associated with intense rainfall events and exacerbated by the artificialization of the bay with human structures. The bay has accumulated sediments and pollutants from the land, a vexing problem that will continue until this inland problem is addressed. Another study by the Luanda Waterfront Project (Nogueira et al., 2021) showed a moderate risk perception by the population towards environmental risks but a high emotional attachment to Luanda Bay as a formerly healthy ecosystem, reinforcing the need to restore its historical function to society.

Figure 1. A general Google Earth map of the study area shows Luanda Bay's location and neighbouring coastal ecosystems

To propose a nature-based solution to restore a healthy ecosystem in Luanda Bay, it is important to first understand how it got there. That history was described by Croese (2018). Portuguese explorers founded the city of Luanda in 1576, and like waterfronts elsewhere in the world, Luanda Bay has traditionally been a place of 'flow' and trade, connecting the city and state at large to the world. For centuries, the bay represented the trading heart of the city, where goods such as rum, food, clothes, sugar, tobacco, and hardware came into Luanda from sailing boats in exchange for slaves, ivory, wax, and seeds. The large sailing boats moored near the Island of Luanda were not connected to Luanda itself on the mainland (Figure 2). Local transport between the sailing boats and the land was then using small boats. The island was vegetated, and Luanda had mangroves and seagrass near the city. The construction of a new port, with its own wharf, under the urbanization plan for the waterfront of Luanda of 1943, shifted the focus of the city's movements from the centre of the bay to the mainland (Gouveia, 1970).

Figure 2. Historical photographs of the Luanda waterfront. ***Top*** 1^{ST} ***line****: left and centre: The city of São Paulo de Luanda during the XIX century; right: Luanda in 1908.* 2^{nd} ***line****: right: coffee commerce in 1925; centre and left: Luanda Bay at the beginning of the XX century with natural vegetation (including mangroves).* 3^{rd} ***line****: left and middle: Aerial images in 1956 showing the bridge connecting Luanda Island with the mainland, the channel connecting the upper bay with the ocean, and two sand bars (https://www.persee.fr/doc/jhydr_0000-0001_1957_act_4_1_3342). Right: That channel was filled thereafter.* 4^{th} ***line****: Recent urban development and more landfill around the bay including over the historical channel Images of the proposed plan are available at https://www.slideshare.net/Jals/projectos-para-a-baia-de-luanda -1178921 (accessed 14 March 2024).* 5^{th} ***line****: Left: Aerial photograph of Luanda Coastal area, Mussulo lagoon in first plan. Middle: Chicala lagoon, with intense pollution visible. Right: postcard picture of Luanda Bay showing the waterfront with more land reclaimed for recreational activities and some planted palm trees.*



Later in the mid-20th century, Luanda experienced rapid urban expansion, due to migration from the countryside and rapid demographic growth, characterized by three significant periods – late colonial (1948–1975), postcolonial amid civil war (1975–2002) and postcolonial at peace (2002 to the present; Viegas, 2016).

In this context of rapid economic growth, fuelled by a coffee boom and increasing investments in and growth of the city during the 1950s and 1960s, the Bay of Luanda became a place of wealth and leisure—the symbol of the city's transformation to modernity and the postcard image of the jewel of the Portuguese colonial empire. During this period, Luanda Island became connected to the waterfront of Luanda through a bridge (Figure 2) (da Fonte, 2007). When Angola attained independence in 1975, and during the post-colonial civil war period, the bay's waters became increasingly polluted as public investment in urban infrastructures ceased and sewerage and drainage systems stopped working. By the war's end in 2002, raw sewage continued to flow into the bay, roads and buildings on the waterfront were frequently flooded. During the postcolonial period at peace, plans were commissioned by the Ministry of Public Works to redevelop the bay. The proposal included, among other things, plans for dredging and cleaning the bay, the extension of the waterfront road and the construction of parking lots and green spaces (Croese, 2018). Land was reclaimed using dredged sediment to increase the land area around Luanda Bay for urban development, including replacing the bridge by a landfill. This cut off the ocean and upper bay's historical water connection. The construction work on the first phase in mid-2008 and was completed by August 2012 (Lopes & Eugénio, 2012), with a 3 km promenade lined by over 2,000 newly planted palm trees, 147,000 m^2 of pedestrian space, about three km of cycle lanes, ten new open spaces along the beachfront, three playgrounds, three sports fields, five basketball courts and five spaces for cultural events, in addition to a new wastewater system, a six-lane road (three lanes in each direction), a fuel station and a flyover connecting the waterfront to the Luanda Island (Figure 3; Croese, 2018).

Notwithstanding these developments on the land, the quality of water in Luanda Bay was severely degraded (Nicolau, 2016). Thus, the motivation for the Luanda Waterfront Project (https://ccemarluandawaterfront.com/en/home_en/), funded by Aga Khan Network (AKN) and by the Portuguese Foundation of Science and Technology (FCT), was not just to increase the knowledge about marine biodiversity and ecohydrology of this previously unstudied area but mainly to develop solutions to increase the health of this emblematic ecosystem and the life of the residents (Teodósio et al., 2018). The approach that not based on finding an exclusively engineering solution, but instead proposes a nature-based solution (i.e., an ecohydrology solution) to restore the ecological processes of a healthy coastal ecosystem including its fisheries resources and biodiversity. It integrates the hydrological processes, the trophic web dynamics, and the historical evolution of the natural system (Wolanski et al., 2008). Nature-based Solutions (NbS) were recognized by the United Nations Environment Assembly as a key approach to tackling global issues such as the one in Luanda Bay (Sowińska-Świerkosz and García 2022; Melanidis and Hagerman, 2022). In this chapter, we will present the challenges to Luanda Bay Angola, the environmental quality of the marine ecosystem, and the quality of life of the people. Our aim is to use ecohydrology science to propose a remedial environmental engineering cum nature-based solution, based on historical information, to alleviate the severe water degradation problem of Luanda Bay. This solution would improve the health of both the local communities and the coastal ecosystem.

2. LUANDA BAY ENVIRONMENTAL AND QUALITY OF LIFE: CHARACTERIZATION, AND CHALLENGES

Luanda Bay is 7 km long and shore-parallel, 2.3 km wide, 30-40 m deep for 2/3 of its length, but very shallow (< 0.7 m) in the upper third. It is protected from the sea by Luanda Island, limited in the North by the harbour of Luanda City (Leitão et al., 2016). It is currently separated from the Chicala and Mussulo lagoons by the landfill that constitutes the access to Luanda Island (Figure 1). It is a rich ecosystem providing wide diversity of fauna and flora species, working as growth, recruitment, feeding and breeding area for several species of fish, crustaceans, bivalves, cephalopods, etc., as well as for livelihood and income for the local fishing communities (Masifundise Development Trust, 2013; Nicolau, 2016, Baptista et al., 2020; Faria et al., 2021; Canda, 2022).

In recent years, there have been several scientific research projects on Luanda Bay, some in collaboration with international researchers. One of these projects was the Luanda Waterfront Project, which found that the bay is used by a wide variety of organisms, such as phytoplankton (dominated by diatoms and dinoflagellates; Costa, 2022), zooplankton (Andrade, 2022), fish (including commercially important species; Canda, 2022), benthic invertebrates (such as worms, cockles, clams, mussels, cuttlefish, starfish, crabs, etc.), seabirds (two of which are classified as endemic, one from the waters of the cold Benguela Current and the other from the coastal areas of south-west Africa), marine mammals and sea turtles that use the bay in search of a safe place to breed, grow and feed (Figure 3).

Figure 3. Some inhabitants of Luanda Bay: upper – commercial fish species, Sardinella maderensis (left) and Cephalopholis taeniops (right); middle left – bivalve, Senilia senilis; middle right – cuttlefish, Sepia spp.; down left – crab, Callinectes marginatus; seabird, Egretta garzetta.

Previous studies had reported multiple anthropogenic pressures that are threatening Luanda Bay over the last decades (e.g., Leitão, 2016; Nicolau, 2016; Pestana et al., 2020). This bay, surrounded by the largest urban area in Angola, experiences daily discharges of solid waste (including plastic), domestic wastewaters, agricultural industrial effluents, rainwater run-off, and untreated run-off from street-washing (Leitão et al. 2016; Nicolau 2016; Pestana et al., 2020) (Figure 4). All these factors result in water with high microbial activity and low oxygen concentration (Nicolau, 2016). The bay also supports the Angola's most important commercial harbour (Port of Luanda), a refinery, a naval base, a fuel station, petroleum and cargo terminals, and other activities, that also contribute to water pollution in this ecosystem (Leitão et al. 2016; Nicolau 2016; Pestana et al., 2020) (Figure 4), as well as for the biological invasions due to the continued movement of recreational and commercial boat and ships from different parts of the country and the world (Pestana et al., 2020). There is also siltation that retains pollutants, anoxic sediments, a high concentration of faecal coliforms and heavy metals, namely Cr, Cd, Cu, Zn, Pb (Santos, 2012). The Luanda Waterfront Project also found significant pollution in the upper shallows of Luanda Bay, threatening the consumption of marine resources used in subsistence fishing (Faria et al., 2021). This pollution was evident in project results parameters such as pH, dissolved oxygen, suspended solids, nutrient concentration, bacteriological analysis, and Harmful Algal Blooms (HABs). This was due to runoff from the watershed, which was associated with intense rainfall events bringing in pollutants and sediments from the land and was exacerbated by the artificialization of the bay with human structures (Figure 4).

Figure 4. Anthropogenic pressures in Luanda Bay: upper – strong surrounding urbanization; middle left – sewage discharge point in the bay; middle right – rainwater run-off coming from a local neighbourhood; bottom – solid waste, including plastics.

Nowadays, pollution is an obstacle for sport, tourism, and high-end recreation (Figure 5). It also has numerous socio-environmental impacts on the population including threats to public health, social inequality, pollution of water resources/insecurity, urban pollution, unproductivity and reduction of local income, and curtailing activities that depend on environmental quality, such as fishing, and constant flooding on rainy days. This pollution results from the misfunctioning of a sewage system dumping untreated domestic effluent daily into the bay, and poor or non-existent solid waste collection services. Despite all this, Luanda Bay still provides essential ecosystem services, though much degraded, to the residents. The bay remains a refuge for small-scale artisanal fishers, mainly from Luanda Island (Muxiluanda community), who fish there and collect marine organisms by mollusc gatherers, as a means of subsistence and income. Hundreds of people also collect molluscs and sea worms to sell on the streets of Luanda (Faria et al., 2021).

Figure 5. Touristic and recreational activities in Luanda Bay (Angola): upper left – sailing competitions; upper right – seabirds' observation; bottom – recreational vessels at the Luanda Naval Club.

Faria et al. (2021) described a new fishing technique in Luanda Bay, whereby the fishermen use smaller and traditional vessels, including some made of Styrofoam boards (Figure 6). Fishermen operate traditional and manually hauled fishing gears with low impact on the ecosystem, such as line/hooks, shovel, seine, gillnet, trawl, traps and cast nets (Figure 7). This activity in Luanda Bay provides livelihood for local communities, with maximum earnings of about 39 € by fishing day (Faria et al., 2021), which is larger than the average income per person (20.09 € in 2019; Faria, 2021). Thus, the quality of life of these communities is highly depending on this local fishing activity (Faria et al., 2021). While fishing in the bay serves as a source of income for the local communities, existing legislation permits this activity solely for subsistence purpose (Aquatic Biological Resources Law No. 6-A/04 of October 8 by the Ministry of Fisheries, Angola, 2004; Presidential Decree No. 41/05 of June 13 by the Ministry of Fisheries, Angola, 2005). However, despite regulations such as Presidential Decree No. 28/15 of 13 January by the Ministry of Fisheries, Angola (2015), which prohibits the capture of bivalves in closed areas of Luanda Bay, inadequate enforcement leads to uncontrolled fishing practices and challenges in resource management. The situation is exacerbated by poor legislation, fostering unreported landings and the consumption of contaminated species. Moreover, the emergence of biotoxins in the bay poses serious health risks, particularly through the contamination of bivalves and certain fish species. This contamination by HABs can lead to various health issues in humans, including neurotoxic effects such as Amnesic Shellfish Poisoning (ASP) and Paralytic Shellfish Poisoning (PSP) (Vale et al., 2009; Branco et al., 2010). Consequently, the quality of life for local communities is adversely affected (Faria et al., 2021).

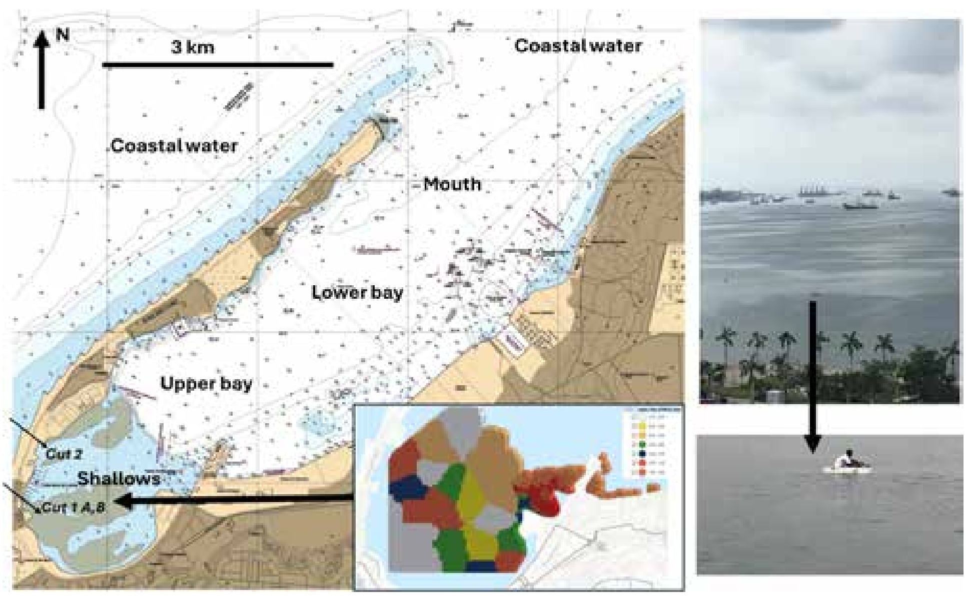
Figure 6. Fishing activity in Luanda Bay: upper – catching molluscs and sea worms with the support of the adapted vessel of Styrofoam boards; bottom – using seine net (left) and gillnet (right) to catch fish.

The communities living around Luanda Bay are conscious of the environmental problems that they face, and they are generally willing to actively engage in efforts to protect the environment (Nogueira et al., 2021). The direct relationship with Luanda Bay is part of the life of the people around it. Beyond all the impurities, the waters of Luanda Bay carry memories from generation to generation, as does the relationship between a people and the territory in which they live. The leisure activities of the people who were born and grew up there are mostly related to the beaches, even if some of them are now considered unsuitable for bathing. A clean and protected Luanda Bay would bring much more economic activity to Luanda through sustainable tourism and fishing, it would create new jobs, development, and opportunities for the city, and, more importantly, it would restore the quality of life for its people.

3. METHODS FOR ECOHYDROLOGICAL MODELLING TO ANSWER CHALLENGES

Luanda Bay was divided in the mouth (30 m deep in the middle) and coastal water (also typically 30 m deep), a lower bay (25-30 m deep with shallower water along the coast), an upper bay (typically 25 m deep with shallower water along the coast), and the shallows (Figure 7). The depth in the shallows is commonly no more than 0.7 m.

Figure 7a. The 2022 bathymetry of Luanda Bay from the bathymetric chart INT 2551. The insert is our survey of the bathymetry in the shallows on a 10 X 10 m grid. All depths are in m below Lowest Astronomical Tide (LAT). Depth meshes (resolutions of 10 m and 20 m) were provided by the Portuguese navy built based on the multibeam survey carried out in 2021; with probes represented on the nautical chart 16303 – Port of Luanda. Cuts 1 (A,B) and 2 refer to the proposed engineering works described in this chapter. Cut 1A consists of a dredged channel, 61 m wide and 2 m deep below LAT, and extending 130 m into the shallows. Cut 1B is located at the same site but it is 86 m wide, and it extends 413 m into the shallows on a straight line. Cut 2 is a dredged channel just north of the marina; it is 86 m wide, 2 m deep below LAT, and extends 600 m into the shallows.



Source: https://geomar.hidrografico.pt/

Figure 7b. The domain of the two models.

Source: https://geomar.hidrografico.pt/

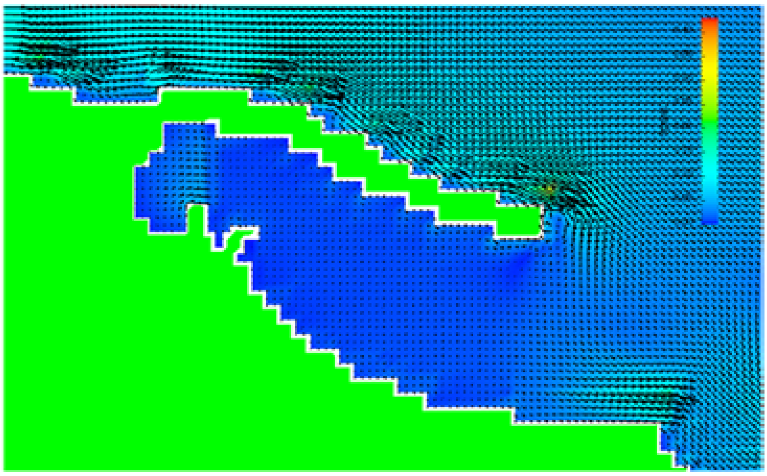
Tidal data for Angola were obtained from the World Tidal Atlas, and the corresponding tidal currents in coastal waters were calculated from the phase differences. The mean longshore currents were obtained from satellite altimetry data (NOAA database) to be highly variable, and they often reverse direction, typically ranging from + 0.06 m s^{-1} to – 0.06 m s^{-1}.

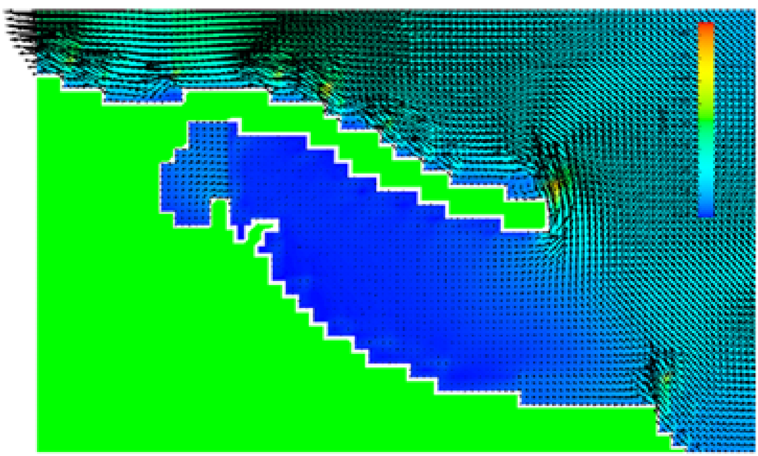
For modelling the hydrodynamics, we used the fully implicit, 2D hydrodynamic model of Baptista et al. (2020). To study the large-scale circulation, a large model domain was used that covered the whole of Luanda Bay and coastal waters (Figure 7b). The mesh size was 285 m. To study the flushing of the shallows and Upper Luanda Bay, a model with a smaller domain (Figure 7b) was used; it was nested inside the model with the large domain; its mesh size was 43 m. The mesh size is limited by the condition in 2D modelling that the mesh size must be larger than the depth. We focused on the dry season. The situation in the wet season could not be studied reliably because there is no data on the inflow of water and pollutants from the land. For modelling the advection-dispersion processes we used the Lagrangian model of Spagnol et al. (2002). 84,000 virtual particles were introduced in the model all over the shallows. They moved with the water currents, and they also dispersed following ambient turbulence. Following Okubo (1971), the sub-grid scale horizontal diffusion coefficient was taken to be 0.1 m^2 s^{-1} for the small mesh. The virtual particles represent polluted water initially in the shallows.

4. PROJECTING RESULTS TO FUTURE SOLUTIONS TOWARDS A HEALTHY LUANDA BAY

The model revealed that the mean currents in the ocean do not strongly affect the bay (i.e., they do not intrude in the bay; Figure 8). This is due to the closing of the south end of the bay, which started in 1957 with the bridge construction and continued culminating in 2012 with more land reclaimed (Figure 2). The currents in the bay are controlled by the tides at the mouth of the bay and by the local wind over the bay. Thus, the net water circulation in the ocean and coastal water does not drive the flushing of Luanda Bay.

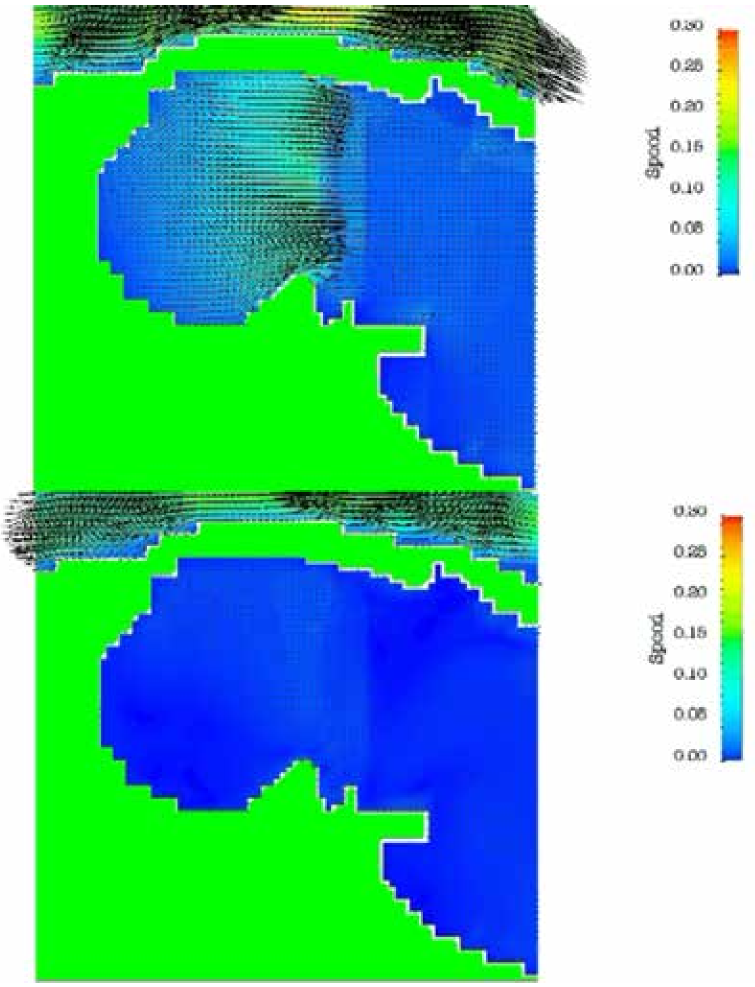
Figure 8. Two snapshots of the predicted currents in Luanda Bay and coastal waters at two opposite times of the tidal cycle in calm weather. The colour bar shows the speed in m s^{-1}.





Snapshots of the currents over the shallows and Upper Luanda Bay at two different times in the tidal cycle, for a 1.4 m tide and calm weather, are shown in Figure 9. The noticeable stronger currents at the outer margin of the shallows are due to the incoming tidal wave in deep water suddenly finding shallow water. The currents are measurably stronger in coastal waters than in the bay.

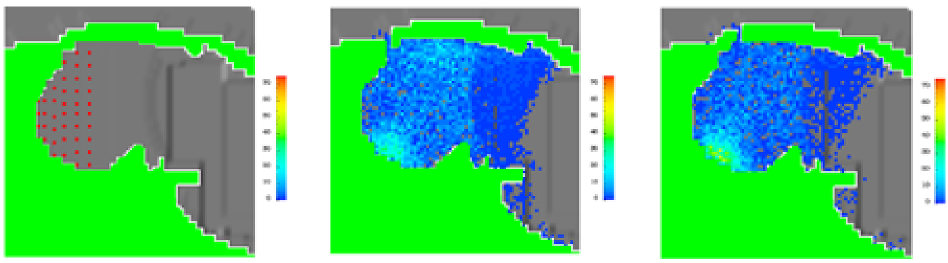
Figure 9. Snapshots of the currents over the shallows and Upper Luanda Bay and coastal waters at two different times of the tidal cycle in calm weather. The colour bar shows the speed in m s^{-1}.



For the present condition and in calm weather, the model reveals that the shallows remain heavily polluted after 40 days, and that Upper Luanda Bay traps pollutants in the shallows (Figure 10a, b). The high number of tagged particles remaining trapped in Upper Luanda Bay implies a persistent pollution problem there. What matters for the biota is the concentration, and the concentration is the number of particles per model cell divided by the depth. The rconcentration of polluted water from the shallows after 40 days is presented in Figure 10c. The pollution of Upper Luanda

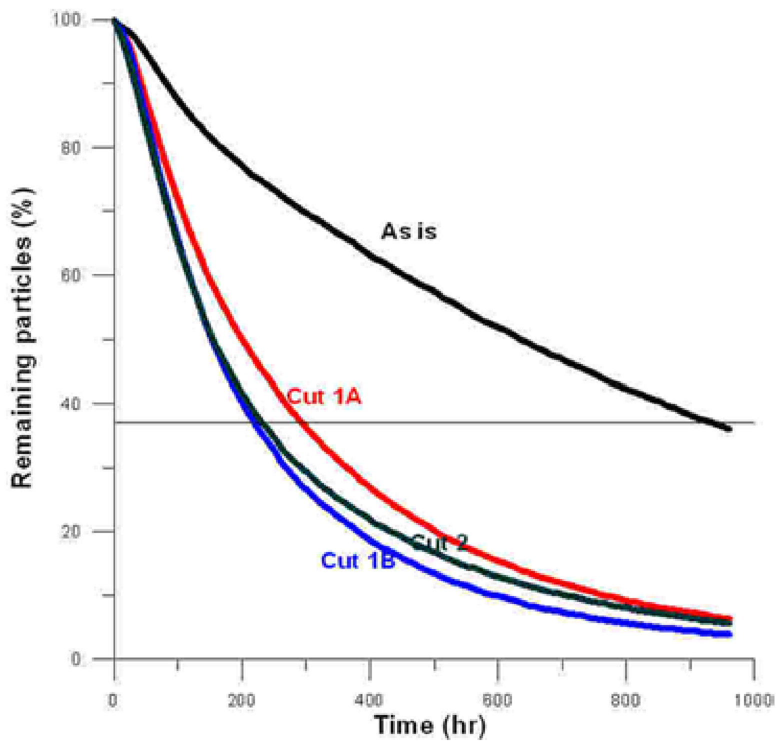
Bay is small compared to that in the shallows and the heaviest pollution occurs in the uppermost areas of the shallows.

Figure 10. The distribution of the tagged water particles in the model (a) at time 0 when they are introduced in the model and (b) after 40 days. In (a) 1000 particles were introduced at each seeded cell. The colour bar shows the number of particles per cell. (c) The relative concentration of polluted water after 40 days of calm weather and no inflow from the land. The colour bar shows the concentration.



The residence time is the time it takes for 1/e (37%) of the particles to remain in the domain (Wolanski and Elliott, 2015). The residence time of polluted water over the shallows in calm weather (labelled 'As is') is 38 days (Figure 11). Thus, pollutants stay trapped for a very long time in the present situation. Our results agree with data from the Lagrangian tracers' study of Rosa (2018). These results suggest that, in the case of discharges of pollutants such as domestic effluents in this inner zone of the bay, the effluent plume is trapped in the shallows. The wind is predicted to play a minor role in the flushing of the shallows. The wind at Luanda is only 'strong' and sustained for long duration in the wet season from December to April (Rosa, 2018); but even then, a 'sustained' wind speed of 19 km h^{-1} is not a strong wind that could drive strong currents. The model indeed suggests that such a wind has a negligible influence on the flushing of the shallows.

Figure 11. Time-series plot of the number of particles seeded in the shallows remaining in the shallows. Where the line intersects the 37% line is the Residence Time (RT) in the oceanographic convention. 'As is' is the present condition (RT = 37.5 days), Cuts (1A, 1B and 2) refer to the situation following channel dredging at the sites shown in Figure 7. Cut 1A consists of a dredged channel, 61 m wide and 2 m deep below LAT, and extending 130 m into the shallows (RT = 250 hours,10.41 days). Cut 1B, is located at the same site but it is 86 m wide, and it extends 413 m into the shallows on a straight line (RT = 9.17 days). Cut 2 is a dredged channel just north of the marina, it is 86 m wide, 2 m deep below LAT, and extending 600 m into the shallows (RT = 9.58 days).



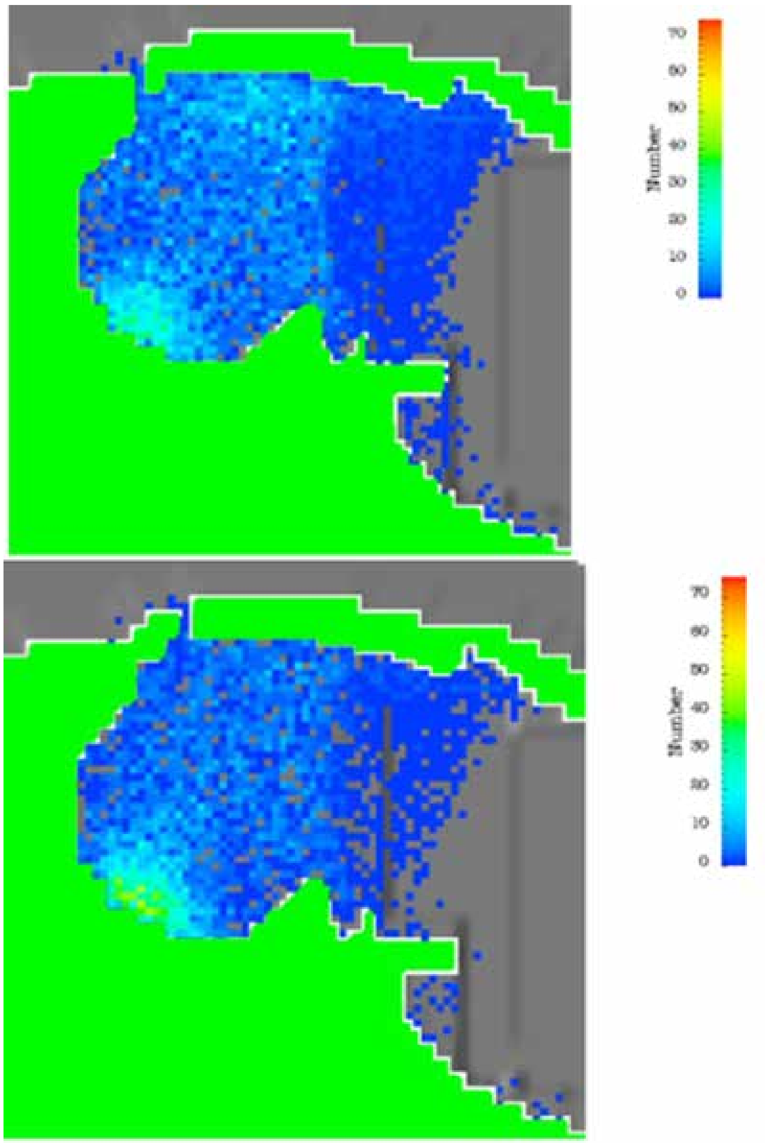
It is possible to use environmental engineering technology to reduce the residence time of polluted water in the shallows. The proposed environmental engineering measure is to dredge a channel to the open seas. It is not a magic solution as it then spreads the polluted water to coastal water where, however, flushing of the coastal water is swift due to dynamic currents in that area, thus presumably the environmental impact is small. Moreover, the new opening will also allow the tidal inflow of coastal water with its planktonic propagules from nearby lagoons (Tavares et al.,

2022) to enhance the colonization of historically relevant species, such as seagrasses, mangroves, and accompanying biodiversity.

Three likely cuts were considered (Figure 7a). Cut 1A consists of a dredged channel, 61 m wide and 2 m deep below LAT, and extending 130 m into the shallows. Cut 1B is located at the same site but it is 86 m wide, and it extends 413 m into the shallows on a straight line. Cut 2 is a dredged channel just north of the marina; it is 86 m wide, 2 m deep below LAT, and extends 600 m into the shallows. The reason for a long channel in the shallows is that the site is far away from the middle of the shallows so the channel must be longer to drain and export water at falling tide from the middle of the shallows.

The residence time of the water in the shallows for cut 1A is 8.7 days, and that for cuts 1B and 2 is measurably smaller (Figure 11). The concentration of polluted water on day 40 for Cut 1A and Cut 2 is shown in Figure 12. The cut has flushed out to the sea much, but not all, of the polluted water from the shallows. Figure 12 also reveals that the concentration in Upper Luanda Bay is always smaller than in the shallows.

Figure 12. The distribution of the concentration of polluted water originating from the shallows on day 40 for (a) case 1A and (b) case 2. The colour bar shows the concentration.



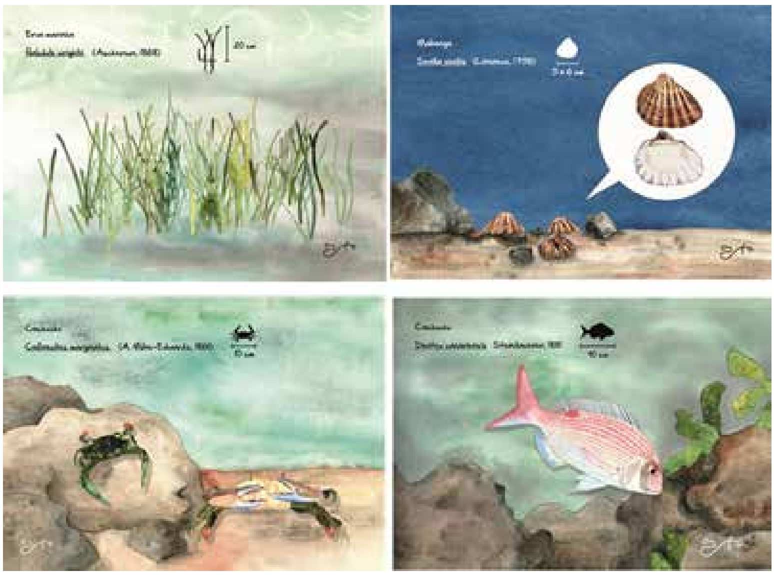
5. CONCLUSION

Land use in the catchment upstream of estuaries, bay and along the shores, land claim in coastal wetlands, pollution, dams/barriers, and dredging, among many other causes, have profoundly degraded many coastal areas worldwide and Luanda Bay is one of them. There are attempts worldwide in many maritime states to restore the ecosystem health of the degraded estuaries and bays. Most commonly, the experience shows that the solution combining physical intervention with wise engineering and eco-engineering (i.e., nature-based solutions) are linked to their restoration with different level of success and time of recovery (Wolanski et al 2008; Elliott et al. 2016, with world-wide examples). Those actions promote recolonization by plants and animals and acknowledge the role of the microbial populations and the materials that they exude (Wolanski & Elliott 2024, review). These responses of nature allow that recovery times are usually short (examples from 6 months are found in salt marsh ecosystems (Chicharo et al. 2008).

Luanda Bay ecosystem health depends on the rate at which water is flushed. The longer the residence time in the system, the greater the likely water quality problems. Ecological integrity also depends on the rate at which fine sediments are sequestrated in tidal wetlands or flushed out to sea. With the actual conditions of Luanda Bay in the shallows, the estimated residence time is over 30 days. The model results show that it is possible to significantly decrease the residence time of water to 9 days, in the shallows of Luanda Bay by opening a cut from the shallows to the sea. This simulates the natural, historical connections of the bay with the ocean near this area (Figure 2 top line) and allow colonization by propagules from the nearby coastal lagoon. This should improve the pollution problem of the shallows but has some negative socio-economic implications in that land will need to be reclaimed, and the cut will need maintenance. Excavating the channel over the land is straightforward engineering. This new channel would extend for some distance over the shallows to draw water in from the middle of the shallows at falling tide; this water is then exported to coastal waters by the tidal currents. The usual dredging ships cannot operate in the shallows because of the small depth. A barge would be needed with a sediment pump powered by a generator. The pump would suck the fine sediment out and pump it through pipes to a storage site. The storage site needs to be enclosed to prevent the sediment from moving out and returning to the dredged channel.

The cut should reduce the residence time of water in the shallows to about 9 days. In the wet season, there is presumably an inflow of water and its pollutants from the land, which would increase the concentration of pollutants in the shallows. Nevertheless, the cut should flush out the pollutants with the same residence time. The polluted water does not disappear in the presence of a dredged channel. Instead, it is transferred to coastal waters, where it is swiftly dispersed by the strong currents. Other measures will also be needed in the future in order to maintain the health of the catchment or drainage basin of Luanda Bay, directly determining a healthy coastal area.

Figure 13. The native biodiversity of Luanda Bay that will be enhanced or restored with our nature-based solution, painted by the artist Sarita Deonilde Encarnação Camacho.



The proposed solution originated from the modelling exercise theoretically will increase the environmental health. The improved water quality and the increased connectivity between the bay, coastal waters and Mussulo lagoon will result in colonization by more key species (Figure 13), including propagules from seagrass and mangroves of Mussulo lagoon as well as invertebrate and vertebrate species. This should lead to the recovery of traditional artisanal fisheries that are now declining (e.g., clams like Mabanga -*Senilia senilis*), because residence time (RT 9 days) still allows post-larvae to settle since most of those planktonic phases have reduced pelagic larval duration, crucial in invertebrates or vertebrates' retention (Teodósio et al., 2016). This should return the system to a more natural state and increase the quality of marine food resources, reduce Harmful Algae Blooms, and improve the quality of life for people in the area, including opening a new waterfront for aquatic recreational activities.

Nevertheless, for long term (several decades) planning, remediation measures on land are also needed to decrease the pollutant load reaching the shallows. There is the experience in Western Australia of dredging a channel from the sea to an eutrophicated lagoon to increase the flushing rate of the lagoon (Wolanski, 2014). In the short-term this improved the ecosystem. However, the pollutant load was not addressed; it even increased over time; and in the long term (a few decades), the eutrophication problem came back. By analogy, the pollutant load to the shallows of Luanda Bay must be addressed. One way could be to build traps in the drains and streams flowing into Luanda Bay, to be cleaned annually. Some of these traps should be small artificial wetlands whose plants should be harvested after the wet season to remove the nutrients; this is a classical method in phytotechnology for urban watersheds (Zalewski et al, 2004). This would also be somewhat expensive and difficult to implement, as the experience with harbours worldwide has shown (Wolanski, 2006). Nevertheless, the nature-based solution we propose would measurably improve the system but not fully restore its historical environmental health.

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KEY TERMS AND DEFINITIONS

Biological Invasions: Are recognised as a major economic and environmental threat worldwide. They occur when species colonise new geographical regions that are isolated from their existing populations. While many invasive species are exotic (non-native), there are cases where native species can also become invasive.

Ecohydrology: The science that relates hydrological processes to the biological dynamics of ecosystems at different spatial and temporal scales in order to develop effective solutions for restoring the health of aquatic ecosystems. The concept of ecohydrology was developed within the framework of UNESCO's International Hydrological Programme (IHP).

Environmental Engineering Technology: A specialised field within Engineering Technology that focuses on the application of scientific and engineering principles to address environmental challenges and concerns. Overall, it is a vital field that contributes to the sustainable development of societies by addressing environmental challenges and promoting responsible practices. Environmental Engineering Technology professionals combine technical knowledge with a commitment to environmental stewardship to create a healthier and more sustainable future.

Eutrophication: The process where an excess of nutrients in a water body leads to harmful algal blooms, reduced dissolved oxygen levels, and can result in the death of invertebrates and aquatic vertebrates, and in some cases, ecosystem collapse. This nutrient enrichment process, particularly compounds of nitrogen and/or phosphorus, accelerates algal growth, primary production and biomass, causing significant changes in nutrient balance, composition of aquatic organisms and degradation water quality.

Exotic Species as Invasives: Exotic species, introduced intentionally or unintentionally by humans, often become invasive. Global trade, tourism, and climate change contribute to their spread. These invasives disrupt ecosystems, alter biodiversity, and affect ecosystem services. Efforts to prevent and control invasions rely on understanding their physiology and ecology.

Hydrodynamic Models: Mathematical and computational tools used to simulate the movement and distribution of water and its constituents within diverse aquatic environments. They help understand and predict the behaviour of water bodies under different conditions, and are essential to study hydrodynamic problems, water resource management and environmental protection.

Mangroves: A coastal ecosystem from tropical and subtropical regions, characterized by salt-tolerant trees that grow in the transition between terrestrial and marine environments. They act as nurseries and buffers against climate change, playing ecological, economic and social roles.

Native Species as Invasives: Although less common, native species can also become invasive. A native plant that expands aggressively due to changes in environmental conditions (e.g., increased nutrients or altered disturbance regimes) can become invasive. The dynamics of native invasions differ from those of exotic invasions, but both impact ecosystems.

Nature-Based Solution: A holistic approach that integrates hydrological processes, trophic web dynamics and the historical evolution of natural systems to restore the ecological processes of a healthy ecosystem, including its fisheries resources and biodiversity, i.e. an ecohydrology solution.

Residence Time: The time it takes for 37% of the particles to remain in water body studied (the model domain) according to the oceanographic convention.

Seagrasses: A group of marine flowering plants that are found typically in shallow waters. These plants play an important role in coastal ecosystems supporting food security, mitigating climate change, enriching biodiversity, purifying water, protecting coastlines and controlling diseases.

Subsistence Fishing: Refers to fishing practices that is carried out primarily for the livelihood (to feed the family and relatives of the person who fishes) and income of the local fishing communities. This type of fishing generally implies the use of low-tech 'artisanal' fishing techniques and plays an essential role in food security, cultural heritage, and the livelihoods of many coastal and inland communities around the world.

Watershed: A hydrologic unit that encompasses all drainages flowing to a common water source. It includes streams, precipitation, and even groundwater and is used as a unit of measure for managing and delineating natural resources on a landscape scale.