DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
THE COMMONWEALTH OF PUERTO RICO
DEPARTMENT OF PUBLIC WORKS

HYDROLOGIC INVESTIGATIONS
ATLAS HA-430 (SHEET 1 OF 2)

STORM-WAVE SWASH ALONG THE NORTH COAST OF PUERTO RICO

Large waves generated by distant Atlantic storms battered the north coast of Puerto Rico in three major events during the period 1962–67 and in one lesser event in 1968. Destruction of ocean-front structures, erosion and movement of beach sand, and disruption of coastal vehicular traffic were common. This presentation is concerned with the magnitude of the wave swash during these events and, in particular, the coastal areas affected by the waves in 1967. Wave swash is the water that is carried inland by momentum as the energy of the wave dissipates on the shore. The report should be useful in land-use planning and engineering design pertinent to the coastal development of Puerto Rico.

SOURCE OF THE WAVES

The storm waves along the north coast of Puerto Rico between 1962 and 1968 resulted from Atlantic cyclonic storms. The waves generated by these storms generally traveled as much as 1,000 miles before breaking upon the coast of Puerto Rico.

Typically, storms passing over the continental United States move eastward off the continental land mass and over the Atlantic Ocean. Once over the ocean, these storms generally move rapidly, dispersing their energy over a large area. On occasion, movement may be slow or a storm may be stationary for as long as 30 hours. It is during these periods that gigantic waves are generated.

The height of the storm-generated waves as they approach the coast of Puerto Rico has never been measured, but a U.S. Geological Survey engineer was in a boat just off the northeast tip of Puerto Rico when the storm waves of January 1, 1963, struck. He estimated the conchoidal shaped waves to be at least 25 feet from trough to crest, based on the height of the masts in the boat.

The paths of the storms responsible for the events of 1962, 1967 (two storms), 1968, and the location of the 1963 storm center are shown in figure 1. Information on the location and movement of the storms was supplied by the San Juan office of the U.S. Weather Bureau.

Data from U.S. Weather Bureau

FIGURE 1.—*Paths of storms creating high waves on the north coast of Puerto Rico.*

The waves of November 17, 1962, were generated by a storm that moved off the coast of Florida on November 13. The storm path curved northeastward and movement was rapid until the 15th, when the storm became nearly stationary for 24 to 30 hours and generated the waves reaching Puerto Rico on the 17th.

The early history of the storm generating the swells of January 1, 1963, is not known, but the main generating area is shown on figure 1. The generation occurred while the storm was relatively stationary for a 24-hour period, probably on December 29 or 30, 1962.

Two storms were involved in the waves of December 3–10, 1967. The first was a severe North Atlantic storm that moved off the Virginia-Carolina seaboard and intensified considerably over the Atlantic. By December 1, the storm was about 1,200 miles north-northeast of Puerto Rico, with winds of 50 to 60 miles per hour over a large area. By December 2 the storm center had moved eastward and northward to a position about 1,700 miles north-northeast of Puerto Rico; but on that day, a North Atlantic cyclone in the vicinity of Bermuda, west of the primary storm center, contributed to the generation of the waves. The waves spread southward and reached Puerto Rico in about 24 hours. The second storm moved out of the Virginia-Delaware area on December 3 on a northeast track and then swung southeastward. Waves reaching Puerto Rico from this storm were smaller than those a few days earlier.

The waves of December 23, 1968, were generated by a North Atlantic storm that moved off the New Jersey coast on December 20. The storm reached its peak during the afternoon of December 22. At this time it was about 1,800 miles north-northeast of Puerto Rico.

EFFECTS OF THE STORM WAVES

The storm waves that struck Puerto Rico on November 17, 1962, were second in wave-swash magnitude of the four storms. Long sections of Highway PR-681 between Arecibo and Palmas Altas, as well as the unimproved beach road between Boca de Cangrejos and Loiza Aldea, east of San Juan, were inundated and covered with beach sand. Low sections of Highway PR-165 were inundated between Punta Salinas and Cataño. Wave action at Bahia de San Juan destroyed pipelines and pontoons being used for dredging the ship channel.

Six weeks later, on January 1, 1963, storm waves again smashed into the Island. The swash from these waves did not attain the magnitude of the previous event, but they continued the destruction begun by the 1962 storm waves.

No further wave events of consequence occurred until December 4, 1967. The highest wave-swash elevations during the period 1962–68 occurred on this date, as great waves pounded the north coast. The maximum wave-swash elevations occurred the first day of impact and slowly receded to near normal by December 10. Although no loss of life resulted, more than 300 homes were destroyed or damaged, and untold numbers of homes were flooded. Losses were notable in the vicinity of San Juan and Arecibo, where nearly 1,000 people were left homeless.

The most extensive damage was suffered in the La Perla area (fig. 2), where housing supported by pilings had encroached upon the edge of the sea (fig. 3). The line on the photograph delincates an area of total destruction in La Perla. Many houses landward from this area were damaged to varying degrees. Parts of the coastal roads between Camuy and Loiza Aldea were blocked by sand and water.

Photograph courtesy of the San Juan Star

FIGURE 2.—*Storm-wave damage at La Perla in December 1967.*

Photograph courtesy of the San Juan Star

FIGURE 3.—*La Perla prior to the December 1967 storm waves. After the waves receded only debris of shattered homes remained from the line seaward.*

The lowest wave-swash elevations of the events studied occurred on December 23, 1968, although these storm waves were the greatest of the year. Damage from these waves was minor, except between Boca de Cangrejos and Piñones, east of San Juan, when the coastal road was blocked by sand and water.

DATA COLLECTED

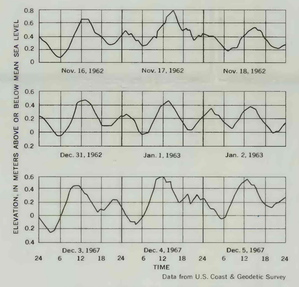
Surveys were made and levels were run after each wave event to obtain the elevation of the highest points reached by the wave swash. These elevations, in meters above mean sea level, are shown in figure 4. The elevations for the 1967 wave event between Fajardo and the mouth of Rio Grande de Loiza were estimated on the basis of field inspection and topographic maps.

Generally, for all events the maximum wave-swash elevations were between Quebradillas and Barceloneta. There was a decrease in wave-swash elevation from Rio Grande de Manati to Rio Cibuco. From Punta Salinas eastward to Fajardo, there was a gradual decline in swashline elevations to about 25 percent of those in the Quebradillas-Rio Grande de Manati area. The coast west of Quebradillas, with the exception of the Aguadilla area, was not investigated because of the abrupt rise in the terrain at the coastline and the small probability that any structures would be built on the sheer slopes.

The penetration of the waves upstream along river courses was minor for all events. Wave energy was dissipated by sandbars, vegetation, and the sinuous courses of the rivers. Some of the most extensive flooding occurred where waves washed over natural levees near the mouths of the rivers; the water trapped behind the natural levees then moved inland in adjacent mangrove and sedge-grass swamps.

The rapid degrading of the waves inland was well illustrated in Bahia de San Juan during the December 1967 waves. At La Perla, on the oceanfront east of the entrance to the harbor, wave swash reached an elevation of about 7 meters. The waves dissipated rapidly after entering the harbor. At Cataño, directly in line with the entrance, wave swash was only 1.4 meters.

Little pile-up of water in bays and estuaries was observed. Stages recorded at the U.S. Coast & Geodetic tide gage in San Juan harbor show little variation from normal tide levels. The hourly stages for the three major wave events of 1962–67 are shown in figure 5.



Data from U.S. Coast & Geodetic Survey

FIGURE 5.—*Tide stages in Bahia de San Juan.*

During and after the 1967 event, inundated areas were sketched on topographic maps by field parties. Also, the points of penetration through which the sea rushed inland beyond the beach ridge were noted. Aerial photographs were taken along the coast to ascertain the land area affected.

The inundated areas and inland points of penetration are shown on the topographic maps.[1] The location on the topographic maps of the coastal area in relation to the Island is shown in figure 4.

[1]The topographic maps are strips from the regular 1:20,000 scale topographic quadrangles published by the U.S. Geological Survey: Camuy, Arecibo, Barceloneta, Manati, Vega Alta, Bayamón, San Juan, and Carolina.

STORM-WAVE MAGNITUDE AND FREQUENCY

Wave-swash elevations are controlled by the swell magnitude, offshore topography, configuration of the coast, and land slope. Because of variable coastal conditions, caution should be used in estimating a wave-swash height between two known elevations. For example, in 1967 the series of elevations determined in the vicinity of Arecibo varied from 4.7 to 7.7 meters in height because of local conditions. The average height was 5.8 meters.

The wave-swash elevations obtained for the four events during the period 1962–68 define the stage-frequency relation at several places. It is important to bear in mind that these places have a steep land slope and present abrupt, effective barriers to the waves. Where land slope is not steep, the waves dissipate their energy with inland movement, and the wave swash does not reach as high an elevation as where inland movement is impeded.

Figures 6 to 10 illustrate the stage-frequency relation at several places along the north coast.

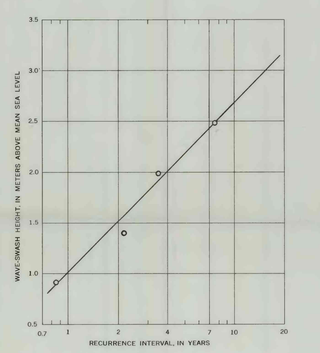


FIGURE 6.—*Stage-frequency relation of wave swash at Cataño, on Bahia de San Juan, longitude 66°08′.*

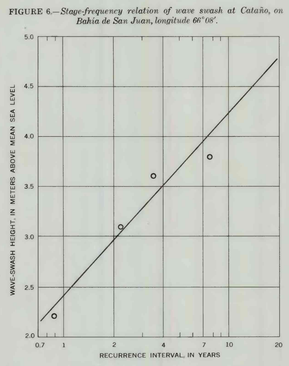


FIGURE 7.—*Stage-frequency relation of wave swash at Punta Corozo, longitude 66°12′.*

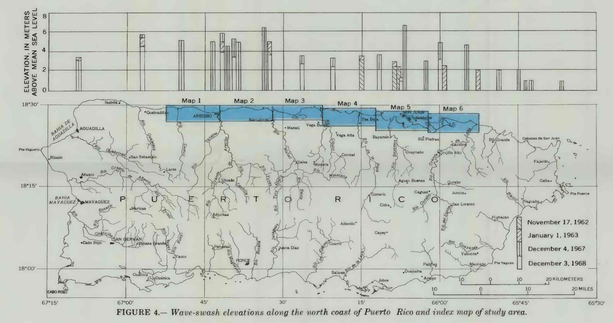


FIGURE 4.—*Wave-swash elevations along the north coast of Puerto Rico and index map of study area.*

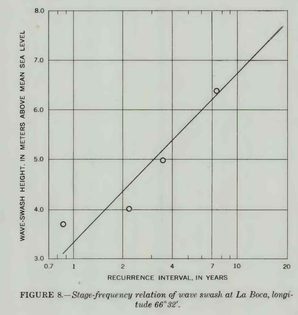


FIGURE 8.—*Stage-frequency relation of wave swash at La Boca, longitude 66°32′.*

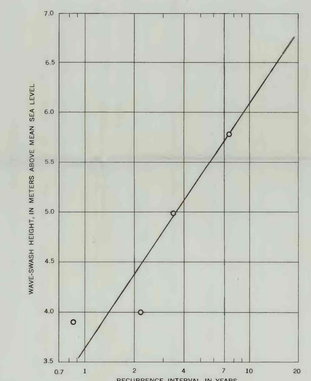


FIGURE 9.—*Stage-frequency relation of wave swash at Arecibo, longitude 66°43′.*

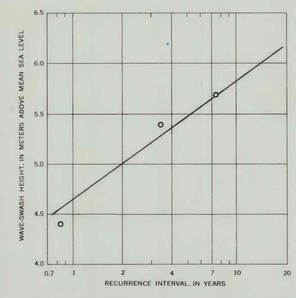


FIGURE 10.—*Stage-frequency relation of wave swash at the mouth of Rio Guajataca near Quebradillas, longitude 66°58′.*

There are no means of predicting the date that wave swash of a given magnitude will occur. If a long enough record of wave-swash stages is available, however, the average recurrence interval of a given wave swash and the probability of its occurrence in any year can be computed. The recurrence interval, or frequency, is the average length of time during which that wave swash will be equaled or exceeded. For a wave swash greater than the 10-year wave swash, the reciprocal of the recurrence interval is virtually the probability of occurrence in a given year; thus a 20-year wave swash will have a 5-percent chance of occurring in any year.

Although several parameters affect wave-swash magnitude, offshore topography probably is the principal factor to consider in evaluating the potential wave-swash height at a particular site with an effective barrier in place. The distance from the shore seaward to the 120-foot depth curve has been combined with the stage-frequency relations defined at several sites, as shown in figure 11. The 20-year recurrence-interval stage was extrapolated on the basis of the 1, 5, and 10-year values. Figure 11 can be used to approximate height requirements of protective structures for buildings and highway embankments, for various recurrence intervals at sites along the north coast.

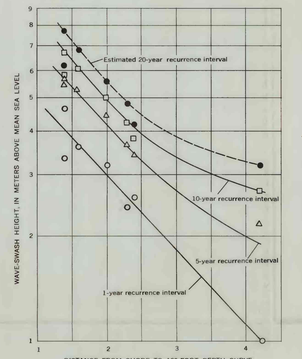


FIGURE 11.—*Relation of stage and frequency of wave swash to distance between shoreline and the 120-foot depth curve.*

Figures 6 to 11 have been defined from sparse data and will be refined as additional information is collected.

COASTAL RELIEF

The coast west of San Juan is relatively unprotected from the effects of heavy swells. From San Juan eastward, the remnants of well-cemented fossil sand dunes lie 100 meters to 2 kilometers offshore. The dune reefs are scattered between San Juan and the Playa de las Tres Palmitas area, 13 kilometers to the east. Eastward of Tres Palmitas, the dune reefs form a nearly continuous barrier. They were an important factor in dispersing the energy of sea swells. However, where storm waves were funneled through breaks in the reefs, erosion was severe.

The area between Boca de Cangrejos and Piñones was severely eroded by wave action in 1967. The beach and sand ridge were destroyed as sand was carried inland nearly 300 meters into a mangrove swamp (fig. 12). The seaward erosion of beach sand can also occur as shown in figures 13–15 which portray the before and after effects of the erosive power of the waves. The locations and lines of view of the photographs are indicated on the topographic maps.

FIGURE 12.—*The beach and beach ridge between Boca de Cangrejos and Piñones were destroyed when the December 1967 waves carried the sand landward. The photograph was taken after the storm waves eroded the area.*

FIGURE 13.—*Beach near Piñones after the 1967 storm waves. Note the beach rock exposed by the erosion of about 1 meter of sand from beach ridge.*

Photograph courtesy of P. R. Department of Public Works

FIGURE 14.—*View east along beach toward Punta Vacia Talega before the storm waves.*

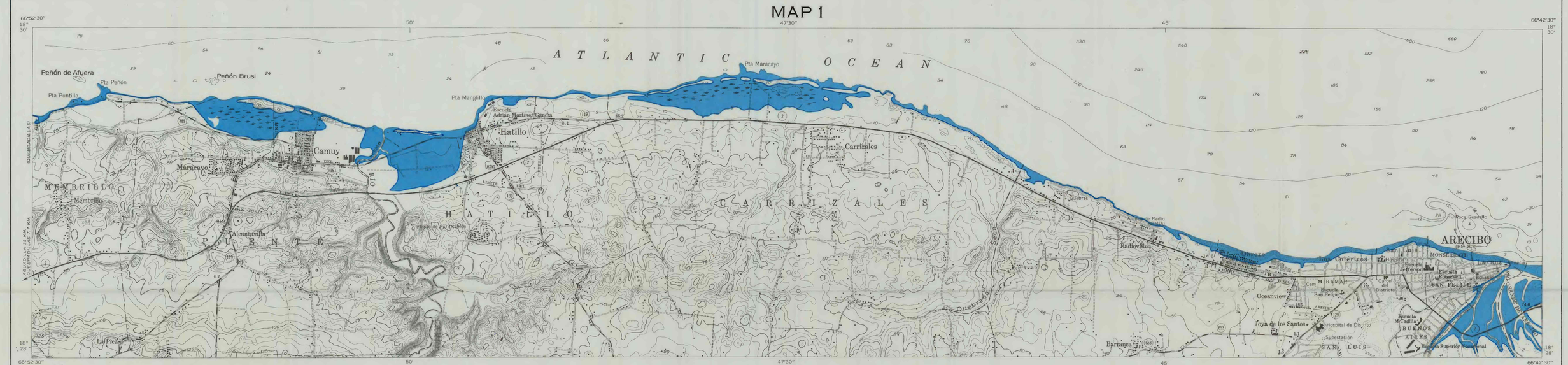
FIGURE 15.—*Beach near Punta Vacia Talega after the 1967 storm waves. Note erosion of beach and beach ridge.*

COOPERATION AND ACKNOWLEDGMENT

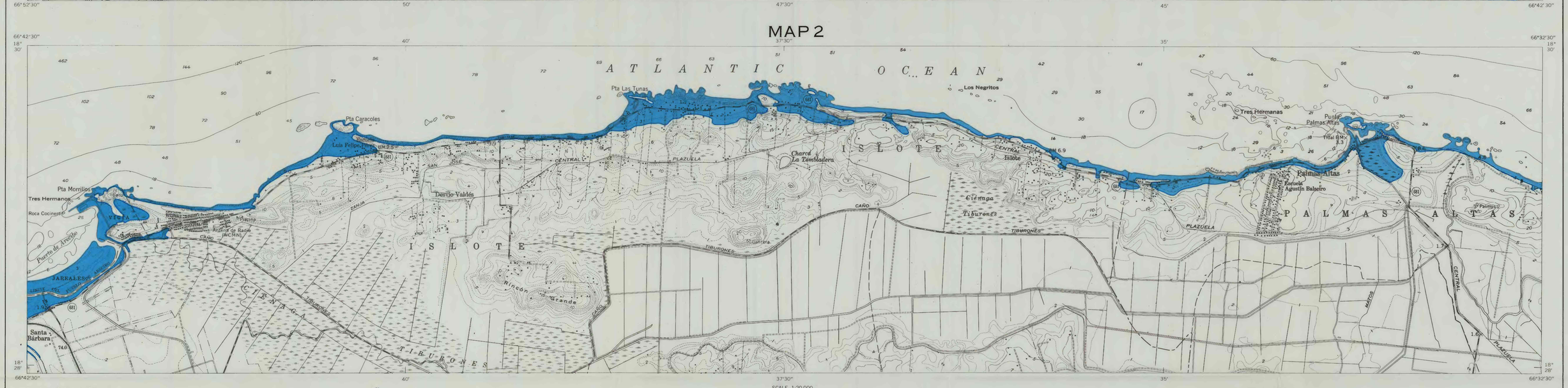
Preparation of this report is a part of a flood-mapping project financed through a cooperative agreement between the Department of Public Works, Commonwealth of Puerto Rico, and the U.S. Geological Survey.

Acknowledgment is made to R. P. Briggs and D. H. McIntyre of the U.S. Geological Survey, who mapped the inundated area from Punta Salinas to Boca de Cangrejos, to the San Juan Star and the Puerto Rico Department of Public Works for the use of photographs from their files, to the San Juan office of the U.S. Weather Bureau for meteorological and damage information, and to the U.S. Coast & Geodetic Survey for tidal information.

MAP 1



MAP 2



Base from U.S. Geological Survey topographic quadrangles

APPROXIMATE MEAN DECLINATION, 1972

SCALE 1:20 000

1 .5 0 1 2 KILOMETERS

1 ½ 0 1 MILE

CONTOUR INTERVALS 5 AND 10 METERS
DASHED LINES REPRESENT 1- AND 5-METER CONTOURS
DOTTED LINES REPRESENT 1-METER CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET—DATUM IS MEAN LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 0.3 METER

EXPLANATION

Area inundated by the storm waves of December 4, 1967

Boundary of inland penetration of storm waves of December 4, 1967. Boundary undefined in some low-lying areas

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1972—W71014

STORM-WAVE SWASH ALONG THE NORTH COAST OF PUERTO RICO

By
Fred K. Fields and Donald G. Jordan

1972

For sale by U. S. Geological Survey, price $1.00 per set