

Coastal Structures - Puerto Rico

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Physical Character

Puerto Rico was formed early in the tectonic history of the Caribbean as the North American and South American plates separated during their westward drift. It originated as a chain of volcanic islands during the late Jurassic and early Cretaceous around which Cretaceous limestones were deposited. This island arc evolved into a central volcanic range flanked on the north and south by limestones. From late Mesozoic through early Tertiary the sedimentary and volcanic rocks were subjected to periods of intense deformation resulting in extensive folding and faulting of the island.

The Oligocene to Recent rocks are limestones and surficial sedimentary deposits were concentrated in the coastal areas.

Alluvial deposits of the north coast form a reworked blanket of sand and sandy silts inside the karst topography of the older limestones. Coastal deposits of sand dunes, eolianite, beaches, beachrock, and lagoon and swamp deposits interact in the modern environment. The south coast is dominated by a series of alluvial fans which coalesce into broad alluvial plains that are narrower than those found on the north coast. Sedimentary deposits found on the south coast are similar to those of the north coast, except for the general absence of eolianite and beachrock.

Eolianite exposures and beachrock deposits on the north-coast shelf and shore provide some protection to the beaches. On the south coast similar shoreline protection is provided by coral reefs.

The island of Puerto Rico is 60 km wide and 170 km long. It has approximately 740 km of coastline of which 210 km (28%) are beach. [Morelock and Trumbull, 1985](#) There are more than 150 individual beaches, which have been divided into 37 separate beach systems (Figure 1). These systems are isolated from one another, function as independent units, and are supplied with sediment from river drainage basins, coastal erosion, and biogenic carbonate production from the shelf.

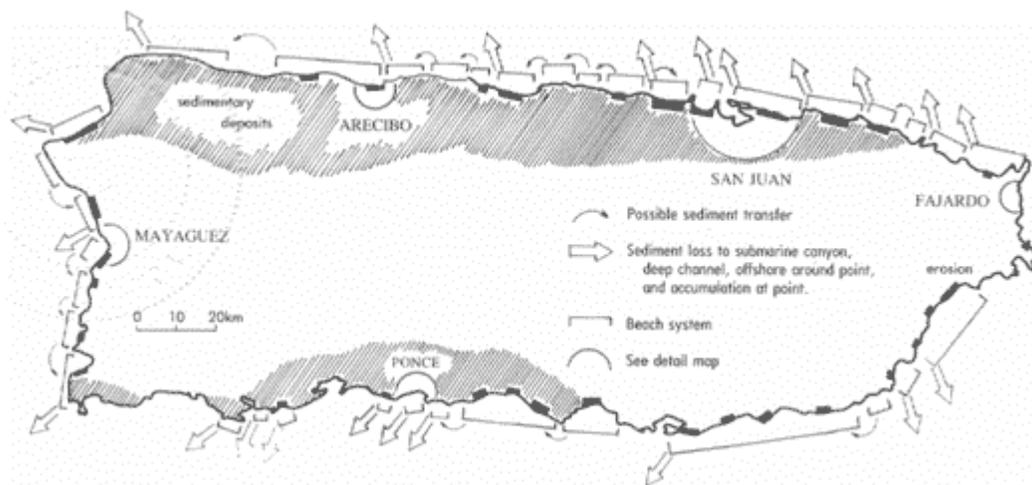


Figure 1. Puerto Rico beach systems

The north coast has a narrow shelf (less than 3 km wide) with relatively uniform wave conditions over its entire length. The predominant wind direction is from the east, with prevailing winds from the southeast and northeast. Waves incident on the north coast are generated in the Atlantic, and during winter reach heights in excess of 6.0 m. Shelf width on the south coast varies from 2 to 17 km which allows differing wave regimes to reach the coastline. The basic swell generated in the Caribbean is a 5 to 8 second wave with a height of 0.6 to 1.5 m. ^{Lugo, 1982} This is a much lower height than the 1.5 to 4.0 m generated by the Atlantic swell that impinges on the north coast. ^{Kaye, 1959} The west coast is leeward and relatively calm except for refracted waves from the Atlantic. The east coast is protected by a broad reef-covered platform that extends 210 km eastward to include the Virgin Islands.

Current directions and net shore-drift on the north and south coasts are dominantly to the west, except for local, seasonally eastward, drift systems. Movement on the west and east coasts is dominantly to the south. Because of the variation in mineral content of the beach sands, it is possible to determine the direction of net shore-drift on most beaches, and to analyze the degree of communication between different beach systems. The termination of individual beach systems is usually a point of removal of sand from the system by impoundment against an obstruction or offshore loss into a submarine canyon or deeper water.

There is coastal erosion around the entire island. Because the eolianites of the north coast are loosely cemented and not reinforced by coral growth, they are being breached and the amount of erosion of the coast is increasing. Beachrock gives some protection to the beach, but soon weathers away allowing erosion to continue shoreward. The protection offered to the south coast by coral reefs is gradually being reduced as the increased influx of terrigenous sediment and nutrients have diminished the ability of many of these reefs to survive. ^{Morelock, et al., 1980}

Many aggradational features in Puerto Rico show a shift to erosion. ^{Morelock, 1984} The change of Puerto Rico's coastline from aggradation to a state of erosion may be a maturing process. The change may be an evolving adjustment to present sea level or a response to rising sea level.

Human Modification

Construction has crowded close to the shoreline because of the limited availability of level land and reduced construction costs, along with an almost universal desire to live "on the beach." This has not only aggravated erosion, but has raised the value of imperiled land. The required structural remedies (*i.e.*, riprap) often create new problems.

There has been relatively little development of man-made structures within the beaches of Puerto Rico. Forty-one public beaches are sited around the Island. ^{U.S. Department of Commerce 1978} Several of these (*i.e.*, El Tuque and Punta Salinas) have problems with severe erosion (more than one meter per year loss). In response to the amount of erosion, the most common man-made structures on the island are riprap emplacements and concrete bulkheading.

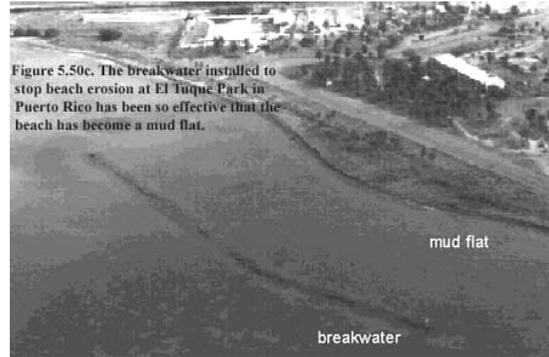
Artificial Structures

Structures capable of modifying coastal processes have been divided into four categories:

- block riprap (Figure 2)
- bulkhead/ breakwater (Figure 3)
- jetty/ groyne (Figure 4)
- docks (Figure 6)



Riprap of boulders



breakwater



Groyne



seawall - harbor

Riprap has been emplaced around much of Puerto Rico's coastline (Figure 6). It is normally in the form of rock fragments ranging from 0.5 to 1.0 m in diameter, but may also include car bodies, broken highway concrete, old tires, and kitchen sinks. There are numerous docks on the west, south, and east coasts, but wave conditions limit the number of north coast docks. Jetties are associated with most of the harbours, and are also used at points of river discharge and in areas where sand-drift trapping has been approved.

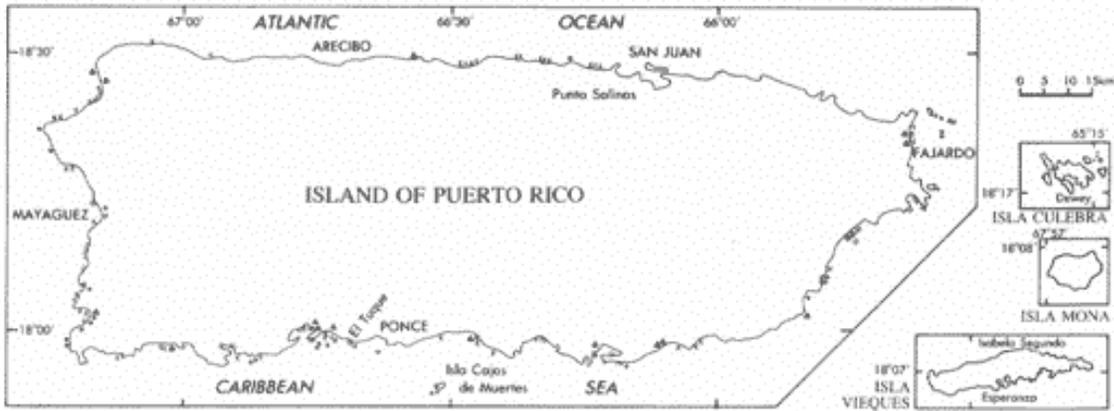


Figure 6. observed riprap

Although there are many small islands associated with Puerto Rico, only four have significant coastal structures. These are Isla Vieques and Isla Culebra off the east coast, Isla Mona off the west coast, and Isla Caja de Muertos south of Ponce.

Isla Vieques has several significant coastal structures. These are:

- a 610 m long concrete jetty on the northwest coast built during WWII to be used as a dock for naval vessels (Figure 7)
- a bulkhead and dock at Isabel Segunda
- a pier supported on pilings at Esperanza

Figure 7. Concrete jetty (groyn) on north side of Vieques

On Isla Culebra there is some bulkheading and a pier supported on pilings at Dewey.

There is approximately 20 m of bulkheading on Isla Mona associated with a docking facility on the west coast and an abandoned freighter aground on the rocky south shore. In March of 1985, a ferry went aground on a reef near the freighter. Efforts are underway to remove it because its movement, in response to wave action, is grinding up the reef upon which it rests. This is resulting in an influx of coastal sediment which could potentially destroy portions of the surrounding reef.

On Isla Caja de Muertos there is an abandoned concrete pier approximately 20 m long.



Harbours and Marinas

Major harbour and marina development in Puerto Rico is limited to San Juan, Mayagüez, Ponce, Fajardo, and Arecibo. These areas will be discussed individually.

San Juan

More than half of the coastline between Punta Salinas and Punta Cangrejos (encompassing the Greater San Juan area) has been subjected to structural modification (Figure 8). The activity has been concentrated in Bahía de San Juan, Bahía de Boca Vieja, and along the coast from Punta del Morro to Punta Piedrita.

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Figure 8. San Juan structures

In Bahía de San Juan the construction is dominantly bulkheading and docks related to both commercial ship facilities and to residential and commercial buildings. Because Bahía de San Juan is very protected and encased in vast quantities of concrete, little erosion has occurred. In Bahía de Boca Vieja, construction has been for flood control, recreational facilities, and protection from erosion. The discharge of the Río Bayamon was diverted from Bahía de Boca Vieja to Bahía de San Juan by construction of a solid causeway between the mainland and Isla Cabras (Figure 9). This has changed the shape of Bahía de Boca Vieja and its sediment input budget. Additional changes have been introduced by the construction of three jetties (Figure 10) and a flood control channel at the south center of the bay shoreline, two jetties on the shore to the east, three to the west, and emplacement of solid riprap along the east shore of Punta Salinas. Measurements of coastline change made from aerial photographs spanning 25 years have shown erosional rates of 2.0 to 3.0 m per year in different parts of Bahía de Boca Vieja. Morelock 1978



Figure 9. Isla Cabras causeway



Figure 10. Levittown jetties

Old San Juan is built on a resistant eolianitic and surrounded by a city wall of rock and concrete rising from the eolianitic. The coast east of the harbour entrance consists of extensive exposures of eolianitic and embayed beaches. This is further protected by linear exposures of eolianitic offshore. There are 7 individual beaches in 2 beach systems that are separated by the entrance to Bahía de San Juan. ^{Morelock 1978} Sediment is lost from these beaches by offshore transport, offshore wind transport with removal by garbage trucks, and impoundment behind jetties installed by several hotels to form beaches.

Many individual residential areas have been bulkheaded in the upper beach to protect property. The jetty and bulkheading at Boca de Cangrejos constitutes a major change in shoreline conditions (Figure 11). This was accompanied with the opening of Boca de Cangrejos channel to release swamp water into the ocean and create a marina. This activity killed the reef encrusted eolianitic offshore, and reduced the resistance of the coast to erosion.



Figure 11. Boca de Cangregos jetty and riprap

Mayagüez

Coastal modification at Mayagüez includes extensive bulkheading in the Malecon (Figure 12) industrial area and Mayagüez Harbour, channelization of the Río Yaguez, and riprap from the center of Bahía de Mayagüez to the north of the Río Guanajibo (Figure 13). The solution to beach erosion at Mayagüez has been replacement of the beach with rock riprap. This is a situation in which the riprap had to be continuously extended as each effort created more erosion outside of the protected area.



Figure 12. Mayagüez harbor, docks and seawall



Figure 13. Structures at Mayagüez

The deep harbour channel (more than 10 m deep) at Mayagüez separates the Añasco and Mayagüez beach systems. Sand at the terminus of the Añasco beach accumulates against the Malecon bulkhead. Because of the lack of sediment supply (there is no upstream source and no effective offshore source – it has a very low CaCO₃ content) Mayagüez beach is susceptible to erosion. The construction of houses close to this shoreline, often over the berm, was a certain prelude to requiring riprap.

Ponce

Commercial harbour and docking facilities, city-front riprap and bulkheading, and yacht facilities account for most of the coastal modifications in Ponce (Figure 14). Until recently there was removal of coastal sands from behind the beaches, resulting in accelerated erosion by washover and breaching. The ocean fronting the urban area is heavily bulkheaded and the harbour area is lined with concrete.

The Ponce Yacht Club was constructed over a small barrier reef and the lagoon between this fill and the commercial dock has been bulk-headed. The seaward-facing side of the yacht club consists of riprap composed of broken highway concrete. Jetties have been added to the west tip of the club's "peninsula" to protect a bathing beach.

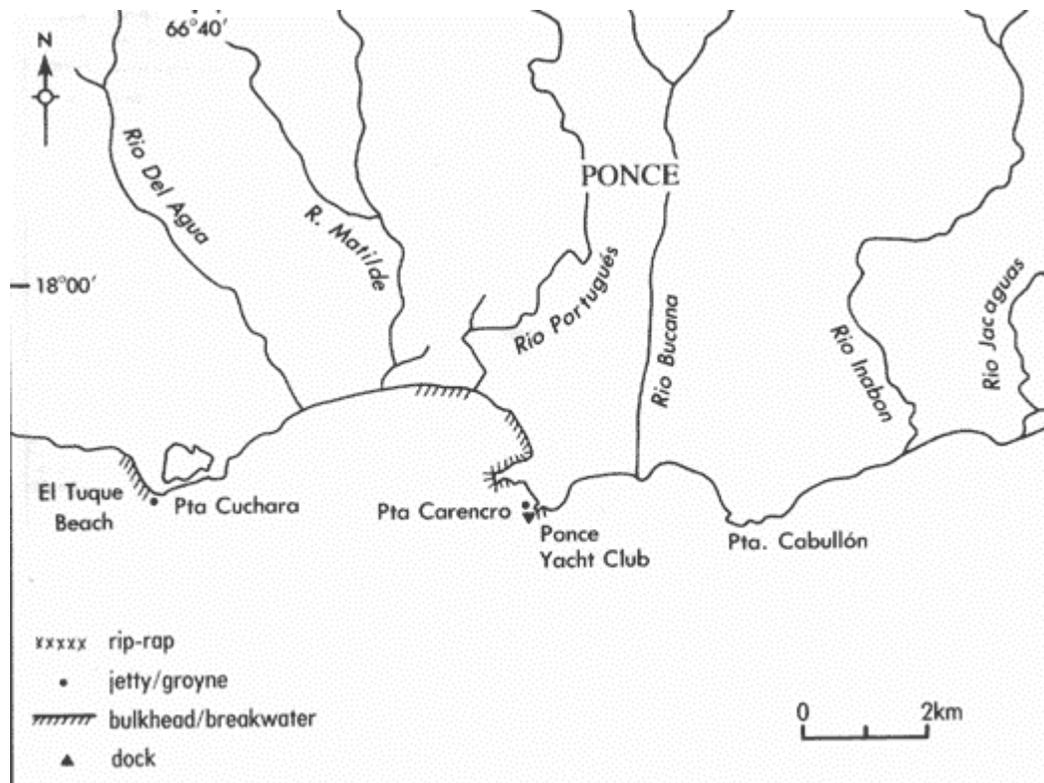


Figure 14. Ponce structures

El Tuque Beach, west of Ponce has been modified several times in the past 20 years in attempts to restore it as a public beach and retard erosion (Figure 15). The first attempt consisted of a massive artificial nourishment effort with sand. Unfortunately the grain size did not match the energy environment, and there was more than 7 m per year of erosion after the introduction of the fill [Morelock, 1984](#). The most recent effort involved the construction of offshore breakwaters and a jetty to the south, accompanied by artificial nourishment with dark-mineral rich sand. The beach has developed large erosional scallops during the past year.

The beach sediments near Ponce are composed dominantly of igneous rock fragments, feldspar and quartz, and some skeletal carbonate grains [Morelock, 1978](#). The coast is a low-lying alluvial plain with a massive accretionary beach area at Punta Cabullon.



Figure 15. Erosion, groyne and breakwater at El Tuque

Fajardo

The beaches at Fajardo are relatively narrow and at the town consist of quartz, feldspar, and igneous rock fragments from the Río Fajardo. [Morelock, 1978](#) The beaches north of the town are composed of skeletal carbonate grains deposited behind a fringing reef. Sediment and effluent influx have almost completely killed this reef. Coastal modification includes bulkheading and dock facilities fronting the town, the development of six marinas with extensive (Figure 16).

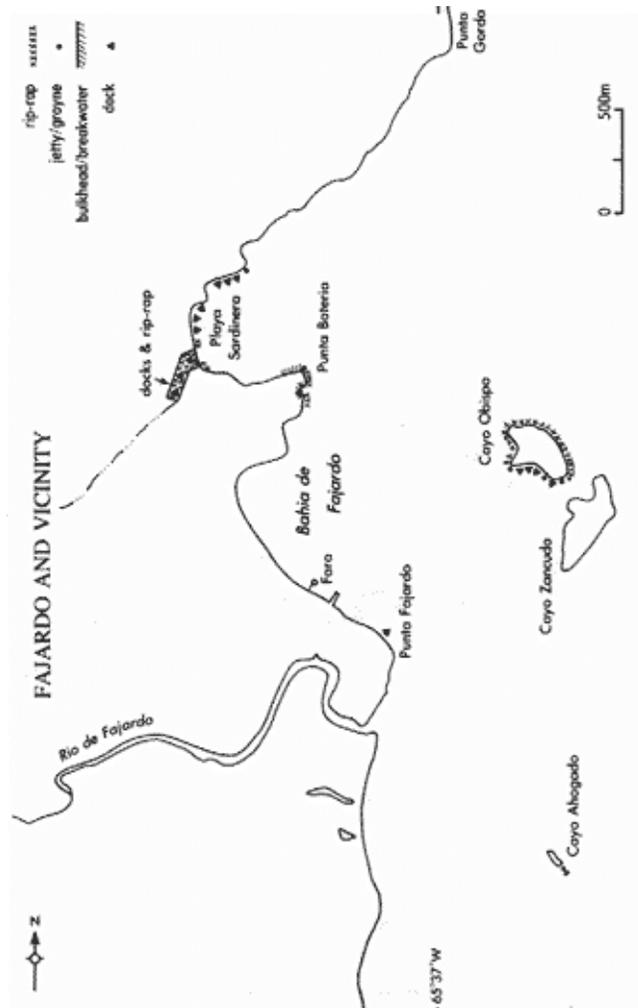


Figure 16. Fajardo structures

Arecibo

The coast at Arecibo is beach plain, eolianitic, and fill. The addition of fill to an eroding coastline for shore-front urbanization has required extensive bulkheading of the city shoreline (Figure 17). The Arecibo harbour is one of only two on the north coast (Arecibo and San Juan). Eolianite exposures at the east end of the harbour did to extend far enough to form a natural harbour so a rock jetty and concrete dock was attached to the rock, extending westward. This has modified the wave and current regime within the bay and both Briggs ¹⁹⁶¹ and Morelock ¹⁹⁸⁴ accredited the coastal erosion of more than one m/yr for the subsequent 30 years to the change. Recently a controlled and jettied channel has been added at the old river mouth to develop a yacht club.

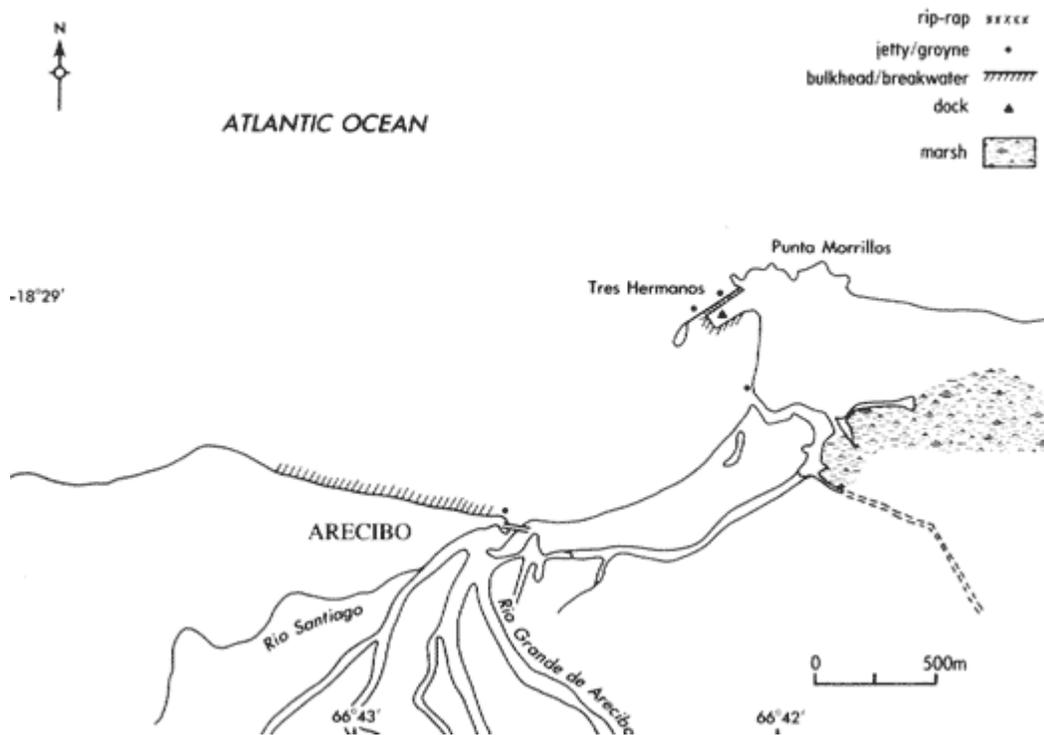


Figure 17. Structures at Arecibo

Conclusions

The construction of structures at the shore is not the only means by which significant coastal change is being effected in Puerto Rico. The extraction of coastal sands for use in construction is a major factor affecting the stability of the dynamic equilibrium in the coastal system.

Borrow pits are a common sight at the coast, particularly along the north coast where there are large coastal dune systems (Figure 18). Sand at these sites is commonly extracted to a depth well below sea level and to within several metres of the beach, leaving only a thin barrier between the borrow pit and the ocean. The result has been an overtopping by storm waves with subsequent breaching of barriers. Flooding of lowlying backshore areas, accelerated shoreward erosion, and loss of land followed. This loss of land occurs not only in the immediate vicinity of the extraction because of breaching but also down-drift because of the reduced ability of the shore to resist wave attack as the beaches diminish.

In Puerto Rico, as in many other coastal regions of the world, attempts at regulating the development and use of the coast have been initiated in hopes of mitigating the impact of present and future coastal use. The necessary laws and regulatory programs to achieve this goal have been created at both federal and local levels. It is now a matter of properly enforcing the laws, educating the public about coastal processes, and time



Figure 18. Coastal dune mining, northwest Puerto Rico