MARINAS DESIGN IN AREAS OF HIGHLY ENVIRONMENTALLY SENSITIVE (CASE STUDIES)

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ABSTRACT

The calm always comes after the storm and, in our case, after a period of economic circumstances which were unfavorable for us, the sharp improvement in the nautical sports sector has resulted in the need for new berths, whether it be through expansions or new locations. The latter, given the degree of occupancy on the coast as well as the correct environmental protection measures to be applied, are very complicated to place.

As a result, innovation, environment, development, land-use and sustainability must join forces in order to find products and solutions with a similar effect on society, significantly decreasing the environmental impact created, working with natural processes to protect, restore or even improve the environment.

1. GLOBAL DESCRIPTION OF THE WORLDWIDE NAUTICAL OFFER

The recreational nautical industry is an economic activity that has historically been closely linked to both tourism and infrastructure as well as the real-estate sector.

If we take a look at worldwide macro values, according to data from the National Marine Manufacturers Association (hereafter NMMA), we can highlight:

- There are more than 25 million recreational watercraft registered and in service around the world.
- This impacts the service industry by favoring the creation and existence of more than 100,000 small and medium enterprises.
- More than 25,000 marinas of different types and sizes are registered around the world, directly creating one million jobs.

For this reason, the sector must be taken care of given its important impact. However, at the same time, we need to monitor and condition its continuity and growth while fully respecting the basic environmental principals, assuring the future sustainability of the environments in which both marinas and economically associated businesses are found.

Today, a true Ecosystem (a name also used by the NMMA) has been created around the maritime sector which encompasses numerous sectors and activities. This ecosystem is a true economic force creating value that cannot be jeopardized and must be strengthened by the sensible use of natural resources both during design and when developing facilities.

This important ecosystem is made up of retail stores, restoration, marina infrastructure, vessels, sailors, accessory factories and distribution, sailing schools, distributors, service providers, brokers and many more.

As far as we understand, recreational nautical infrastructure has often been linked to a “payback” resulting from real-estate investment, forgetting that, in this sector, a significant number of activities intertwine which, in addition to adding considerable value, help repay the investment necessary to create the infrastructure itself.

Additionally, outsiders (as well as some insiders) associate the nautical industry with giant yachts, luxury cars and products which are completely inaccessible to the middle class, which should be the real target population.

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All data points to recreational boaters being members of the middle class, with moderate income, who see this pastime as one more target within today's day-to-day value scale.

According to data from the NMMA, 95% of watercraft registered in the United States measure 8 meters (24 feet) or less in length. We must also add that only 1% of boats registered exceed 12 meters (37 feet). This figure is also reflected in other countries such as:

- France: 91% of boats measure 8 meters or less in length.
- Queensland and New South Wales: 94% of boats measure 8 meters or less in length.

Economic models also reflect these figures.

At a recent meeting of the International Council of Marine Industry Associations (ICOMIA) in Amsterdam, Adjiedj Bakas also pointed out that the recreational boating industry was on the path to a collaborative economy which presumes a boom and revolution we must be ready for. Bakas stated:

…"*the middle class will have less money but more time thanks to robotization. In the* ***Boating and Marina*** *market trends, people will look for affordable boats with low maintenance costs, often sharing them through* ***collaborative economy****. Marinas will go from being parking lots for boats to places where people share a* ***community lifestyle****".*

…" We have to change the garage into a ***leisure destination****"…*

However, we cannot forget about the mega yacht market which, in spite of the economic crisis we've seen, has not stopped growing. According to Gregorio Méndez de la Muela at the V Foro Náutico de Colombia, held in Santa Marta, *"In spite of the economic uncertainty after the 2007 economic crisis, the* ***mega yacht market continues to grow annually****. In recent years, shipyards in Italy, France and the United Kingdom have built nearly 500 yachts."*

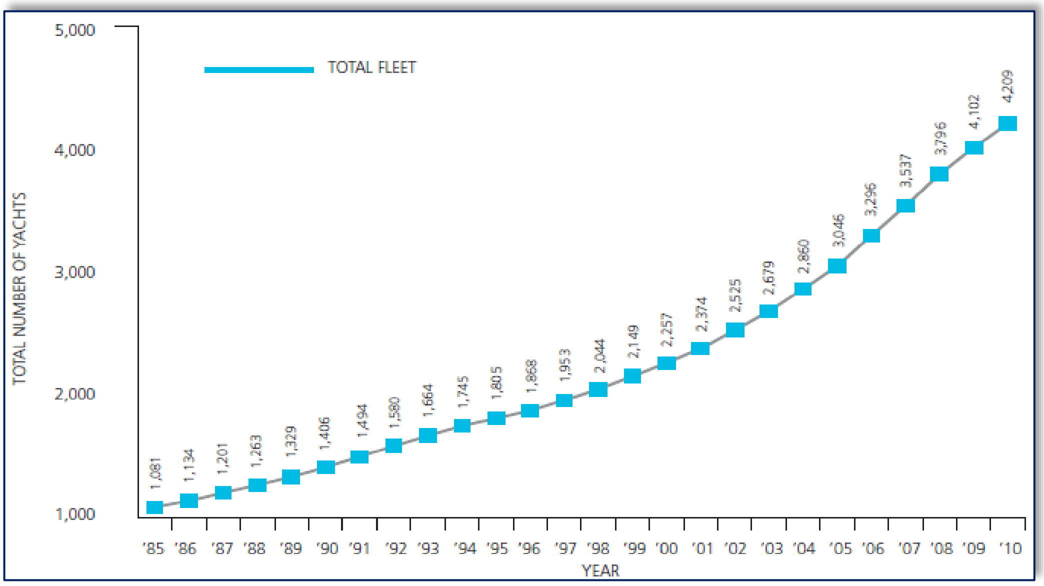


Figure 1: Evolution of the Mega Yacht fleet since 1995. (V Foro Náutico Colombia, 2017)

In summary, the recreational nautical industry is booming and all signs point to significant future growth which we must be prepared for in order to create new infrastructure able to meet the growing demand while having as small an impact as possible.

Our contribution to this prestigious conference will discuss this: the possibility of balancing highly environmentally sensitive areas with the construction of low-impact marina facilities, controlled investment and highly beneficial effects for the local economy.

We will mention three practical cases, some already in place, which show major investment is not necessary and that the return on these facilities is guaranteed without the need for large real-estate promotion or land creation that is incompatible with coastal sustainability.

2. NEW FACILITIES: ENVIRONMENTAL CONDITIONS AND RISKS

There is a mature market in developing countries, where the majority of concessions are advanced. The mooring offer adapted to demand until 2007, but since then there has been practically no evolution.

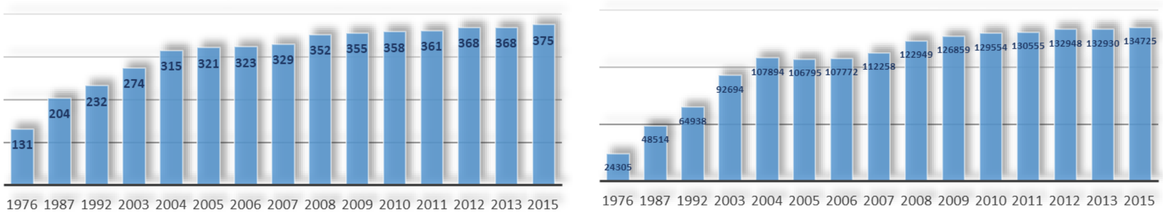


Figure 2: Evolution of marinas (left) and moorings (right) in Spain. (FEAPDT, 2016)

The number of vessels has continued to grow while the number of berths available has not, thus resulting in today's saturation. This shows the difficulties arising from expanding or creating new marina infrastructure. A marina is not simply a place to tie up boats.

Marinas are facilities designed by specialized engineers to be able to resist extreme wave heights, currents and winds, along with actions caused by boats and humans. This entails significant design of protection structures if the waters are not protected naturally. At the same time, the impact on the local hydrodynamics, coastline dynamics and marine environment must be taken into account.

Furthermore, economic, market and environmental issues must be integrated and we must calculate whether investment will be worthwhile, what the current and future nautical trends are and if the market will be sustained in the long term. The high depreciation costs for protective structures are not compatible with concession periods (a maximum of 30 years in Spain), meaning the payback on investment is not guaranteed. This issue is magnified by the correct and necessary environmental restrictions of the *Ley de Suelo* (Land Law), which prohibits real-estate development being associated with the marina, as was done in the past. Puerto Sotogrande, Puerto Banús, Marina del Este, etc. are worth mentioning as large investments that, without taking real-estate development into account, would have been practically impossible to have been repaid.

Figure 3: Marinas Sotogrande, Banús y Marina del Este

As a result, <u>building new facilities</u> in developed countries is a very complex task. In Andalusia, for example, where its coastline is its greatest strength, not one marina has been built in unprotected water in the past 20 years.

Another alternative is to <u>expand existing ports</u>, which, in any case, also has major obstacles to success. The previously mentioned concession periods limit the large investment necessary for expansion in the case of unprotected waters. This is the case of the Puerto Deportivo in Benalmádena and Puerto José Banús as well as the recently failed concession of the Marina la Bajadilla.

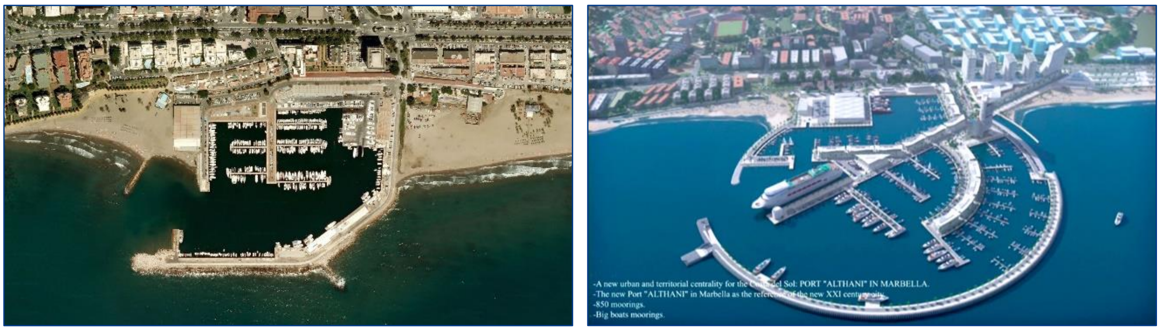


Figure 4: Marina la Bajadilla present and future. (Berenguer Ingenieros, 2012)

Yet another alternative or solution is to analyze the coastline in order to determine those zones which have their own natural protective condition, making it unnecessary to build rigid protective constructions that can adversely affect the costal dynamic, thus making them opportune areas to place new maritime facilities. Working with, not against, natural processes can lead to less costly and more sustainable solutions.

If opportune measures are taken, these areas, initially dismissed for their high environmental sensitivity, could harbor a marina with absolutely no environmental effects. Such sensitive areas require measures which allow us to reduce the effect on marine ecosystems.

Biotic, abiotic and socioeconomic environmental components must be taken into account when evaluating the environmental impact of each stage in marina design and construction.

Measures must be arranged to control solid, liquid and gas emissions that may alter surroundings. In general terms, control measures that must be taken include:

- Air Quality: Occasional irrigation, using tarps on trucks, using vehicles with emission control systems, restricting working hours to avoid disruption during rest periods, etc.
- Soil Quality: Heavy equipment or areas with impervious containment, promoting suitable classification and disposal of waste or solid urban waste, etc.
- Protection of Flora and Fauna: Controlling periods of maximum wildlife activity, promoting activities to protect the ichthyofauna present, beacons to minimize the area of operation, etc.
- Water Quality: Using geotextile barriers, promoting an emergency plan in case of unexpected spillage, promoting an annual code of conduct manual for users, etc.

In addition to designing a structure that is compatible with nature, it is fundamental for structures to include the equipment and facilities necessary to reduce possible environmental effects. Among others, this must include:

- Implementing systems that use renewable energy to supply electricity.
- Using energy-efficient luminaires.
- Bilge cleaning systems.
- Removable anti-contamination barrier to avoid the escape or entry of spills in case of accidental spillage and to facilitate marina cleaning.

At the same time, there is currently no European regulation regarding ecological requirements for watercraft, but it is in the development stage, thus the use of hybrid and ecological watercraft will be another aspect to take into consideration.

By keeping the abovementioned practices in mind, we can be sure to have modern and complete facilities for recreational nautical use and complementary activities, without any risk for a location which is invaluable from the environmental perspective.

3. PROTECTIVE CONDITIONS AND OPTIMAL WAVES

In recent years, we have had the opportunity to design several marinas in specially protected areas. Particularly noteworthy are the nautical sports facilities in the Río Piedras natural marshlands and the El Rompido sandbar in Huelva, Spain, the Archipelago of San Andrés, Providencia and Santa Catalina in the Colombian Caribbean, and the Topocoro reservoir in Santander, Colombia, all of which are classified as highly environmentally sensitive.

Occasionally, nature does us a favor by offering naturally protected areas which do not require rigid protective constructions that can adversely affect the costal dynamic, thus leading to collateral damage. Such is the case in the areas mentioned above. In the first case, we have the El Rompido sandbar to provide refuge for watercraft, a coastal reef in the second case, and the Topocoro marina is located in a reservoir.

The protection provided by the area itself allows for “permeable” structures, like a floating breakwater, to guarantee marina operability. Energy dissipation is left to the natural structures, leaving short-period residual waves to the floating barriers.

The following are the required wave conditions in marinas:

- Hs = 0.25-0.30 m ....Comfort limit for small watercraft (L < 12 m)
- Hs = 0.35-0.40 m ....Comfort limit for large watercraft (L > 20 m)
- Hs = 0.50 m ....Guaranteed limit for floating docks
- Hs = 0.60 m ....Safety limit for small watercraft (L < 12 m)
- Hs = 0.80 m ....Safety limit for large watercraft (L < 20 m)

The aforementioned concrete docks or floating breakwaters provide extraordinary attenuating effects for low-period swells characteristic of semi-protected areas.

Figure 5: View of floating breakwater attenuating effect.

Floating breakwaters have traditionally been believed to be unstable structures associated with small recreational vessels. This is due to the fact that, until recently, the preferred construction material was metal profiles (aluminum or hot galvanized steel).

The boom in concrete as a construction element in void boxes completely changes the scene and, for the first time, floating barriers can be used which feature stability and resistance similar to that of fixed docks made with slabs of the same material. Additionally, both maintenance and environmental impact are negligible.

By forming a single segment without individual floats, concrete wave barriers offer great stability (from 400 to 1,200 Kg/m^2) and resist waves in semi-protected areas quite well (up to 1.5 m high waves).

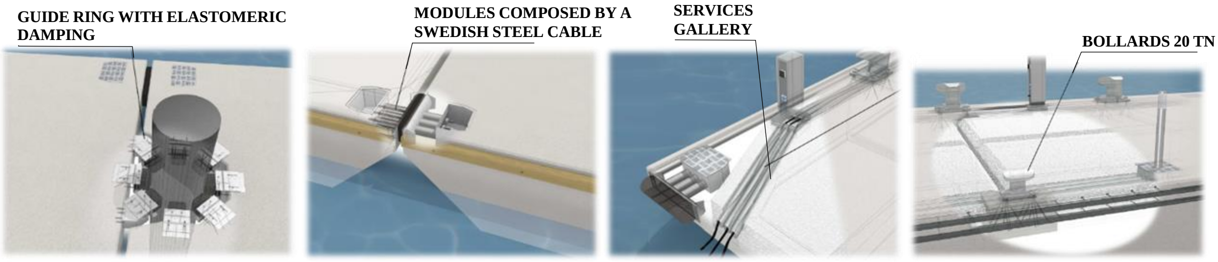


Figure 6: Floating breakwater details (MSI)

The units have service galleries through which the networks needed for water supply and electricity run. They are anchored with chains and deadman anchors or piles. However, in the case of the latter, it should be noted that studies are scarce. By using piled wave barriers, induced movements are eliminated, only allowing degree of freedom z in their movement. This type of equipment offers two advantages:

a) It doesn't lead to any snaking on the ground. Some manufacturers also avoid this by installing post-tensioned cable.
b) It allows mooring larger watercraft on its sheltered coast (yachts and mega yachts).

Floating breakwaters can be used in both protected and semi-protected areas which require high quality and stability.

Their dissipating effect is backed by the reduced model from the Institute of Applied Hydrodynamics (INHA, Spanish acronym) in its study "Three-dimensional tests of floating docks to analyze their hydrodynamic behavior against wave transmission which our firm has had access to"[4] at the request of Marina System.

Figure 7: View of INHA's reduced model.

Given the fact that a large number of phenomena intervene in the interaction between waves and the structure, there is no floating breakwaters that is a completely reflective system. To estimate transmission coefficient k_T of the structure, we need to study the variables that influence it. We must keep in mind the incident wave, the geometry of the wave barrier, its mechanical properties, moors available and surrounding water viscosity. Taking all these basic parameters into consideration, the dimensional analysis provides expressions like:

$$k_T = f\left(\underbrace{\frac{d}{L},\frac{H}{L}}_{\text{Waves}},\underbrace{\frac{B}{L},\frac{h}{d}}_{\text{Geometry}},\underbrace{\frac{M}{\rho Bh},\frac{I}{MB^2}}_{\text{Mass}},\underbrace{\frac{h_G}{h},\frac{kB}{Mg}}_{\text{Berths}},\theta,\underbrace{\frac{B\sqrt{gd}}{\gamma}}_{\text{Viscosity}}\right)$$

The most important parameters are considered to be that related to depth (d/L), that which controls the vertical distribution of energy flow, and that related to width (B/L). Numerous studies have obtained k_T curves solely based on said parameters.

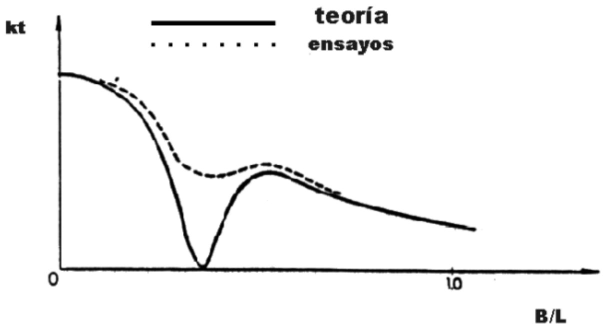


Figure 8: Typical attenuation curves.

[4] Original title: "Ensayos tridimensionales de pantalanes flotantes para analizar su comportamiento hidrodinámico frente a la transmisión de oleaje, al que nuestra firma ha tenido acceso"

Floating breakwaters are structures whose movements are induced by incident waves. These movements, similar to those of a mechanical system undergoing a sinusoidal force, play an integral role in determining the strain on moors and wave attenuation.

For regular waves, there is relatively good agreement between experimental results and theory, with the exception of resonance, where radiated and refracted waves theoretically have opposite phases and the k_T should thus be equal to zero. This is due to the fact that as soon as the dock movements become predominant, the linear model is no longer valid. This is also true because a purely regular wave and perfectly elastic moors do not exist.

In summary, concrete wave barriers perform best when the relationship between ω/ρ (angular wave frequency/angular system frequency) exceeds the unit. The movement amplification factor decreases and the phase approaches 180º. This occurs in short-period waves where the movements of the structure and the waves are significantly lagged.

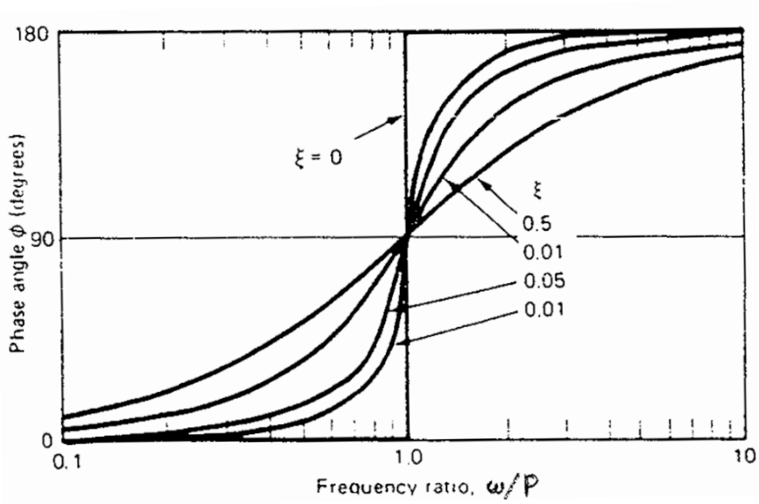


Figure 9: Phase relationship.

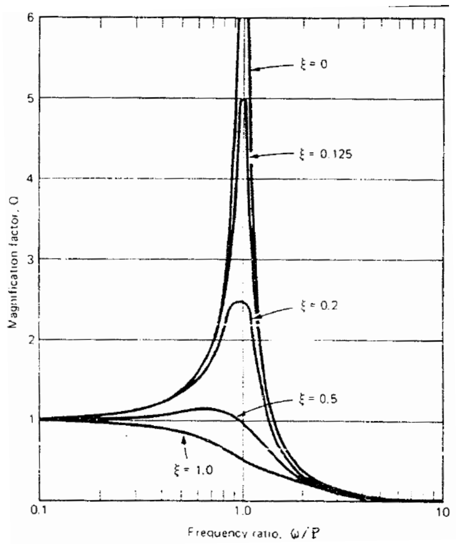
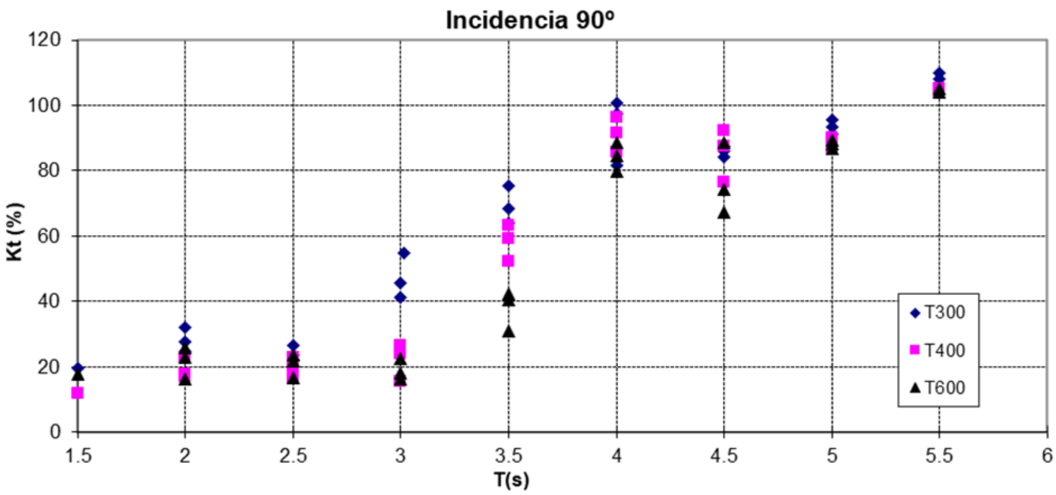


Figure 10: Magnification factor.

We must thus keep in mind that for a specific wavelength, the transmission coefficient k_T is practically independent with regard to the height of the incident wave, except for periods near natural periods of dock oscillation (roll and heave), in which the system produces wave resonance phenomena resulting in increases (when in phase) or decreases (before gaps) in the transmission coefficient according to wave height.

The most noteworthy results of the INHA's reduced model are:



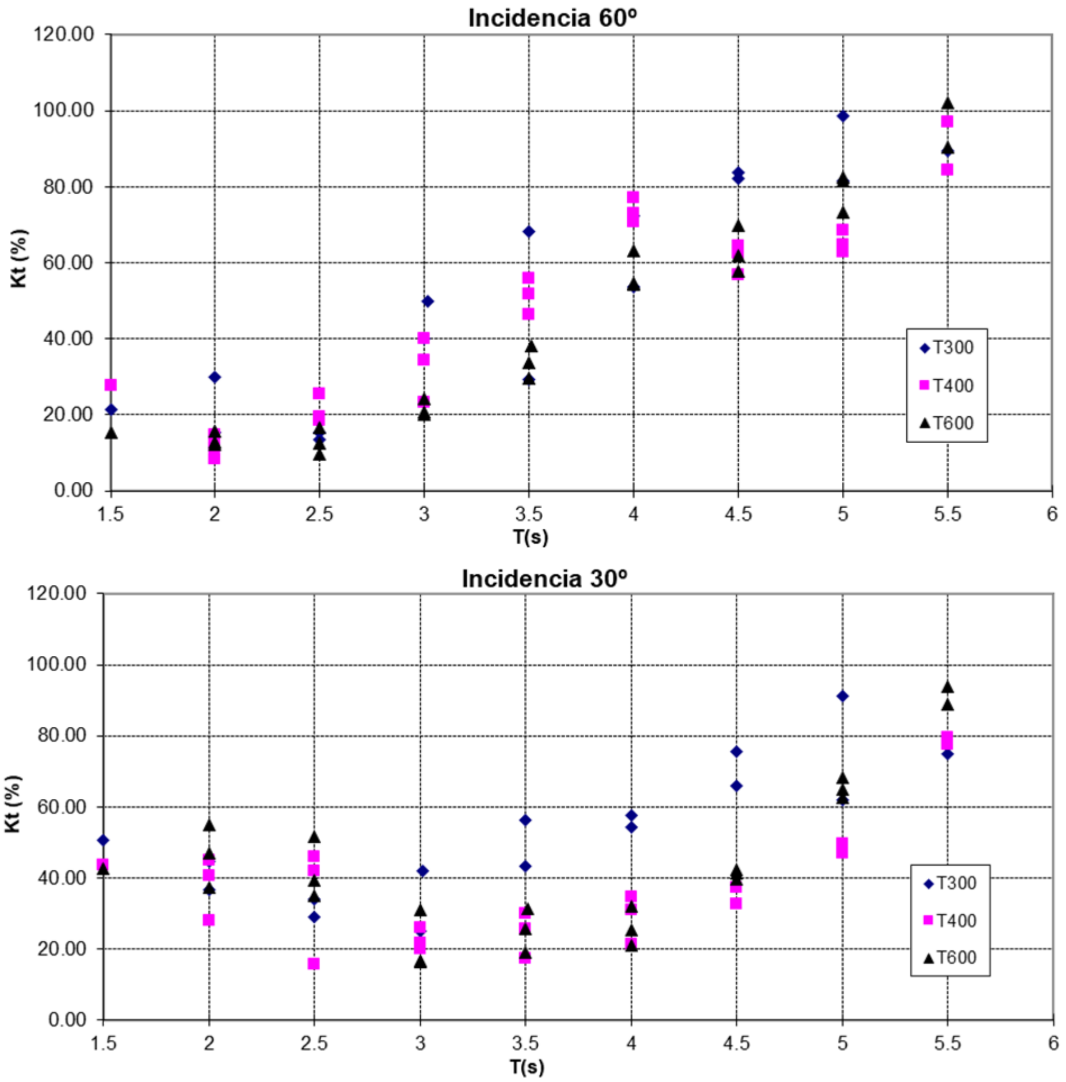


Figure 11: Transmission coefficient for periods between 1,5 and 5,5 s. (MSI and INHA)

In the table above, we can note that the floating docks are able to provide significant attenuation for swells with periods up to 4 seconds. Periods that exceed 5 seconds require excessively wide structures or highly innovative designs.

4. CASE ESTUDIES

We would like to share the following case estudies:

- A.D.N. Nuevo Portil nautical sports facilities, T.M. Cartaya (Huelva, Spain)
- Asociación Náutica San Miguel nautical sports facilities, T.M. Cartaya (Huelva, Spain)
- Club náutico de Rio Piedras nautical sports facilities, Punta de la Barreta, T.M. Cartaya (Huelva, Spain)
- Marina for yachts and sailboats on the island of San Andrés, Archipelago Department of San Andrés, Providencia and Santa Catalina (Colombia)
- Marina in Topocoro Reservoir, Department of Santander, Colombia

These marinas consist of approximately 400 moorings designed in Ría del Piedras and 160 spaces planned for the marinas in Colombia. They consist of sections of piled floating jetty, protected by a floating concrete breakwater anchored to the ocean floor.

These are ambitious marinas designed for customer use and enjoyment, while at the same time respecting the environment.

In addition to a structural design that is compatible with nature, it is essential that the marinas feature fixtures and facilities necessary to reduce possible environmental impacts.

MARINAS AT THE MOUTH OF THE RÍO PIEDRAS, HUELVA (SPAIN)

An area has been chosen within the Río Piedras estuary classified as L.I.C. (Place of Community Interest, Spanish acronym) and close to the Río Piedras natural marshlands and El Rompido sandbar. In order to avoid negative effects in the area, important environmental measures have been taken and navigation and maneuvering have been improved in the estuary by eliminating, or at least minimizing, indiscriminate mooring.

Figure 12: Mouth of the Río Piedras year 2011 and year 2016

Piedras Estuary Constraints

The El Rompido sandbar, which forms a part of the Río Piedras natural marshlands and the El Rompido sandbar, protects the area dedicated to harboring marinas built in the Piedras estuary.

The waves we find in these areas are localized waves created by the wind or the passing of watercraft. With appropriate regulation of maximum speeds through the canal, the waves created can easily be attenuated by the floating concrete barriers proposed to protect these areas.

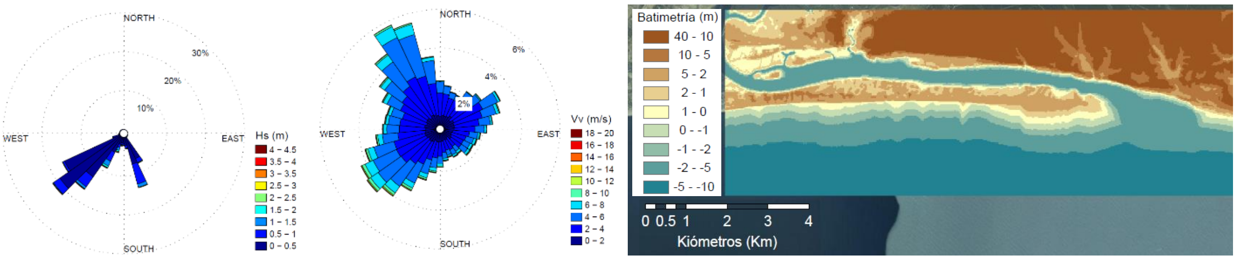


Figure 13: Piedras estuary constraints

A.D.N. Nuevo Portil nautical sports facilities, T.M. Cartaya (Huelva, Spain)

The following are the characteristics of the proposed marina:

- Total built-up area: .... 5.337,36 m²
- Number of moors: ....387 units
- Watercraft length: .... 8, 10 y 12 m

Protection works

- Concrete floating breakwater: ....304,25 m + 97,24 m + 145,95 m

Docks

- Floating units ....12 x 3 m y 12 x 2,5 m
- Number of fingers ....179 units

Walkway to land

- Fixed walkway: .... 101.05 m

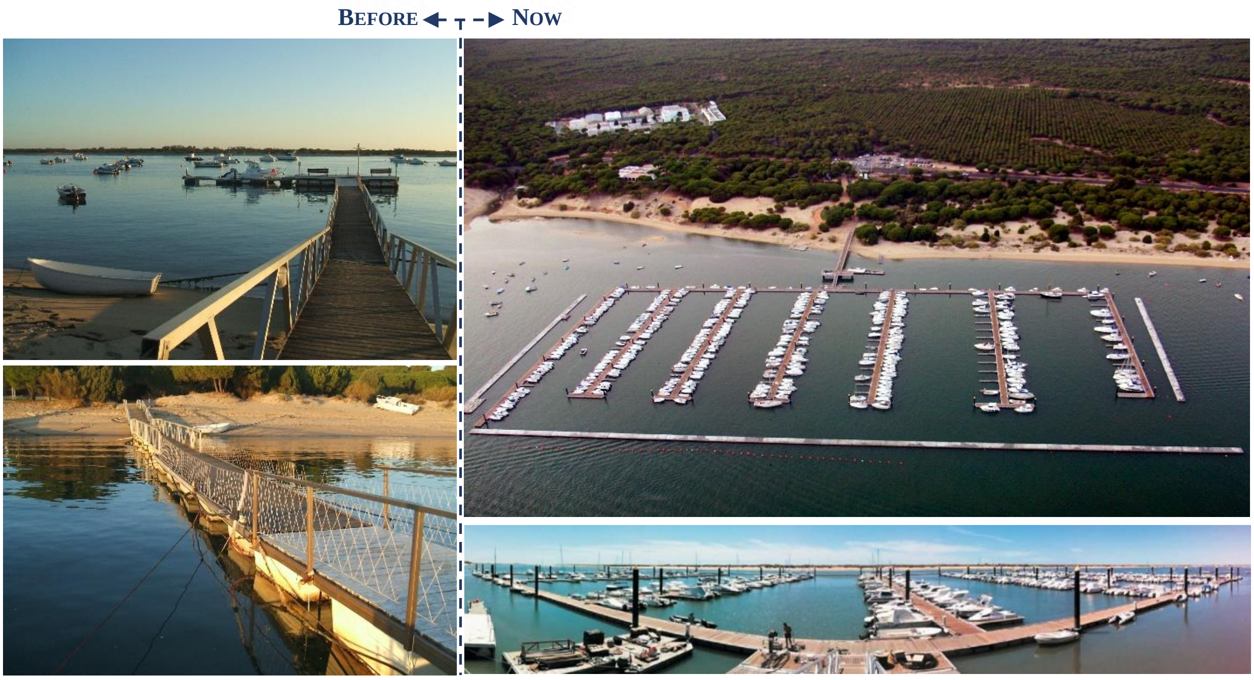


Figure 14: A.D.N. Nuevo Portil nautical sports facilities, T.M. Cartaya (Huelva, Spain)

ASOCIACIÓN NÁUTICA SAN MIGUEL NAUTICAL SPORTS FACILITIES, T.M. CARTAYA (HUELVA, SPAIN)

The following are the characteristics of the proposed marina:

- Total built-up area: .... 16.696,76 m²
- Dredging: 46.672,25 m3
- Number of moors: .... 379 units
- Watercraft length: .... 8, 10 y 12 m

<u>Protection works</u>

- Concrete floating breakwater: ....255,00 m + 133,50 m + 145,65 m

<u>Docks</u>

- Floating units ....12 x 3 m y 12 x 2,5 m
- Number of fingers ....171 units

<u>Walkway to land</u>

- Fixed walkway: .... 73,92 m

Figure 15: Asociación Náutica San Miguel nautical sports facilities, T.M. Cartaya (Huelva, Spain)

Club náutico de Rio Piedras nautical sports facilities, Punta de la Barreta, T.M. Cartaya (Huelva, Spain)

The following are the characteristics of the proposed marina:

- Total built-up area::.. 15.680,67 m²
- Number of moors:...411 units
- Sea walls: 1.693,90 m3
- Watercraft length: .... 8, 10 y 12 m

Protection works

- Concrete floating breakwater: ....257,00 m + 133,00 m + 157,29 m

Docks

- Floating units ....12 x 3 m y 12 x 2,5 m
- Number of fingers ....197 units

Walkway to land

- Fixed walkway: .... 76,72 m

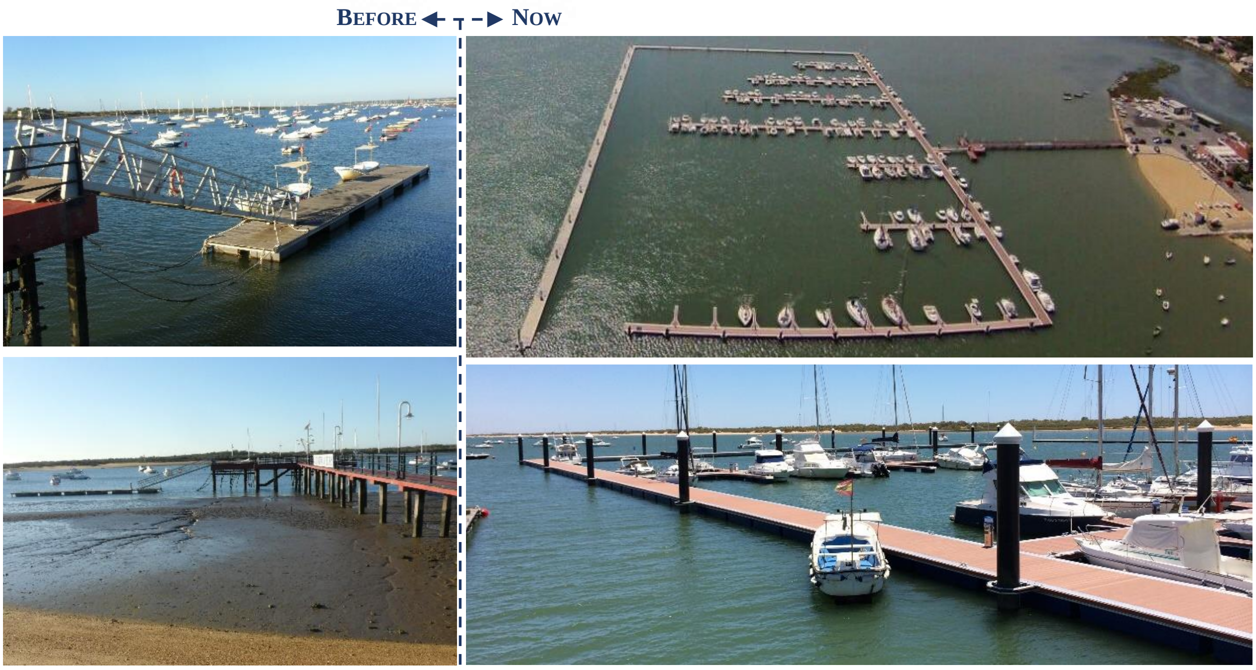


Figure 16: Club náutico de Rio Piedras nautical sports facilities, Punta de la Barreta, T.M. Cartaya (Huelva, Spain)

MARINA FOR YACHTS AND SAILBOATS ON THE ISLAND OF SAN ANDRÉS, ARCHIPELAGO DEPARTMENT OF SAN ANDRÉS, PROVIDENCIA AND SANTA CATALINA (COLOMBIA)

The Archipelago of San Andrés, Providencia and Santa Catalina (Colombia) forms a part of the World Network of Biosphere Reserves with the name SEAFLOWER. All of the necessary measures were taken to obtain an environmental license according to the environmental authorities at the national and regional level such as the National Authority on Environmental Licenses (ANLA, Spanish acronym) and the Corporation for the Sustainable Development of the Archipelago Department of San Andrés, Providencia and Santa Catalina – Coralina.

Figure 17: Archipelago Department of San Andrés, Providencia and Santa Catalina (Colombia), SEAFLOWER

San Andrés Island Constraints

The area is naturally protected from external ocean conditions thanks to its favorable topographical characteristics, among which we can highlight the attenuating effect of the coral barrier that is near the Eastern coast of the island. This barrier absorbs the waves that reach the coastline and reflects those with longer wavelengths and allows for the propagation of smaller ones.

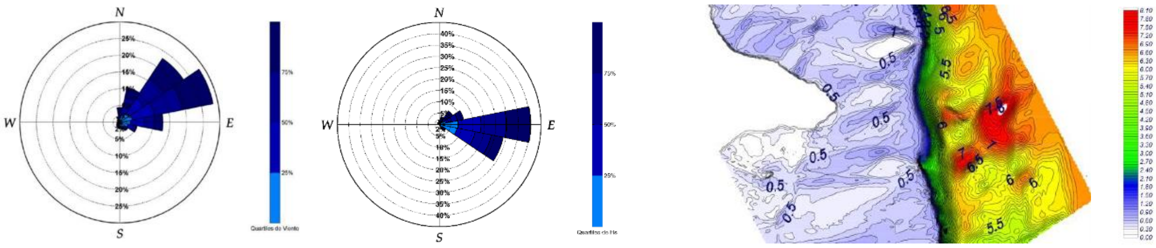


Figure 18: San Andrés Island Constraints

Proposed solution

The following are the characteristics of the proposed marina:

- Total built-up area:..1334.26 m²
- Number of moors:..155 units
- Watercraft length: .... 8, 10, 12, 15, 20 y 30 m

Protection works

- Concrete floating breakwater: ....104,29 m + 96,29 m + 109,27 m

Docks

- Floating units .... 12 x 2,5 m
- Number of fingers ....72 units

Walkway to land

- Fixed walkway: .... 110 m

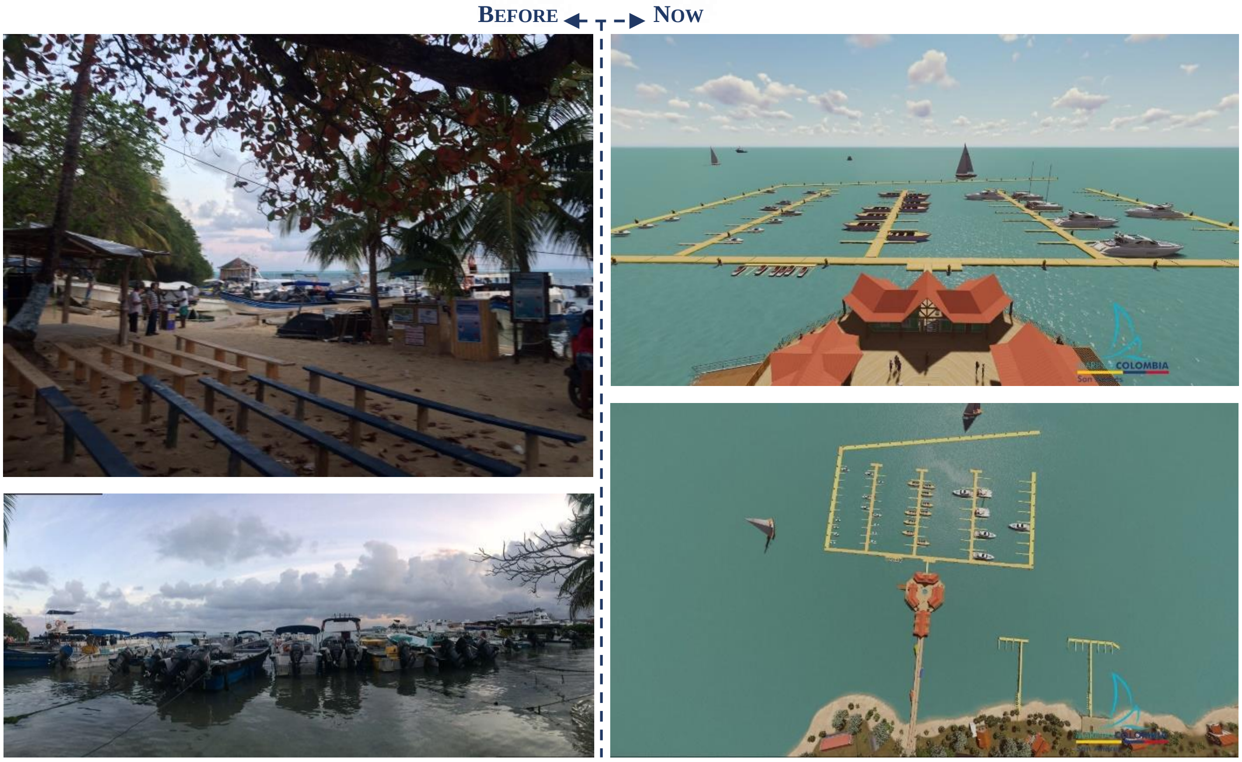


Figure 19: Marina for yachts and sailboats on the Island of San Andrés

Other difficulties: Given the occupancy rate of the land in the area, it was necessary to design a multi-purpose octagonal platform with a surface area of 1090 m^2.

Considering basic user needs in the platform area, a program was developed which includes all uses of the marina (control, administration, sanitation facilities, etc.). It offers a series of commercial uses such as a mini-market, café and retail areas. Finally, in line with ecological considerations and preserving biodiversity in the area, a multi-purpose room for training, a garden with natural coral using Biorock technology and a storage and maintenance hangar for non-motorized watercraft have been proposed.

Figure 20: Multi-purpose area San Andrés Marina

Marina in Topocoro Reservoir, Department of Santander, Colombia

The Topocoro reservoir, created after the construction of the Sogamoso Hydroelectric Plant in 2014, has become the largest in the country with a capacity of 4.8 billion cubic meters.

The location chosen for the marina is within the integrated management district Serranía de los Yariguies, inside the 100-meter buffer zone around the park. As a result, the National Authority on Environmental Licenses (ANLA, Spanish acronym) and the Regional Autonomous Corporation of Santander (CAS, Spanish acronym) have been contacted in order to take their requirements into account throughout the development of the project.

Topocoro Reservoir Constraints

The greatest constraint considered in this design is the variation in water level within the reservoir. Levels vary up to 40 meters annually, making it necessary to consider a maximum variation of 60 meters in the design.

The main external agent to take into account is the wind, as well as the waves it creates.

Proposed solution

To adapt to the large variation in water level that must be considered in the design, the construction of an amphibious walkway consisting of aluminum units with polystyrene floats is planned. This structure is supported by a piled steel frame along the length of the existing slope, making its maximum gradient 20%, requiring the length of the walkway to be longer than 300 meters.

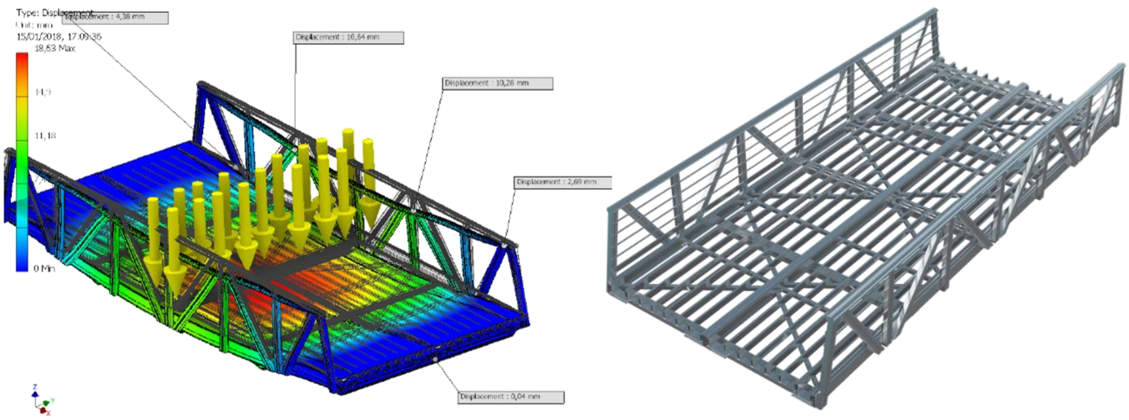


Figure 21: Renders of projected modules

Units are connected using reinforced EPDM elastomer seals measuring 150x150x48 mm which have been reinforced with stainless sheet metal. Four units of pure steel cable will be used throughout the length of the walkway as a safety element. It is designed to avoid being tensioned, but tight. The units are supported by piled horizontal members.

The dock area is protected from nearby waves by a wave barrier consisting of floating concrete docks attached to the ground with cables driven by hybrid winches.

These winches assure that the walkway rests along the planned axis and fix the dock area in position.

The driving of the winches is planned to work in three ways:

- Using a **command panel** located in the floating area. The marina operator can pull or release the winch cable as needed by pressing buttons. This signal is sent via cable.
- Winches can also be driven by **radio control**. A radio control can drive up to 12 winches at a time.
- Finally, they can be driven **manually**. A multiplier will be installed which will allow increasing the torque of submerged cable.

The following are the characteristics of the proposed marina:

- Total built-up area:.. 6.424,50 m²
- Number of moors:...163 units
- Watercraft length: .... 8, 10, 13 y 20 m

<u>Protection works</u>

- Concrete floating breakwater: .... 70 m + 90 m + 90 m

<u>Docks</u>

- Floating units ....12 x 2,5 m, 12 x 3 m y 12 x 5 m
- Number of fingers ....74 units

<u>Walkway to land</u>

- Fixed walkway: .... 320 m

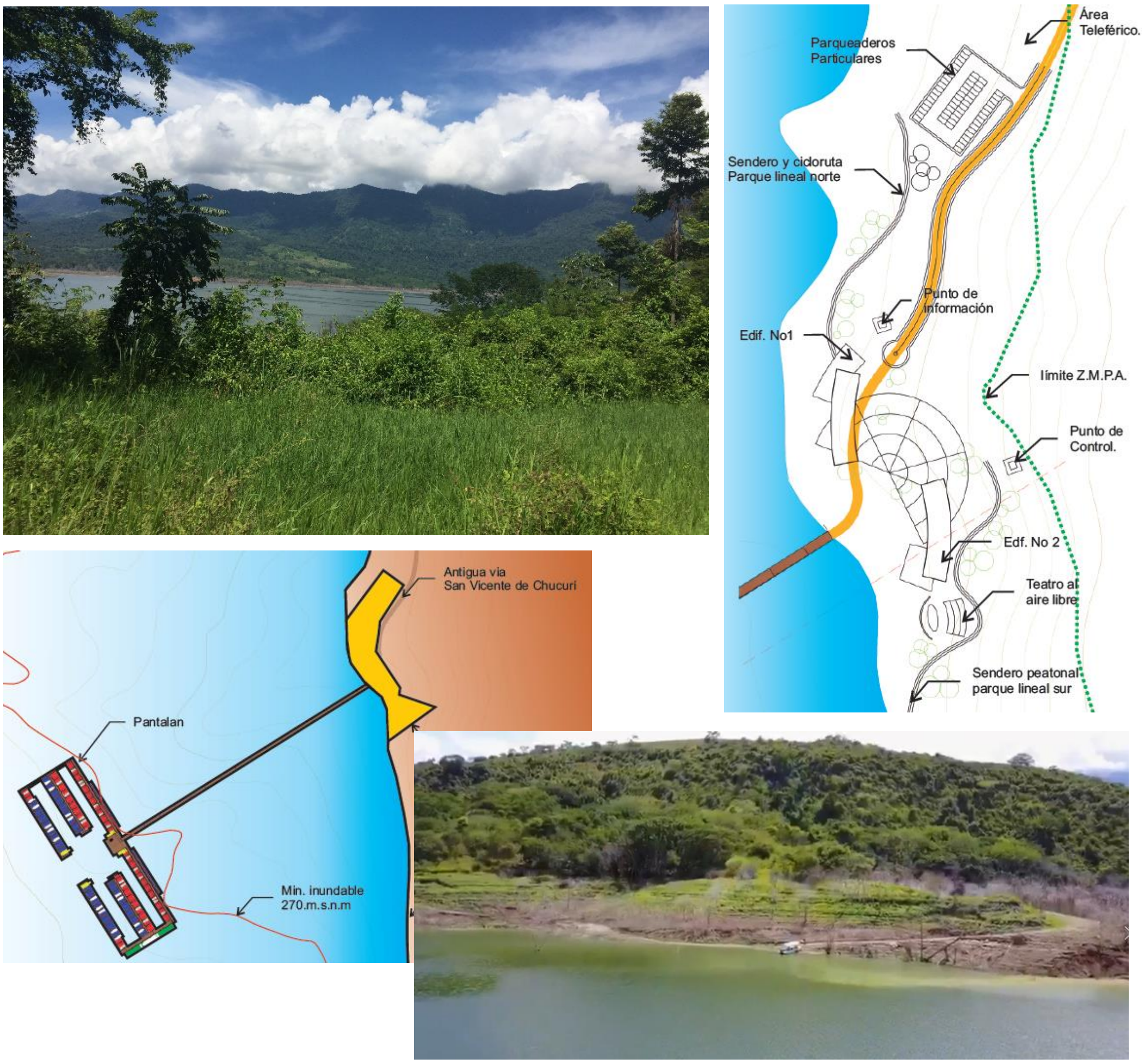


Figure 22: Marina in Topocoro reservoir, Department of Santander, Colombia.

Conclusions

In summary, nautical activity does not have to oppose environmental conservation and suspected water pollution in the area where activity takes place. An example of sustainable activity can be set if it is properly regulated, designed and controlled.

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