CONTENTS

Wave Height and Period Analysis for Selected Locations on the West Coast of Dominica, W.I.

1. Introduction

The General Secretariat of the Organization of American States (OAS), under an agreement with the Office of Foreign Disaster Assistance of the US Agency for International Development (USAID), is executing a five-year Caribbean Disaster Mitigation Project (CDMP). One component of this project is the assessment of potential hazards generated by tropical cyclones in terms of wave attack, storm surge, coastal flooding, and extreme wind.

This document describes a preliminary study of the wave climate at the shoreline for three reaches of the western coast of Dominica, W.I. These results are a portion of the larger storm hazard assessment being conducted for Dominica by the Caribbean Disaster Mitigation Project.

2. Overview of the Methodology

Offshore

It was necessary to separate wave effects in deep water from the more complicated interactions of sea and land which occur in shallow water. This study used several different methods to determine offshore wave parameters.

- ☐ **Normal waves offshore,** and the effects of non-tropical events, were computed by using historical data from the NCAR/NCEP 40-year reanalysis project in the Planetary Boundary Layer model, developed by the US Army Corps of Engineers.
- ☐ **Storm surge, wind, and waves offshore, under storms** were calculated by the TAOS storm hazard model, developed by Charles Watson of Watson Technical Services. The storm parameters input into TAOS were calculated by analysis of the historical storm records, processed by HURSTAT to account for differences in location.
- ☐ **Hurricane swell formation and decay offshore for bypassing storms** were computed using HURWAVE, a program created by Dr. Steve Lyons of the US National Weather Service Tropical Prediction Center. HURSTAT was used to provide input parameters for this model, as well.

Near shore

To determine the characteristics of waves in the near shore region, the outputs of the programs listed above were used as inputs to a spectral wave model developed by the US Army Corps of Engineers Waterways Experiment Station (WES). The WES spectral model was run to produce more detailed data for the area near shore, a resolution of 20 meters per cell. This fine resolution was desired because the characteristic rocky coastline of Dominica was expected to produce extremely localized storm effects.

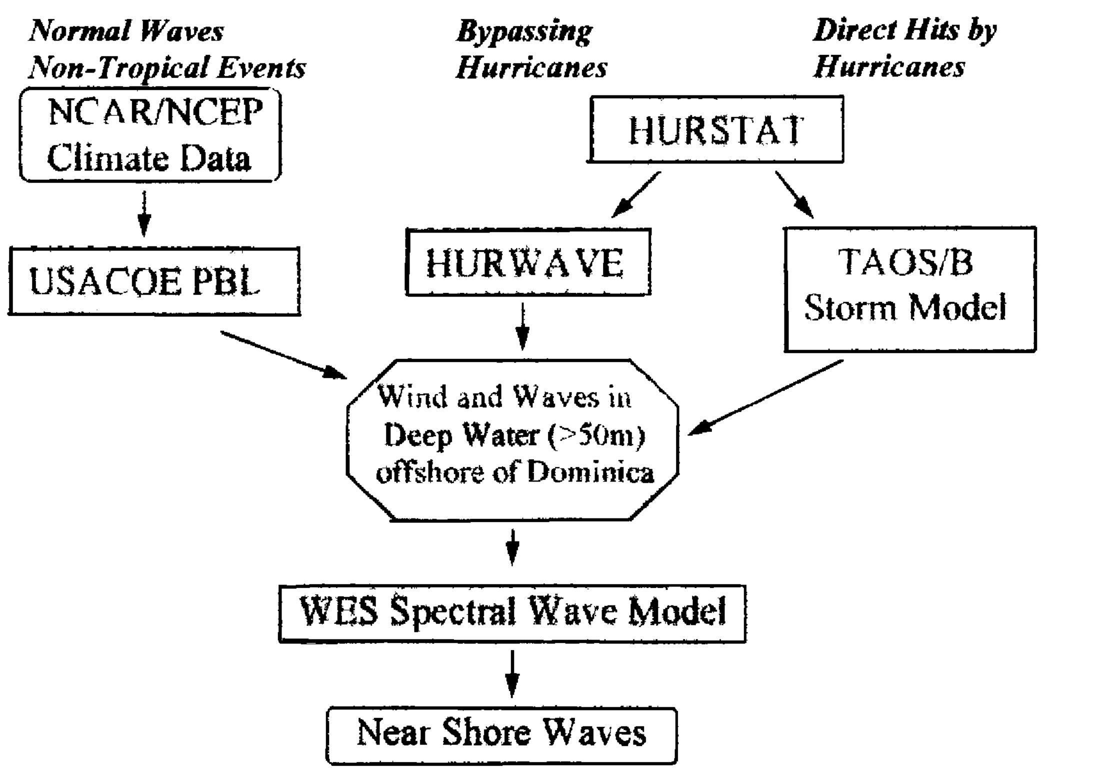


Figure 1: Methodology used to determine wave characteristics.

Normal Waves Discounted: Planetary Boundary Layer model

The normal tide range for Dominica is relatively small. Using data from June 1969 to May 1970, NOAA determined that the tides are chiefly diurnal with a mean range of from +0.16 to -0.20 meters msl, with a highest observed tide of 0.49 meters and a lowest tide of -0.37 meters. Given the short observation period, a model run was made using the University of Texas tide model (see references). This model produced results similar to the NOAA data, and a tide range of +0.20 to -0.28 meters msl was used for all modeling runs.

For the lee side of Dominica, normal wave amplitudes are generally small. A model run was made using the climatalogical mean winds from the NCAR reanalysis project. Given refraction, normal waves are less than .5 meter in height with a period of 12 seconds. With such small amplitudes of both tides and waves, there was no need to model near-shore hazards. No maps or inshore data are provided for the normal wave climate in this report.

3. History of Storms on Dominica: HURSTAT

The events most likely to generate significant waves for the study site are tropical cyclones. As of 1996, the US National Center for Atmospheric Research has 110 years of reliable, standardized weather data for the region. The HURSTAT program, developed by Charles Watson in conjunction with CDMP, extracted statistics for Dominica, using the latitude and longitude of a point near the center of the west side of the island.

The storms are sorted by category of intensity, according to the Saffir/ Simpson hurricane scale. HURSTAT gives the storm category according to the pressure and wind strength at the longitude and latitude chosen. Many of these historical storms had higher intensities at their centers, but the centers did not pass over the chosen location, and HURSTAT compensates for that.

Table 1. Saffir / Simpson Hurricane Scale
Adapted from Lutgens & Tarbuck

Category	Pressure (millibars)	Winds (km/hr)	Storm Surge (meters)	Damage
0 Tropical storm	>= 995	61 - 119	0.5 - 1.2	Some
1 Hurricane	980 - 995	119 - 153	1.2 - 1.5	Minimal
2 "	965 - 979	154 - 177	1.6 - 2.4	Moderate
3 "	945 - 964	178 - 209	2.5 - 3.6	Extensive
4 "	920 - 944	210 - 250	3.7 - 5.4	Extreme
5 "	< 920	> 250	> 5.4	Catastrophic

Table 2. General Statistics for Dominica, at Lat 15.5, Lon 61.4, for 1886 to 1996

Number of storms	61
Years with storms	45
Years with multiple storms	13
Years with multiple hurricanes	1
Category 0, tropical storms	40
Category 1, hurricanes	13
Category 2 "	3
Category 3 "	3
Category 4 "	2
Category 5 "	0

Table 3. Interval Analysis for Tropical Storms or Greater at Lat 15.5, Lon 61.4, for 1886 to 1996

Intervals Found	35
Average Interval	2.885714 years
Maximum Interval	12 years
Minimum Interval	1 year
Interval between storms, in years	Number of occurrences of interval
1	15
2	10
3	1
4	2
5	1
6	2
7	1
8	1
11	1
12	1

Table 4. Interval Analysis for Hurricanes of Category 1 or Greater at Lat 15.5, Lon 61.4, for 1886 to 1996

Intervals Found	17
Average Interval	5.764706 years
Maximum Interval	20 years
Minimum Interval	1 year
Interval between storms, in years	Number of occurrences of interval
1	3
2	5
4	2
5	1
7	1
10	2
12	1
13	1
20	1

Table 5. Interval Analysis for Hurricanes of Category 2 or Greater at Lat 15.5, Lon 61.4, for 1886 to 1996

Intervals Found	7
Average Interval	13.57143 years
Maximum Interval	34 years
Minimum Interval	2 years
Interval between storms, in years	Number of occurrences of interval
2	2
8	1
10	1
13	1
26	1
34	1

Table 6. Interval Analysis for Hurricanes of Category 3 or Greater at Lat 15.5, Lon 61.4, for 1886 to 1996

Intervals Found	4
Average Interval	23.75 years
Maximum Interval	70 years
Minimum Interval	2 years
Interval between storms, in years	Number of occurrences of interval
2	1
10	1
13	1
70	1

Table 7. Interval Analysis for Hurricanes of Category 4 or Greater at Lat 15.5, Lon 61.4, for 1886 to 1996

Intervals Found	1
Average Interval	15 years
Maximum Interval	15 years
Minimum Interval	15 years
Interval between storms, in years	Number of occurrences of interval
15	1
Warning: With only two C4 hurricanes, interval analysis is doubtful.	

The numbers in the tables above need to be used with caution. For instance, Table 3 indicates that there would be an interval of nearly three years (2.88 years) between storms, on the average. But, looked at in another way, the Table 3 says that there are 15 chances out of 35 that any given interval will last only a year, and 25 chances out of 35 that it will last two years or less.

In order to relate these statistics to personal experience, it is useful to remember that Hurricane Marilyn of 1995 was a strong Category 1, and that Hurricane David of 1979 was a strong Category 4 hurricane.

Personal experience offers only limited help in assessing the risk of severe storms, however. Table 4 shows that there was one interval when Dominica did not have a hurricane for twenty years. People who grew up during that calm period may have felt complacent about hurricanes, based on their experience, but they were wrong to do so.

4. Modeling Selected Storms Offshore: TAOS and HURWAVE

The main wave threats to the lee side of Dominica are from two hurricane-related sources. First, there are wind driven waves riding atop storm surge during and after passage of the eye of a hurricane. Second, there are swells from hurricanes which have passed the island.

Four characteristic storms were abstracted from the historical record, as modeled by HURSTAT, above. Each storm event is described with pressure, wind speed, and the general wave characteristics in deep water. These deepwater wave characteristics were output by TAOS and HURWAVE and were used, in turn, as inputs for the WES spectral model of near-shore waves.

- ☐ **5-Year Event: A bypassing Category 1 hurricane.** The parameters used were central pressure 985 mb, winds 148 kph. The deep water significant wave height (Hs) was computed as 3.5 meters with a period of 12 seconds. No wind setup was calculated in the surge, however, wave setup added 0.2 meters to the still water levels in the near shore period. At the mean low water mark at high tide, the average wave height during a 5-year event is estimated to be 1.2 meters.

- ☐ **10-Year Event : A direct hit by a strong Category 1 hurricane.** This event was modeled using a central pressure of 980 mb, with winds at 152 kph. This is similar to Hurricane Marilyn of 1995, but not an exact reproduction of that storm. The deep-water significant wave height (Hs) was computed as 5.1 meters with a period of 11.1 seconds. Waves were superimposed on a 1.1 meter surge. At the mean low water mark at high tide, the average wave height during a 10-year event is estimated to be 1.6 meters.

- ☐ **25-Year Event: A direct hit by a weak Category 3 hurricane.** The parameters used were central pressure of 963 mb, winds 180 kph. The deep water significant wave height (Hs) was computed as 6.1 meters with a period of 12.2 seconds. Waves were superimposed on a 2.2 meter surge. At the mean low water mark at high tide, the average wave height during a 25-year event is estimated to be 2.0 meters.

- ☐ **50-Year Event: A direct hit by a weak Category 4 hurricane.** The parameters used were central pressure of 942 mb, winds 212 kph. This is slightly weaker than Hurricane David of 1979. The deep water significant wave height (Hs) was computed as 7.4 meters with a period of 13.5 seconds. Waves were superimposed on a 3.0 meter surge. At the mean low water mark at high tide, the average wave height during a 50-year event is estimated to be 2.4 meters.

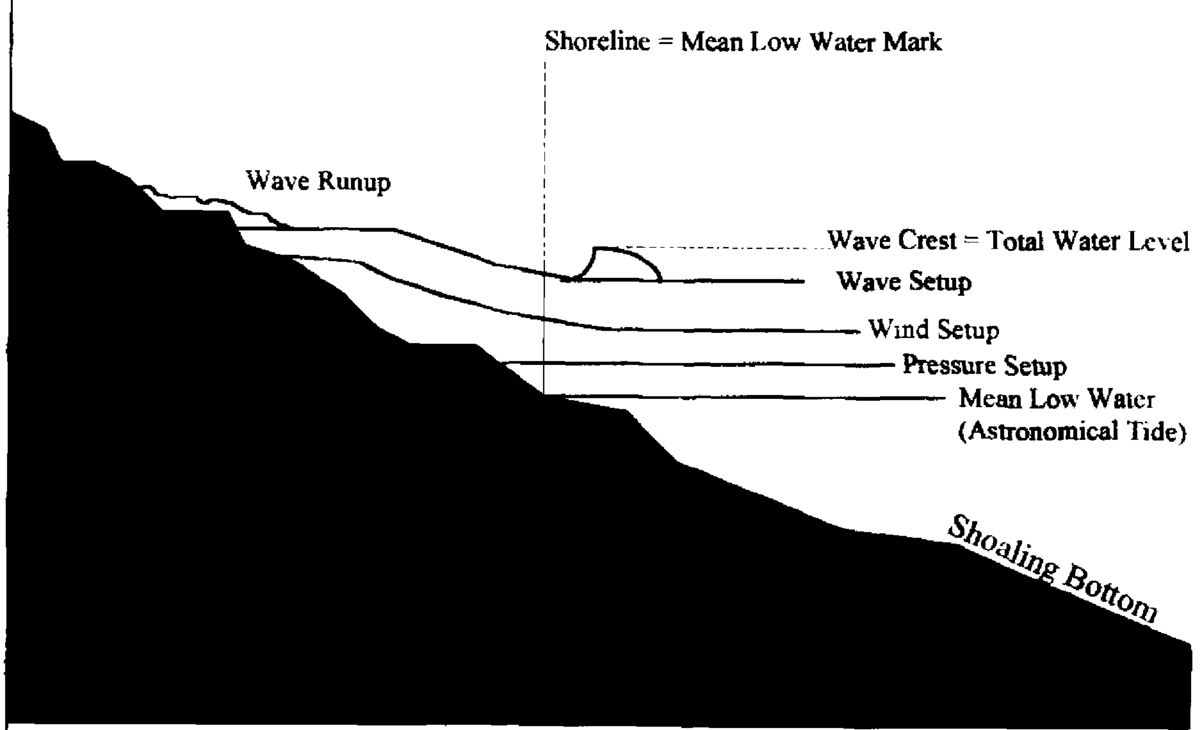
5. Modeling Waves at the Shoreline: Special Considerations

The behavior of storm surge and waves becomes more complicated as they approach the shore. The waves near land are molded by the shape of the shore in each location, both in plan and in profile.

Profile View

As storm surge and waves collide with a shallow bottom, momentum and mass continuity cause the water to pile up. A countervailing effect is the loss of wave energy due to friction and deformation in shoaling water. There are five basic components of a storm surge, caused by various processes in a storm event, plus the normally occurring astronomical tide:

Figure 2: Components of the Storm Surge



1. **Astronomical Tide.** This is the water level due to lunar and solar tides. It is usually small (< 1 meter) in the Caribbean.
2. **Pressure Setup.** This is the water level increase due to the pressure difference between the center of the storm and the periphery. For an intense storm it may be 0.5 meters.

3. **Wind Setup.** This is the result of wind induced currents in the water. On islands it is rarely over 2 or 3 meters for intense storms.
4. **Wave Crest/Total Water Level.** This is the highest water level, including wave crests. It is the highest level any water will reach at a given point.
5. **Wave Setup.** This is the elevation in average water level due to the mass transport effect of breaking waves, and can be as much as 1 meter on islands.
6. **Wave Run up.** After a wave breaks, water will run up above the still water level due to momentum.
7. **Still Water Level:** The still water level at a given point is the highest water level at that point if wave action is smoothed out.

These various effects run over the shore and onto the land to various degrees. In order to have a standard shoreline for reference, it is customary to refer to the height of storm surge and waves vertically **above the mean low water mark.** In addition, it is considered conservative to estimate these effects as if the storm arrived **at** the same time as a, normal, average **high tide.**

Plan View.

The wave energy also changes direction, due to refraction, diffraction, and reflection.

1. **Refraction.** As the edge of a wave passes into shallower water, it slows. The portion of the wave which is still in deeper water passes ahead until it, too, reaches the shallows. In effect, the wave-front turns toward the shallower area.

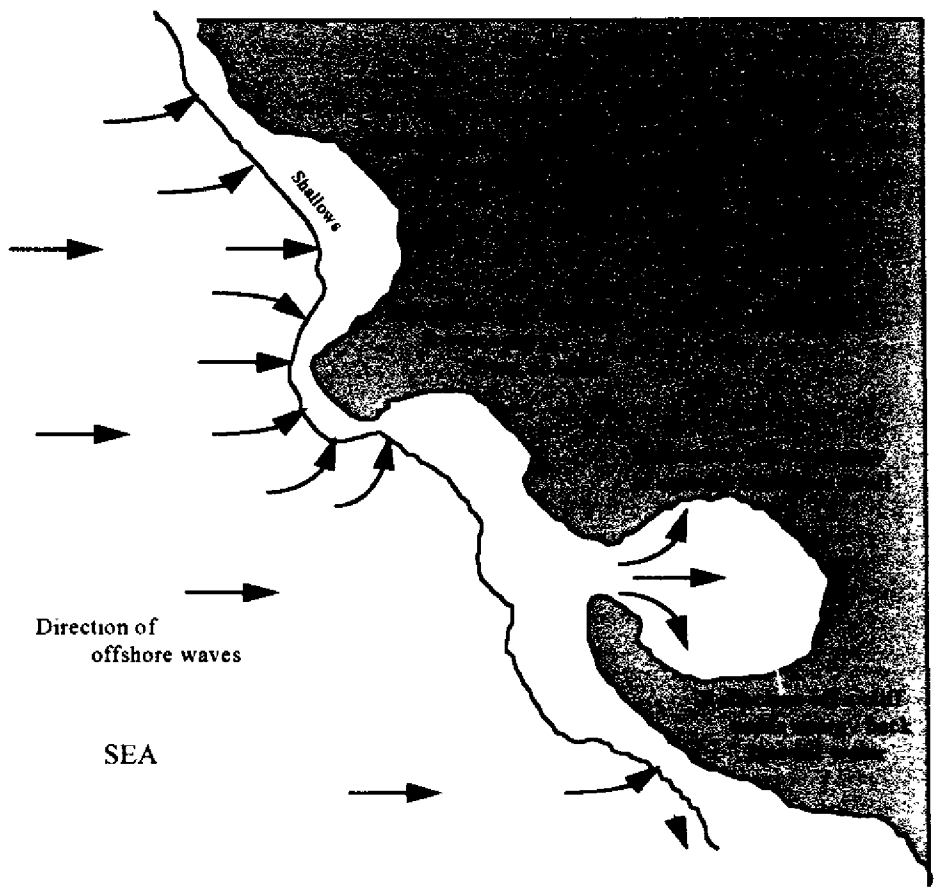
2. **Diffraction.** As a wave passes an obstruction, the energy of the wave spreads into the undisturbed water behind the obstruction.

3. **Reflection.** As a wave meets an obstruction, it reflects back into the water.

These processes are not perfectly efficient; some energy is lost in any refraction, diffraction, or reflection. It is this lost energy which grinds stones to sand, tears down cliffs, and smashes sea walls.

All these local effects are especially accentuated along a rocky, indented shoreline such as the west coast of Dominica. Headlands have the waves refracted around them, so that there is surf on all sides. Coves allow the wave energy to spread out. Deep water near shore allows waves to come close before they start losing energy, and steep beaches get the impact of waves that must be reflected or absorbed.

Figure 3: Wave Effects Near Shore



Because these effects are so extreme on Dominica, extra care was taken to have detailed information on the shape of the shore and shallows near shore. TAOS and HURWAVE used 4-kilometer finite elements for the open ocean, changing to 1-kilometer cells nearer to the islands, and feeding the storm parameters into 100-meter cells ringing the coast. These models used full primitive equations derived from fluid dynamics to calculate wind shear, mass conservation, momentum, and the other physical processes of the storms.

Inside the ring of 100-meter finite elements, the WES spectral wave model took the storm parameters and calculated the same physical processes for cells only 20 meters wide. The model required a high-resolution spatial model of the shape of the shoreline and the shape of the bottom near the shore. A large, detailed digital map of the entire west coast of the island was produced for this purpose.

6. Bathymetry: Detailed Information for Detailed Results

Three primary sources were integrated to create the composite bathymetric map: nautical charts, a Landsat MSS image, and a SPOT image.

The nautical charts were raster-scanned digital copies of paper charts. They included Prince Rupert Bay at a scale of 1:22,000, Roseau Roads and Woodbridge Bay at a scale of 1:12,000, and a chart of Dominica at a scale of 1:75,000. The paper charts were produced by the Defense Mapping Agency of the USA, but the bathymetric information on them was taken from work done by the British Admiralty over a century ago. Although the individual soundings are still accurate, for the most part, they are sparse. There are distances of hundreds of meters between soundings, and the printed numbers themselves are scaled at tens of meters wide. It was necessary to upgrade this data with information from remote sensing.

The MSS image was acquired in 1986. The image consists of four bands with a nominal resolution of 80 meters. There are heavy clouds over the east and center of the island, with a few scattered clouds over Pointe Michel and Coulibistri.

The SPOT image was acquired on December 20, 1994. This image has three bands, green, red, and near-infrared, with a nominal resolution of 20 meters. The 10-meter panchromatic band for this image was not usable. This image has clouds as well, but only about half as much as on the MSS. The west coast is mostly clear, with some haze.

There were differences on the order of 100 to 300 meters in the registration between the sources of data used in this project. In the absence of definitive information, all of the data was registered to the SPOT satellite image. This was accomplished by visually matching features between data sets and either moving or 'rubber sheeting' to register to the SPOT image. Some misregistrations remain, especially in the delineation of the coastline. It should be remembered that the coastline from the nautical charts is a smoothed, conservative registration, whereas the coastline from the remote sensing shows individual rocks and sometimes includes clear shallows.

The remote sensing contained bathymetric information because the amount of sunlight reaching the bottom, reflecting, and exiting the water depends on the depth and the color of the bottom. Light from the sun is reflected, scattered, or absorbed by water, depending on the wavelength. By measuring the difference in the reflected light at various wavelengths, especially in the blue, green and red wavelengths, the depth underwater may be estimated. (Lyzenga, 1978) When using several bands of the electromagnetic spectrum, the depth estimate variable is effectively continuous, with no lowest resolution.

During the analysis of the SPOT image it was determined that a boundary layer, possibly a thermocline or halocline, existed at approximately 10 to 12 meters. To account for this, two different regression equations were derived: one for 0 to -11 meters, and one for -11 meters down. No useful information was obtained deeper than -20 meters, however, given the wave heights impacting the leeward shore, this is not thought to impact the study.

Overall, the impact of the improved bathymetry on the wave hazard study appears to be minor. However, tests reveal that there are a few specific sites where there may be as much as a 10 % increase or 30% decrease in wave impact. This is due to the tendency for the techniques used to derive bathymetry for the original study to overestimate depth in some areas. The additional detail available with the new bathymetric data set will allow much greater detail in the spatial variation of wave energy along the coastline.