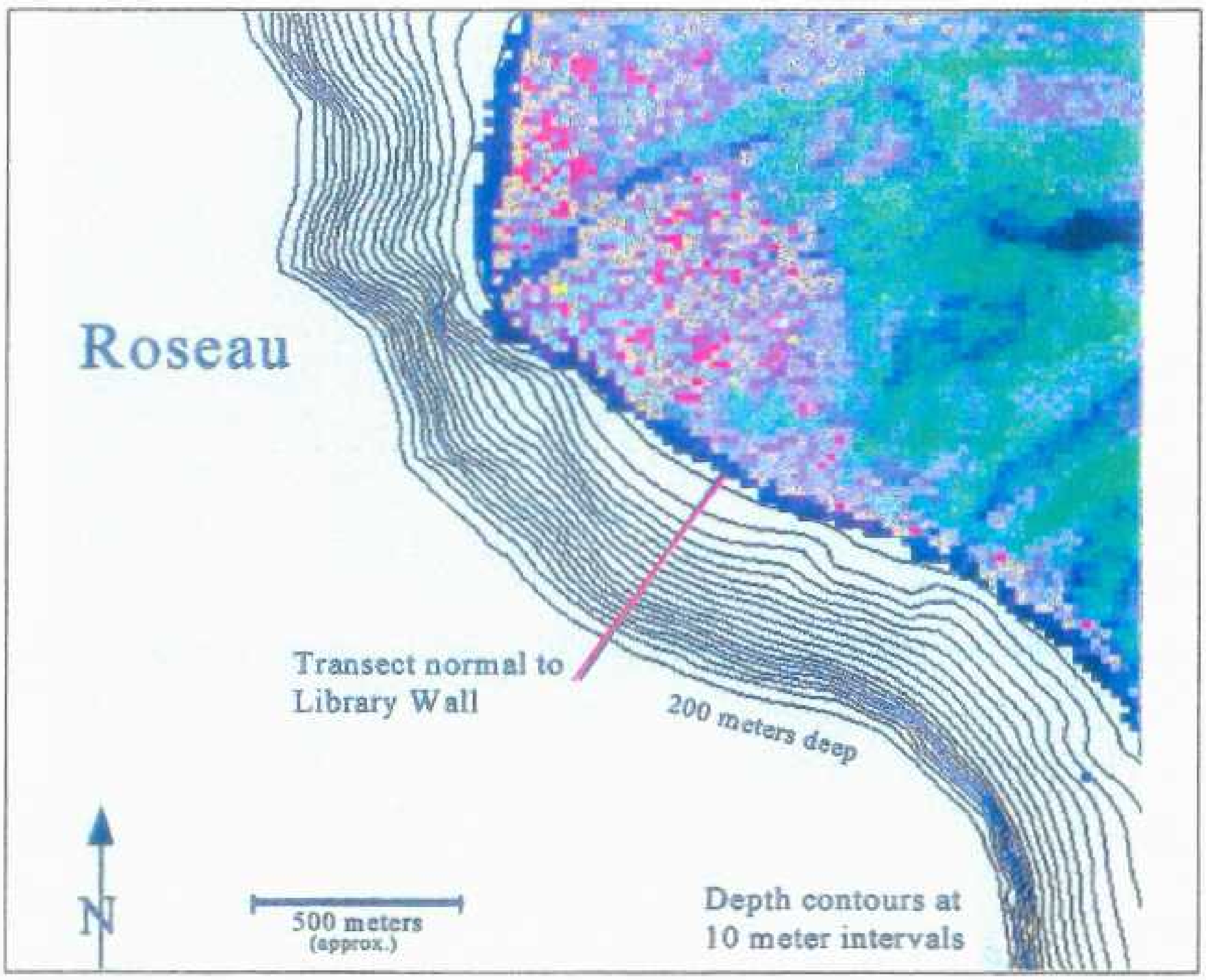
7. Example Sites

The WES Spectral Wave Model produces wave height, wave power, and other storm characteristics for each finite element cell of the input map. The entire coastline is modeled simultaneously, but the volume of output data is difficult to comprehend. Following is a discussion of only six points along the coast and the results at those points. These points are selected because they were damaged during the storms of 1995 and they demonstrate the local effects of an indented, rocky shore.

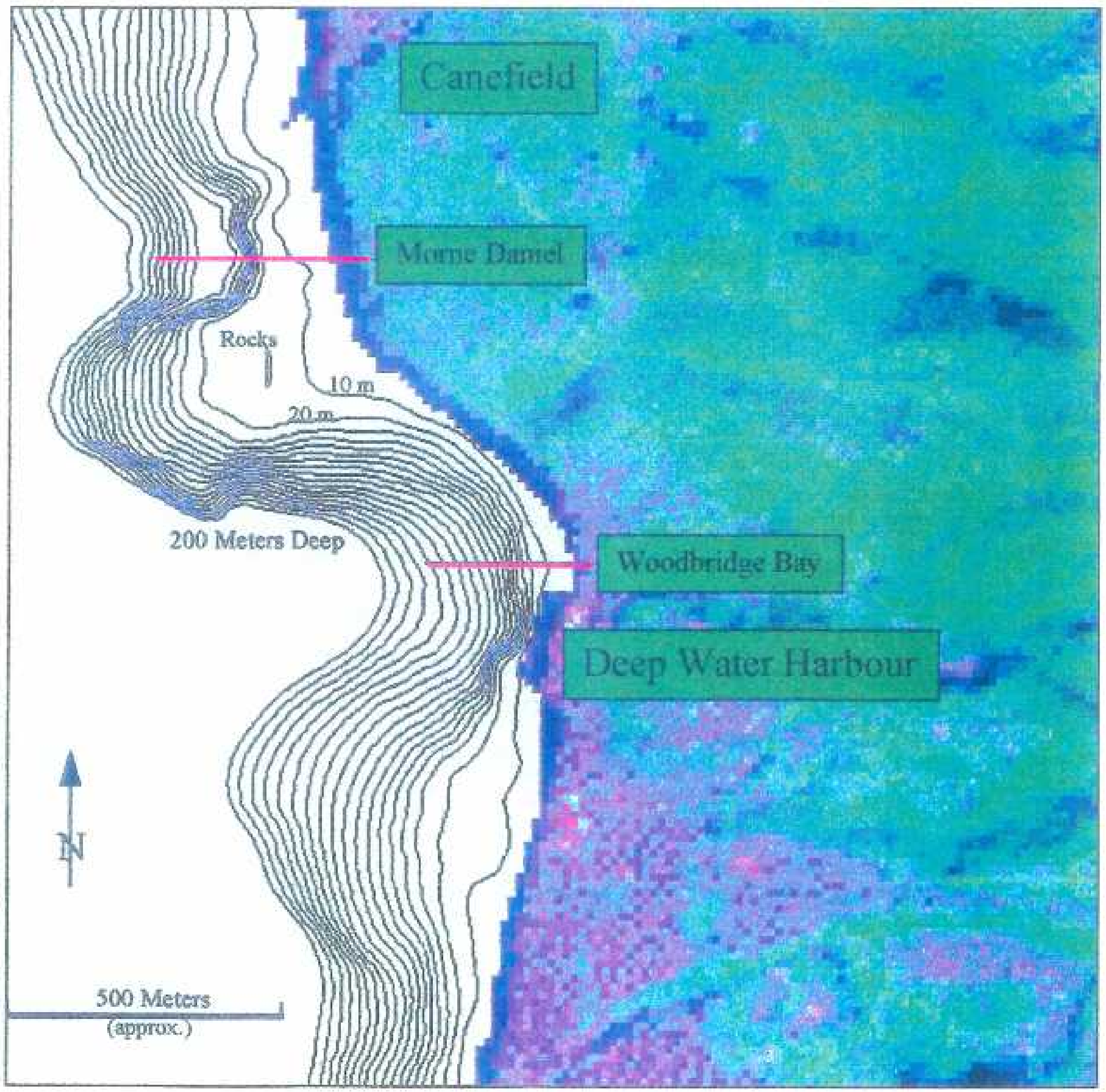
Roseau

The sea wall by the Roseau Public Library cracked and collapsed in places during Hurricane Marilyn in 1995. The Library is atop a bluff, approximately 10 meters above a narrow cobblestone beach. Below the waterline, the ground slopes steadily down with a southwestern aspect. There is ordinarily some swell here, due to diffracted waves from the Martinique Channel which come around Scotts Head.



Deep Water Harbour to Canefield

The deep-water harbour just north of Roseau is the main port of the island. It is usually quite sheltered, since it is nearly a third of the way up the leeward side, with a well-formed cove. It is not a shelter, however, when winds and seas come out of the west, during cyclonic storms, The depth of the water in the center of the cove allows storm waves to approach closely, and the shape of the cove may focus wave energy rather than dissipate it.



In the section of coast from the deep water harbour to Canefield (previous page), the first transect shown leads from the deep water to the most sheltered part of **Woodbridge Bay**, between the port facilities and the boat landing where the local fishing fleet pulls up. There is a sandy beach and a small jetty, not visible at this scale. The coastal road runs along an embankment about 3 meters high, just inland from the beach. The embankment is reinforced with gabions.

The second transect leads from the deep water, between two reef areas, to an exposed part of the coastal road below the cliffs of **Morne Daniel**. The road runs atop a masonry wall about 3 meters high, but so close to the water that there are sections where the edge of the pavement is eroding into the sea.

The transect for Morne Daniel runs across an area where the bottom configuration corresponds to especially severe hazards. Sections immediately north and south of the transect receive some protection from submerged rocks and reefs. That protection is only relative, however, and the entire peninsula experienced damage along the shore in 1995.

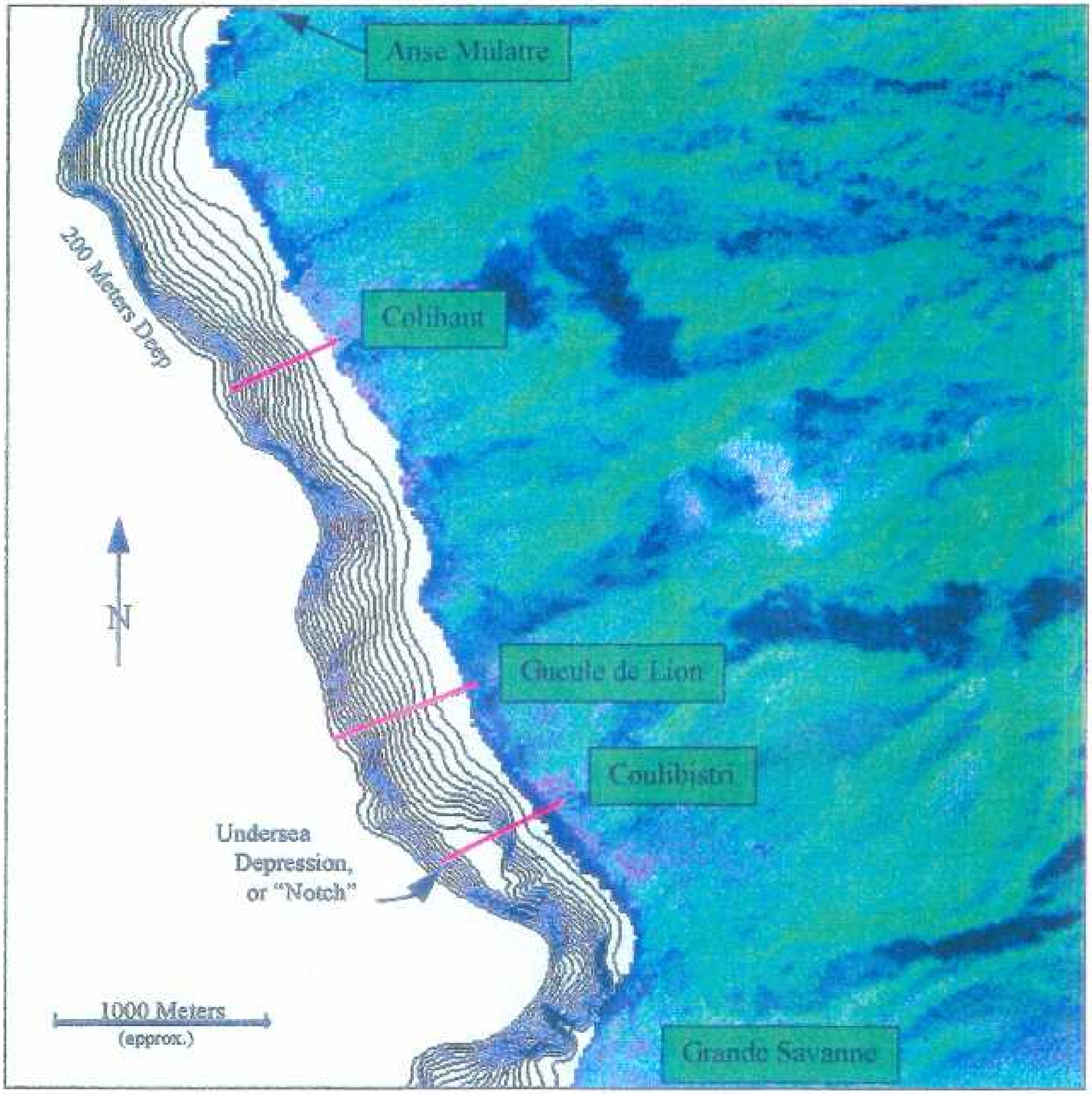
Coulibistri to Anse Mulatre

The map on the next page shows a stretch of coast about two-thirds of the way up the leeward coast. Villages such as Coulibistri sit at the mouth of a small river valleys. Except for the valleys, the coast is steep, with cliffs above the water line and a narrow shelf below. The sea wall for the coast road is mostly gabions, and numerous gabions were undermined, shifted, or broken open in 1995.

The transect for **Coulibistri** leads up the middle of a notch in the underwater shelf. This notch may be due to underwater landslides or to turbidity erosion. The result is that the shelf is especially narrow at this point, and the storm damage showed a local maximum just in front of the village. Reflected waves off of the steep shore at Grande Savanne may be a factor as well.

The bathymetry study which was done as part of this modeling project found several places along the coast with this sort of steep underwater depression. Preliminary observations indicate that these underwater notches are associated with problem areas for storm damage.

Gueule de Lion is just north of Coulibistri. The shoreline is relatively straight, the coastal shelf is narrow, and the natural shore is rocky and steep. The coastal road runs near to the sea atop an embankment reinforced with gabions and occasional lengths of masonry sea wall. Water two meters deep comes to the bottom of the embankment, in places. There was extensive damage to the gabions along this stretch in 1995.



North of Gueule de Lion, the road turns inland and climbs over headlands. It comes down again near a stone quarry and jetty, and runs parallel to the shore until **Colihaut**, where it turns inland again. That turn in the road was severely damaged, with the gabions twisted and collapsed and the pavement gone for about fifty meters. The public school is on level ground near the shore and near the road damage.

8. Summary Statistics & Comparison of Sites

An initial analysis was done using bathymetry derived from the MSS satellite image, with horizontal resolution of 80 meters. This model run also used "worst case" parameters, such as assuming that the storms coincided with the astronomical high tides. After that, the model was run again with improved bathymetry derived from the SPOT image at 20-meter resolution, reinforced by digitized contours from the nautical charts, and a more realistic set of "mixed-case" parameters. The first model run produced wave heights, total water heights, and storm surges at shoreline which were 33% to 45% higher than the values based on the improved bathymetry and moderate assumptions.

The values below are from the second model run. It must be remembered that the 20-meter resolution of the digital maps does not delimit the shoreline precisely. Model output was queried at the transects for the selected sites, and the shoreline was found by extrapolation of bottom slope for the two cells closest to land. Storm parameters at the derived shoreline were developed by interpolation. Values are given to three significant figures in order to allow users to exercise judgement when rounding numbers.

Table 8. Storm Surge at Mean Low Water Line, meters

Storm Event Interval	5 Years	10 Years	25 Years	50 Years
Library Wall	1.38	2.01	2.66	3.30
Woodbridge Bay	1.31	1.96	2.62	3.27
Morne Daniel	1.35	1.99	2.66	3.31
Coulibistri	1.36	2.00	2.65	3.30
Gueul de Lion	1.31	1.97	2.62	3.28
Colihaut	1.32	1.98	2.64	3.29

Table 9. Wave Height at Mean Low Water Line, meters

Storm Event: Interval	5 Years	10 Years	25 Years	50 Years
Library Wall	1.56	1.86	2.17	2.49
Woodbridge Bay	0.88	1.31	1.81	2.27
Morne Daniel	1.29	1.60	2.21	2.59
Coulibistri	1.37	1.75	2.14	2.53
Gueule de Lion	0.93	1.39	1.85	2.31
Colihaut	1.03	1.54	1.97	2.41

Table 10. Total Water Height at Mean Low Water Line, meters

Storm Event interval	5 Years	10 Years	25 Years	50 Years
Library Wall	2.31	3.13	3.96	4.79
Woodbridge Bay	1.84	2.75	3.71	4.64
Morne Daniel	2.12	2.95	3.99	4.86
Coulibistri	2.18	3.06	3.94	4.82
Gueule de Lion	1.87	2.80	3.74	4.67
Colihaut	1.94	2.91	3.82	4.73

From the figures above, it appears that a **50-year storm** event will affect all of the sites uniformly and seriously. Uniformly, because the highest total water level, at Morne Daniel, is predicted to be only 5% higher than the lowest, at Woodbridge Bay. Seriously, because the surge height of 3.30 meters and the total water height of 4.75 meters is just enough to put the coastal road in heavy surf for long stretches. From Woodbridge Bay to Canefield, from Tarou to Layou, and in many other areas, the road runs at the water's edge, elevated only about 3 meters.

At the other end of the scale, **5-year storms** may not cause much damage except where coastal structures are especially weak. The two meters of total water level is not enough to crash up onto the coastal road, and modern concrete structures should withstand these storms.

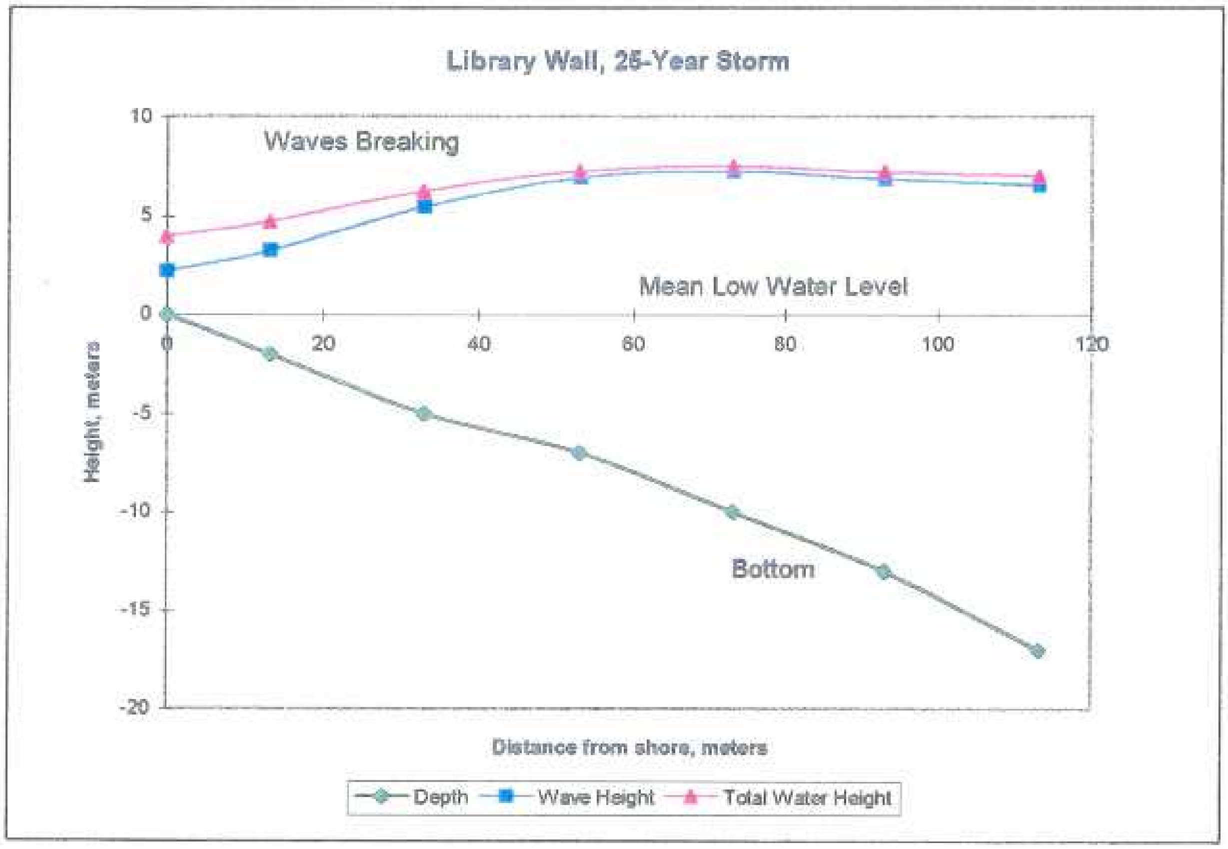
Weak structures that cause concern include gabions and the Library Wall in Roseau. Many coastal structures are built on wire gabions, baskets filled with stones. The foundation under the gabions may be concrete, cast in place over rounded cobblestones, or there may be no other foundation at all. Gabions get much of their strength from friction among the stones in the basket. The lubrication and buoyancy of storm flood waters weaken gabion structures.

The damaged retaining wall at the Roseau Library is little more than a plastering of reinforced concrete over a natural cliff of granular volcanic material. The wall is approximately ten meters high, and less than one-half meter thick. It rests on a shallow concrete foundation cast over rounded beach stones, and the foundation has been undermined. A portion of this wall 3 meters wide has fallen already, and there will be more damage at the next heavy storm.

Storms in the middle range, with **10-** and **25-year** recurrence intervals, require further study. These storms are strong enough to cause serious damage, but the effect is different from place to place. The total water level of 3 to 4 meters at Morne Daniel threatens to cut the road at a critical point. It is the only link between Roseau and the northern two-thirds of the country. Woodbridge Bay, less than a kilometer farther south, might survive the same storm. Woodbridge Bay is predicted to have about 10% less water. It also has a sandy beach and wider setback which will help to protect it.

The beach and setback at Woodbrige Bay bring up another point. In the tables above, Gueule de Lion appears quite similar to Woodbridge Bay. But, instead of a sandy beach, Gueule de Lion has a steep drop-off into 2 or 3 meters of water. Such details can not be resolved at the 20-meter grid size. The model is powerful, but site studies are still necessary for design.

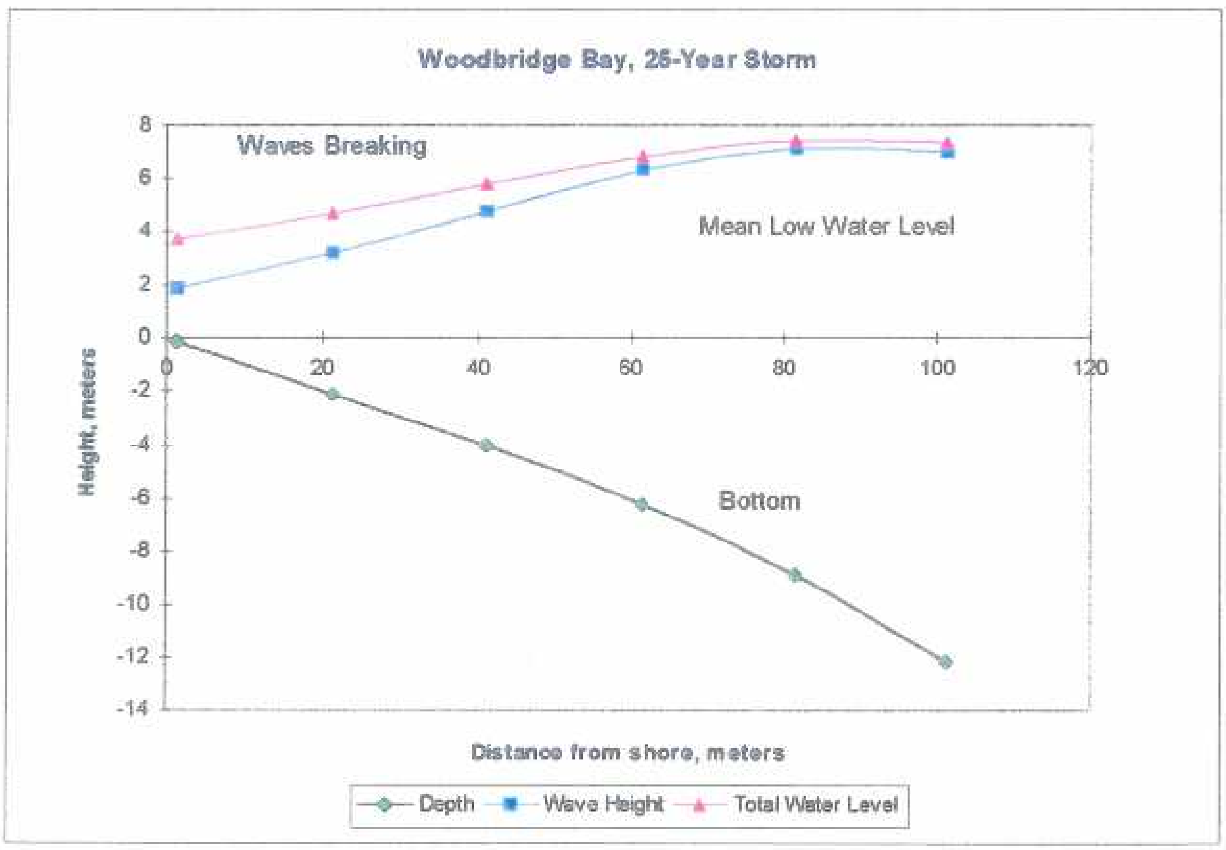
What the model does contribute to the design process is an integrated treatment of the context around each cell. Below is a graph relating the decline in wave height to the distance from shore and the depth for the transect at Library Wall. The graph includes the bottom depth, the wave height, and the total water level for waves tops riding on a storm surge. Since all three variable are in the same units and to the same scale, it is possible to look at this graph as a profile view of the shore during the storm. The bottom rises from the ocean depths to the mean low water line, while the waves and total water height rise above the mean water level.



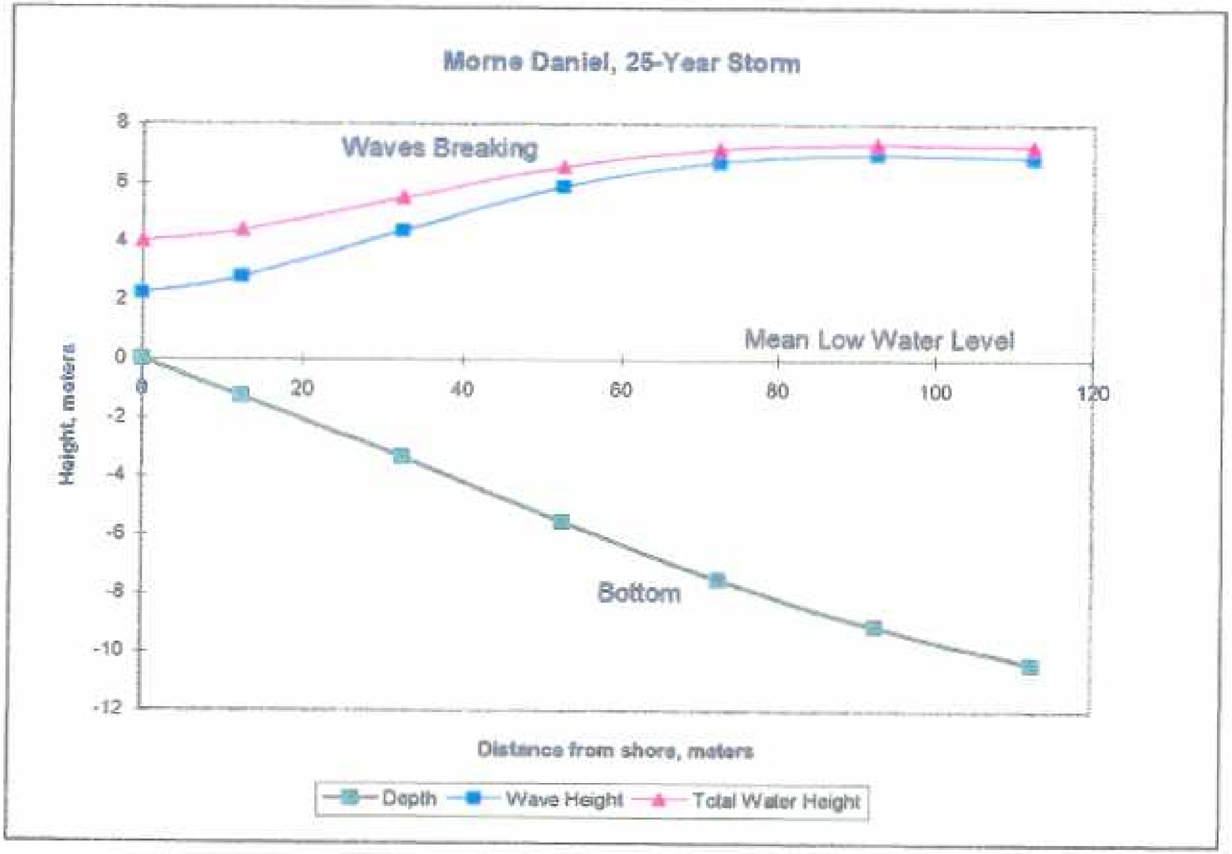
The shore at the library wall, and for some distance north and south of the library, has a uniform slope with few indentations either in this profile or in the plan view. (See site map on page 15.) The storm waves begin to break at about 75 meters from shore, where the total wave height reaches its maximum. The waves steadily lose height and energy as they approach the shore, but there is enough of them left at the shoreline to do damage.

At Woodbridge Bay (below), the waves begin to break nearly ninety meters from shore. That is because the transect was run up into a cove. The depth for breaking waves is the same as at the library; about 11 meters. Again, the waves attenuate steadily over a uniform bottom slope. Less energy reaches the shore because the slope is longer.

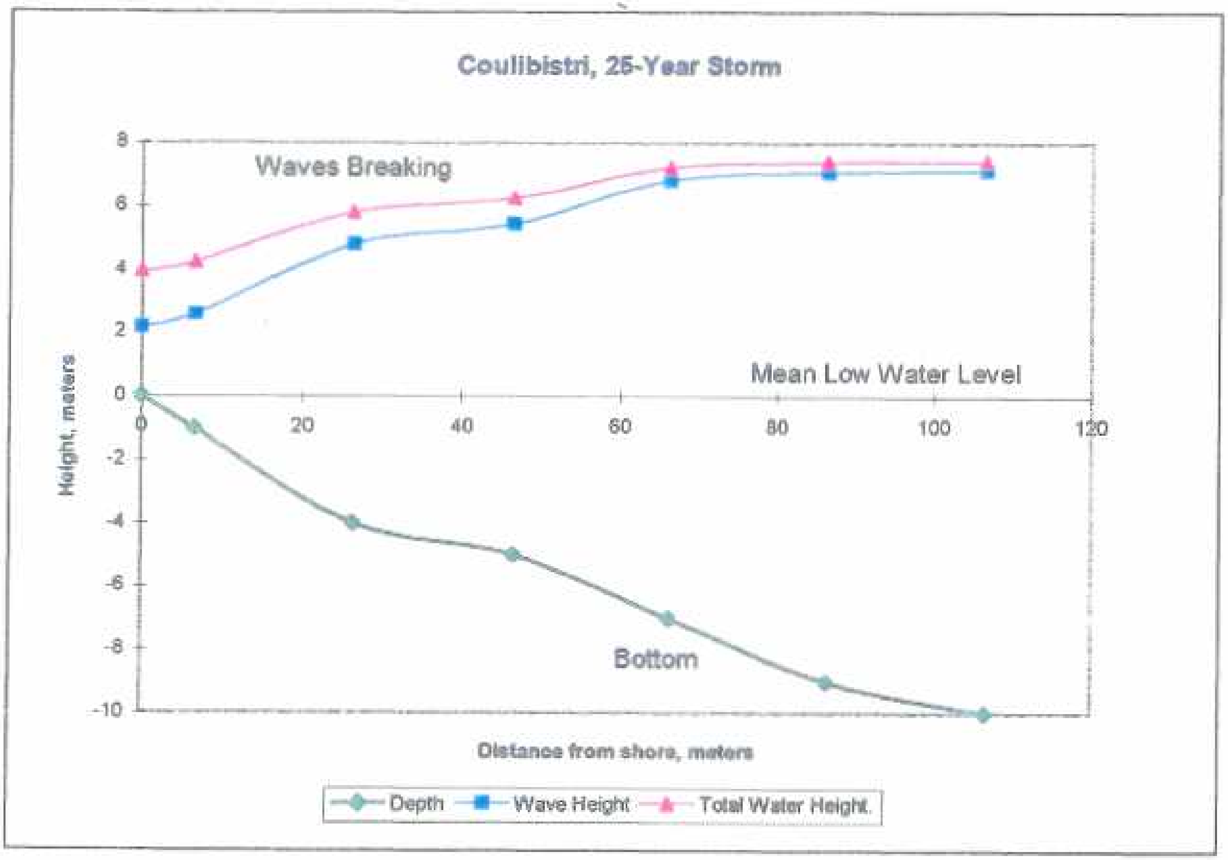
Note however, that this graph shows only the last 100 meters, corresponding to 5 cells on the map. The gentle slope begins close to shore. The deep water port facilities, just south of the transect, project out into deep water, where the dock will have to bear the full force of the waves.



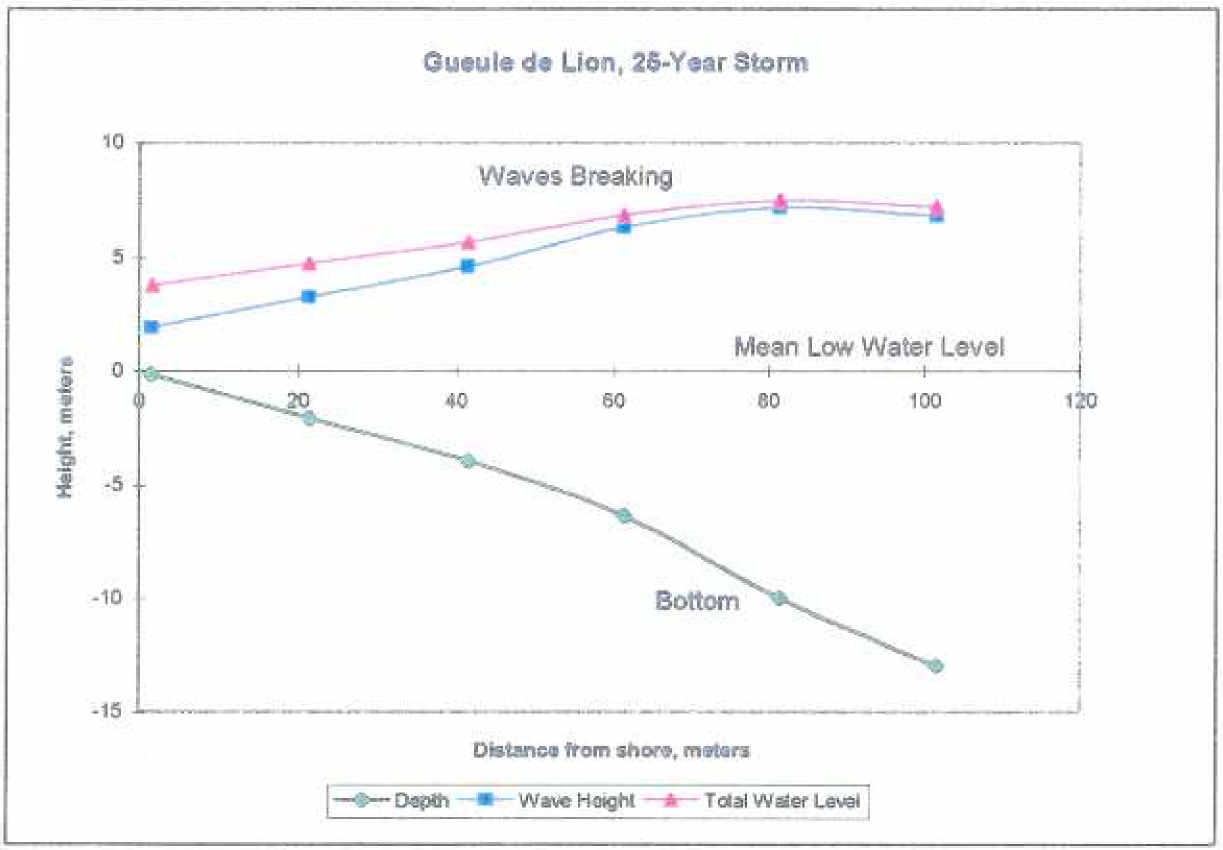
Morne Daniel is a problem area. The cliffs force the coastal road right to the edge of the water, and the underwater configuration brings deep water close to shore. For moderate storms, the rocks north and south of the sample transect help form a buffer. This profile for the 25-year storm shows how that buffer is beginning to be flooded. Waves break 90 meters offshore, and attenuate, but the curves almost level out towards the end.



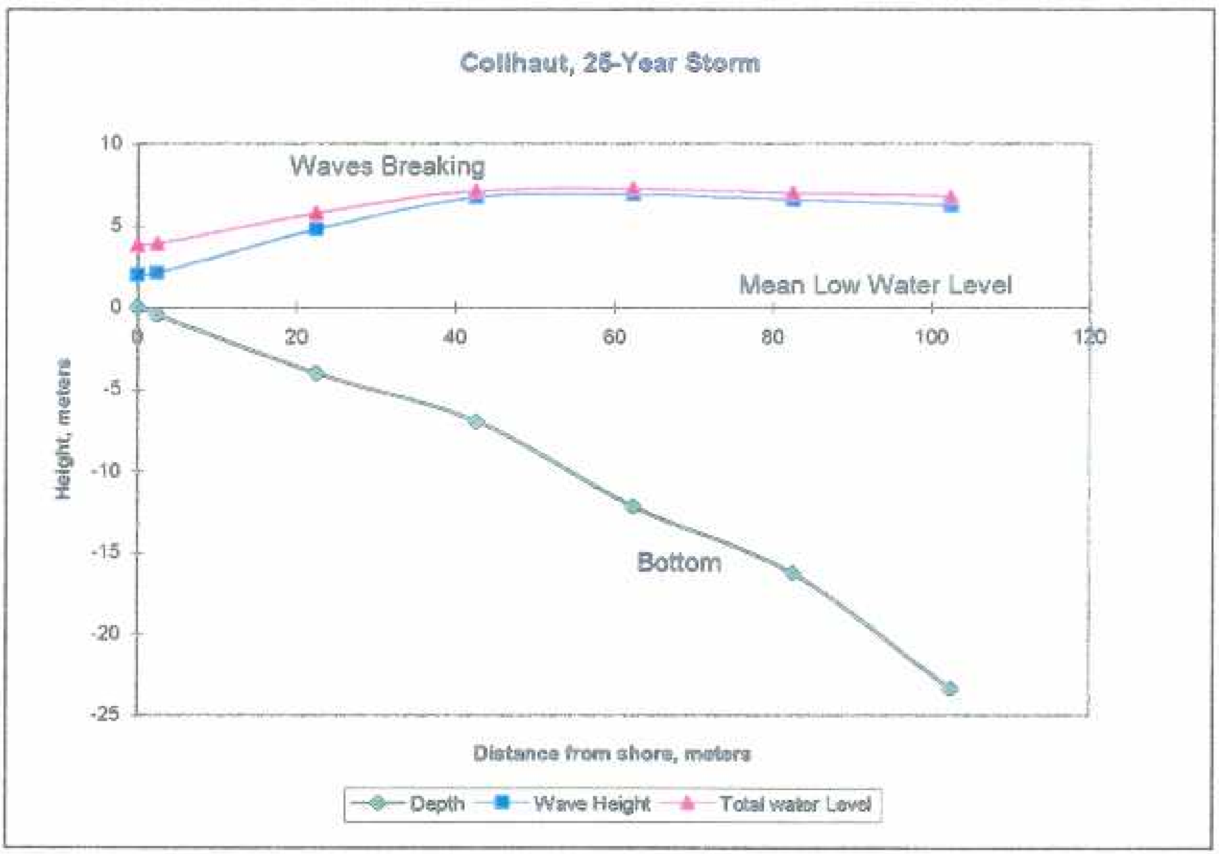
Coulibistri is another problem area. Waves break very slowly, between 120 and 75 meters out. Energy is dissipated steadily from 75 to 40 meters, but the bottom does not have a steady slope. The waves travel forward from 40 to 25 meters without losing much power. As at Morne Daniel, there is an upturn of the curves near the shore. The shore is steep, and some of the wave height may be due to reflection. Looking at the plan view (page 18), it appears possible that there is also a component of energy reflected off the north shore of Grande Savanne towards Coulibistri.



Gueule de Lion has a steep but uniform bottom slope. The waves reach a distinct crest around 80 meters from shore. The trouble here has to do more with the fine details of the road construction, elements smaller than the 20-meter resolution of this model, than with the mesoscale configuration of the coast.



Although the damage at Colihaut was extreme in 1995, the wave height and total water level listed in Tables 9 and 10 offer little explanation. Explanation is in the graph below. The storm waves for a 25-year storm would break at 45 meters from shore, half the distance for Gueule de Lion, Morne Daniel, or Woodbridge Bay. The waves lose height, but only by extreme turbulence and friction on the bottom. A few meters difference in the location of the shore, either in real life or on this interpolated graph, make a big difference in the power of the waves.



9. Conclusions

Dominica can expect to have intermittent cyclonic storms in the future. They occur seldom enough that people are sometimes lulled into forgetting them, but they are a constant hazard.

The western shore of Dominica is sheltered from the surf produced by the tropical trade winds. This relative shelter is null and void during cyclonic storms since, by definition, they blow from all points of the compass.

The western shore is particularly vulnerable to heavy storms. The shore is open, with no distinct bays. It is steep, with a narrow underwater shelf and talus slopes at the mean low water line. The steepness means that coastal flooding will not penetrate far inland, but steepness has also forced the coastal highway and other important infrastructure into precarious sites right on the shore.

Local construction practices reflect the uneven distribution of risk. They are good enough for ordinary weather, but they are not designed to withstand hurricanes.

The hurricane model presented above has revealed that the vulnerability of the coastal structures varies considerably for 10-year and 25-year events. The most vulnerable locations, as revealed by the model, match with the locations where damage was observed after Hurricane Marilyn in 1995.

For stronger storms, the vulnerability becomes more uniform. The rising waters of the storm surges for 50-year events flood the coastal rocks and reefs, where they occur, by two to three meters. Storm waves on top of this flood reach the coast with more of their full force.

It is possible to reduce the uncertainty of tropical cyclonic storms by using mathematical modeling. The digital models discussed above, and the digital databases with which they work, are tools for planning. They produce data precise enough to aid design engineers, and they produce the data for the whole area simultaneously.

10. General References and Data Sources

A Data Sources

NCEP/NCAR 40 year reanalysis project
US Defense Mapping Agency Digital Chart of the World
USGS EROS Data Center, MSS image of Dominica
Dominica 1:50,000 Map Series (UK Directorate of Overseas Surveys)
Dominica 1:25,000 Map Series (UK Directorate of Overseas Surveys)
NOAA/NOS Near Shore bathymetric map of Dominica
NOAA/NOS Tide datum for Dominica
Maptech raster-scanned nautical charts

B. References

Eanes, Richard, Univ. of Texas Center for Space Research, global tide model

Lutgens, Frederick k., and Edward J. Tarbuck, The Atmosphere An Introduction to Meteorology, 3rd. ed., Prentice Hall, Englewood Cliffs, NJ 07632

Lyons, Steve, A Simple Parametric Model for Computing Hurricane Waves, NOAA/TPC internal paper, 1995,

Lyzenga, David R., Passive Remote Sensing Techniques for Mapping Water Depth and Bottom Features, Applied Optics, Vol.17, Feb. 1978

US Army Corps of Engineers, Shore Protection Manual, 1992

US Army Corps of Engineers Waterways Experiment Station, WIS Report # 27, Vicksburg, Miss.

Watson, C. TAOS, A High Resolution GIS Based System for Integrated Storm Hazard Modeling, NWA Digest, December 1995