# A Shore Protection Scheme for Basket Flats, Maurice River Entrance and Cove, Delaware Bay, Cumberland County, New Jersey

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3 December 2019

# INTRODUCTION

The Maurice River discharges into the Delaware Bay in Cumberland County, New Jersey. Over the years the navigation channel has migrated in response to erosion of the marsh areas near the river mouth. Basket Flats is one of those marshes. It is subject to wind waves generated in the Delaware Bay from a range of directions; however, the longest fetch – the over-water area winds can blow to generate waves – is to the south. Further erosion of Basket Flats would result in exposing the town of Bivalve to relatively large waves. Also, erosion would significantly decrease the marsh area. The present analysis presents the design of a revetment to stabilize the easterly end of Basket Flats in order to shelter Bivalve and the design of a series of nearshore, detached breakwaters along the southerly shore of Basket Flats to protect the marsh from further erosion. Physical conditions at Basket Flats are established including the wind climate, wave climate, bathymetry and shore-normal beach profiles. The designs of stone rubble-mound structures for the revetment and nearshore breakwaters are presented.

Figure 1 is an aerial photograph showing conditions of the Maurice River in 2010 and the location of Basket Flats and Bivalve. Figure 2 is a portion of the USGS Port Norris Quadrangle showing conditions in 1956. During this time period Basket Flat has eroded significantly and Fowlers Island has virtually disappeared. As Basket Flats has eroded the navigation channel has migrated. Also, the area shown in red on Figure 2 indicates the disappearance of a large area of salt marsh in the Northwest Reach of the river

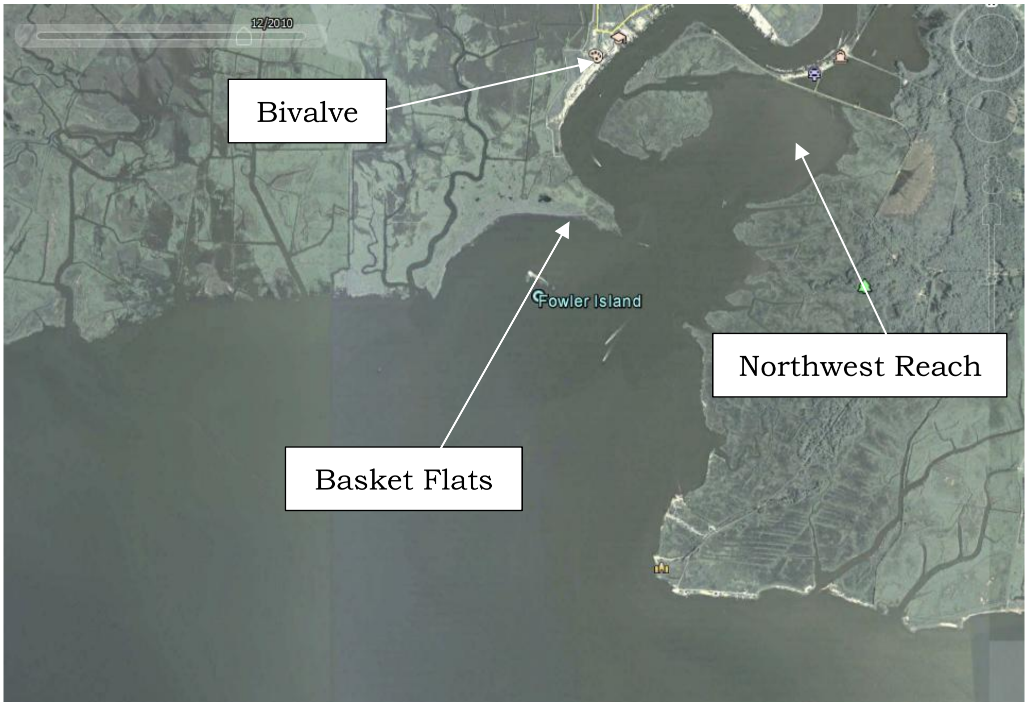

Figure 1 Location of Basket Flats, Bivalve and Northwest Reach, Maurice River, Cumberland County, NJ. (2010 image from Google Earth)

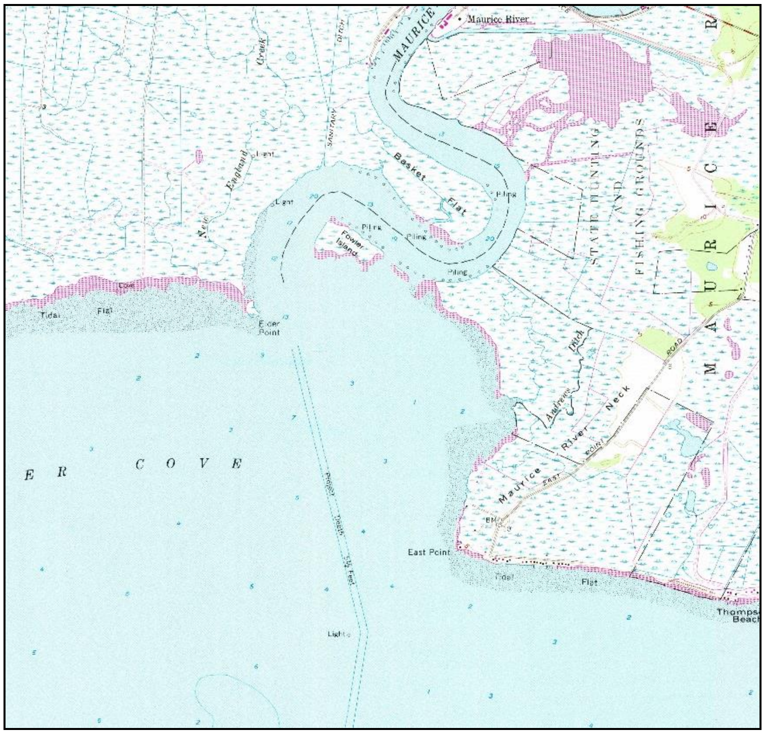

Figure 2 Portion of USGS Port Norris Quadrangle Sheet Showing Maurice River Cove (1956).

## WIND & WAVE CLIMATE – MAURICE RIVER, NJ

### Wind Statistics

Wind statistics were obtained from three nearby sources: Cape May Airport, Dover Air Force Base and NOAA's offshore data buoy No. 44009. A wind rose based on the data from Cape May airport is shown in Figure 3. The rose is based on a relatively short record and shows that winds from the south dominate the record.

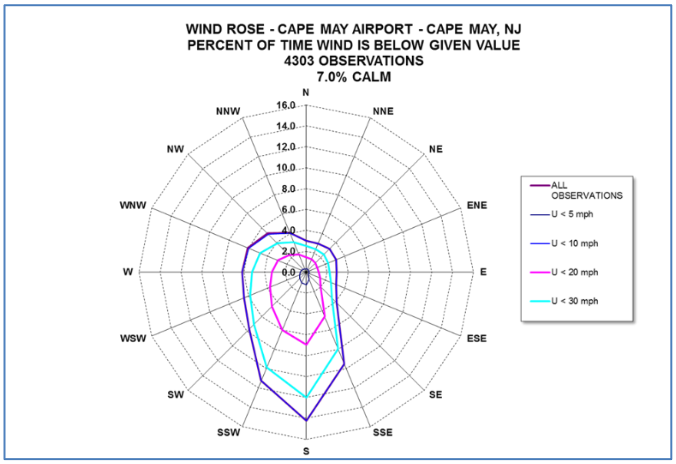

Figure 3 Wind Rose at Cape May, NJ Airport

A wind rose based on data from Dover Air Force Base is shown in Figure 4. Observations at Dover are based on a longer record than the record at Cape May. The predominant westerly direction of the winds at Dover is in keeping with the normal west to east movement of weather systems in the mid-Atlantic U.S.

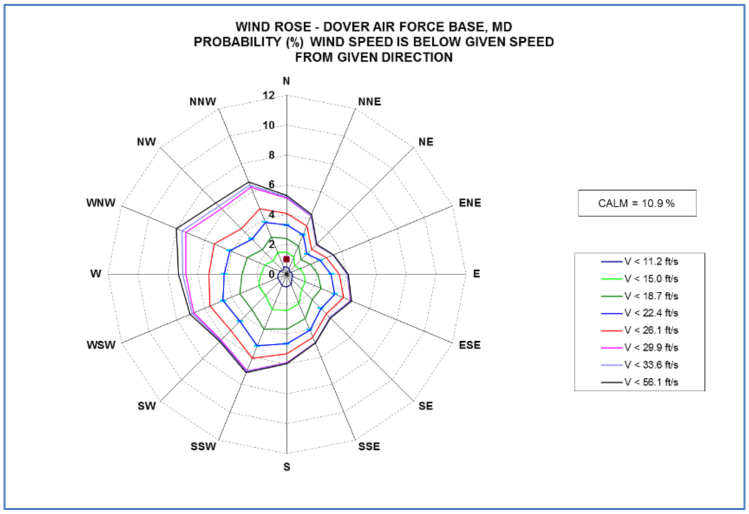

Figure 4 Wind Rose at Dover, DE Airport.

Figure 5 presents a wind rose constructed from data at NOAA's offshore data buoy located about 26 nautical miles southeast of Cape May - approximately offshore of the Delaware-Maryland border at 38.461° N and 74.703° W. See Figure 6. Twenty years of data (1984 to 2004) were used to construct the rose. It shows that winds approach the buoy most often from the north-northeast and from the south. Unlike winds obtained at land-based stations, winds at the buoy are not affected by the surrounding land mass and are probably more representative of the over-water winds that produce waves. Consequently, the data buoy wind data were used to construct a wind wave climate at the Maurice River entrance in Delaware Bay.

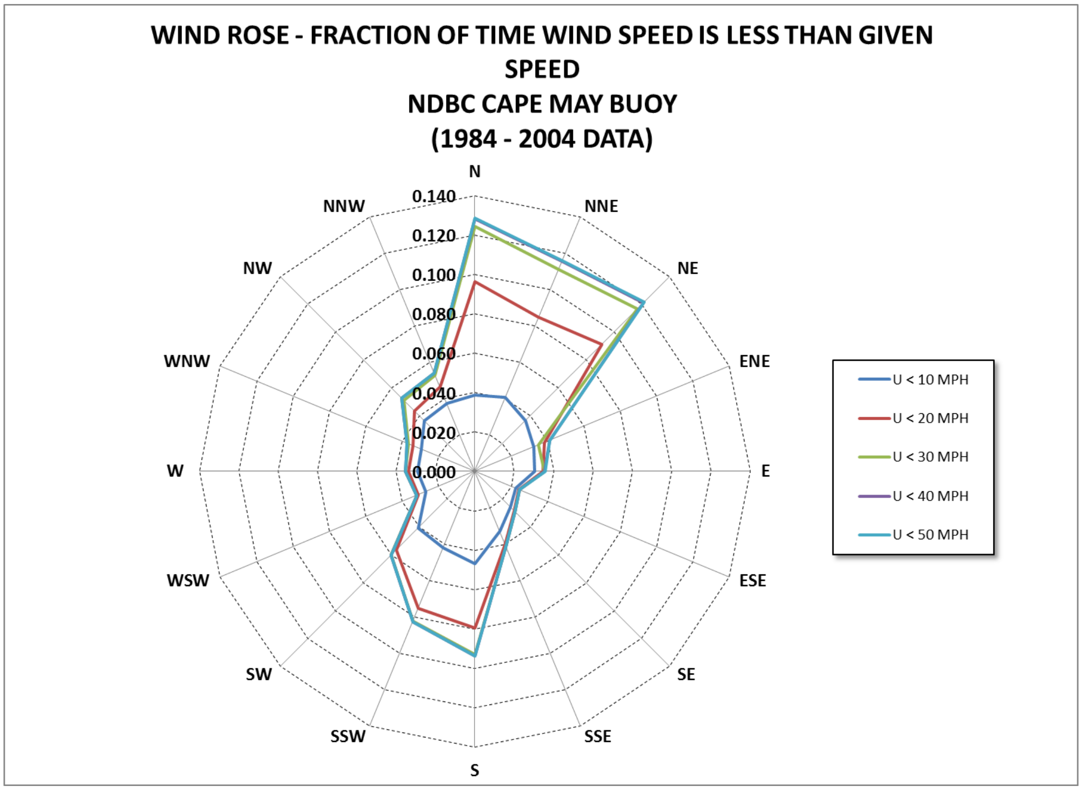

Figure 5 Wind Rose at NOAA Data Buoy 44009

Figure 6 NOAA Data Buoy

## Wind Wave Climate

The wind wave climate at the Maurice River was produced by first constructing 3° radials from the river mouth and calculating the effective fetch using a procedure developed by Dr. Zeki Dmirbelik at the US Army Coastal Engineering Research Center for the South Florida Water Management District. The effective fetch is calculated as a nine-point moving average of the 3° radials.

Typical fetch radials are shown in Figure 7. The actual fetch distances and the effective fetch calculated using the Dmirbelik procedure are shown in Figure 8 and a summary of the fetch distances and estimated water depth along the fetch are given in Table 1.

Figure 7 Location of Maurice River Showing Fetch Radials.

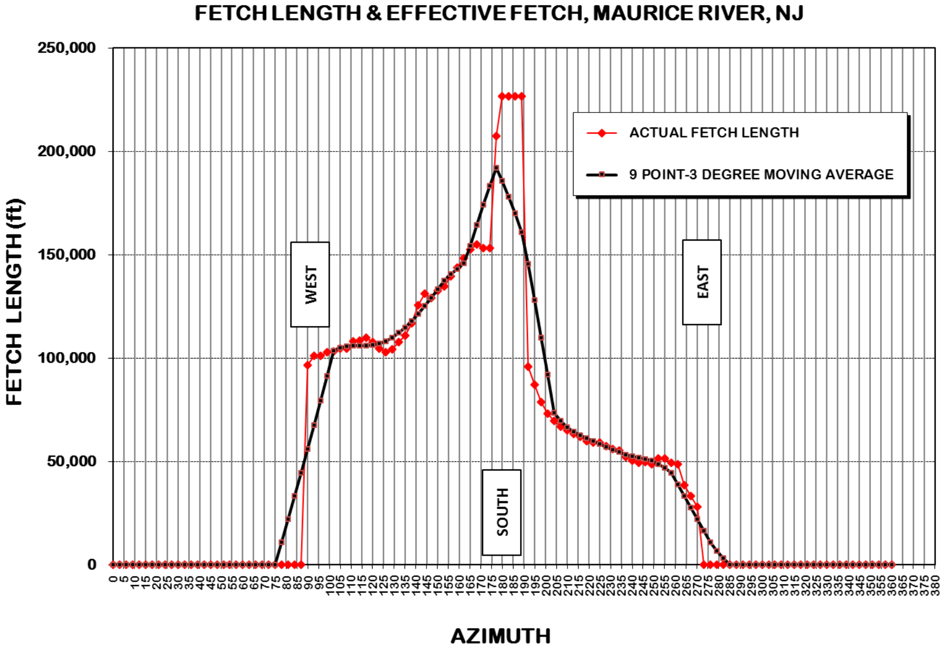

Figure 8 Fetch Distances at Maurice River Entrance, Delaware Bay, NJ.

Table 1 Fetch Summary, Maurice River, NJ

| Direction | Fetch Length (feet) | Effective Fetch (feet) | Effective Fetch (miles) | Average Depth (feet) |
|---|---|---|---|---|
| EAST | 27,878 | 21,954 | 4.16 | 7.0 |
| ESE | 48,787 | 50,259 | 9.52 | 7.0 |
| SE | 59,242 | 58,351 | 11.05 | 12.0 |
| SSE | 69,696 | 73,568 | 13.93 | 20.0 |
| SOUTH | 226,512 | 185,662 | 35.16 | 30.0 |
| SSW | 143,574 | 143,109 | 27.10 | 25.0 |
| SW | 110,817 | 114,689 | 21.72 | 20.0 |
| WSW | 108,377 | 105,938 | 20.06 | 19.0 |
| WEST | 96,529 | 56,067 | 10.62 | 17.0 |

The statistical distribution of data buoy winds from the west is shown in Figure 9. Similar distributions were developed for each of the 16 compass directions and used to construct the wind rose and wave climate. Wave heights as a function of wind speed, wind direction, fetch length and average water depth along the fetch were calculated using the wave forecasting equations in the U.S. Army "*Shore Protection Manual*" (USACE, 1984) The equations give the significant wave height which is the average height of the highest 1/3 of the waves in the spectrum. The resulting wind wave climate is shown in Figure 10. Significant waves 6.64 feet high will occur on average for one hour per year. For the 20 year-long wind record at NOAA's data buoy, the largest waves at the Maurice River would have been 7.7 feet high. Wave heights and periods for winds from all relevant cardinal compass directions are given in Table 2.

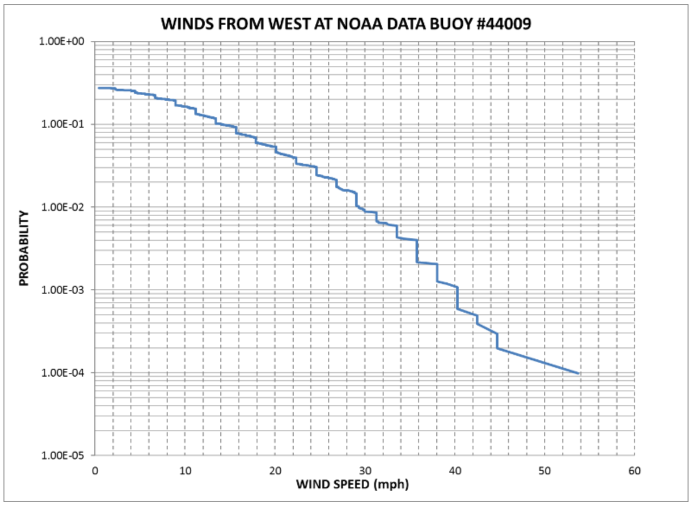

Figure 9 Typical Plot of Wind Statistics at NOAA's Data Buoy #44009 (Example for Winds Blowing from the West.)

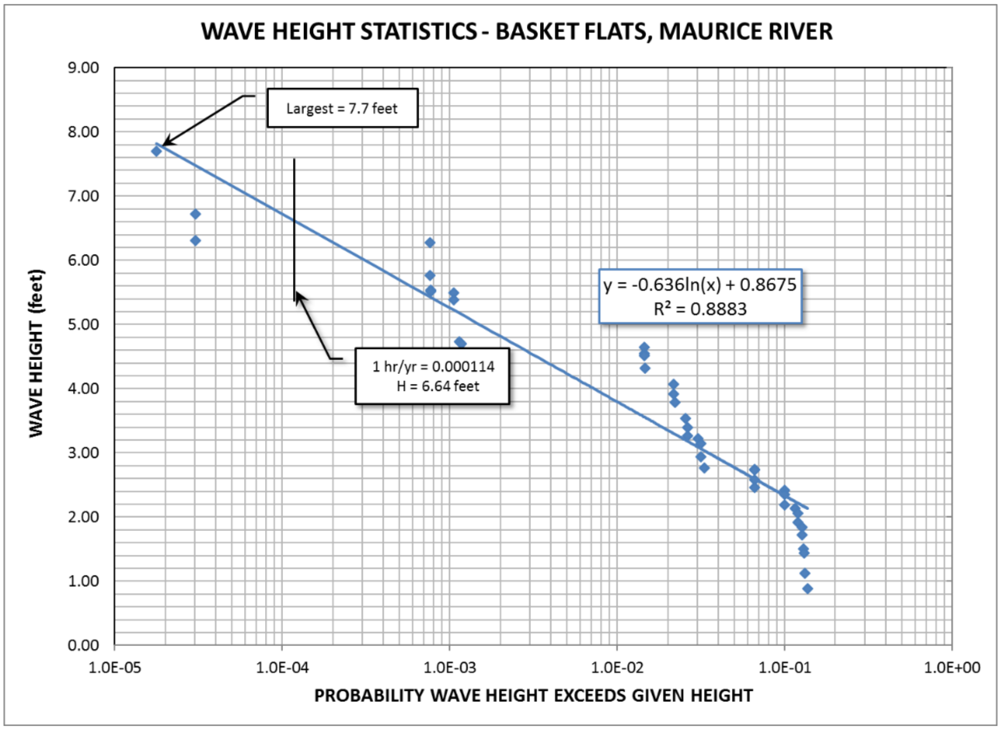

Figure 10 Wind Wave Climate at the Maurice River, NJ

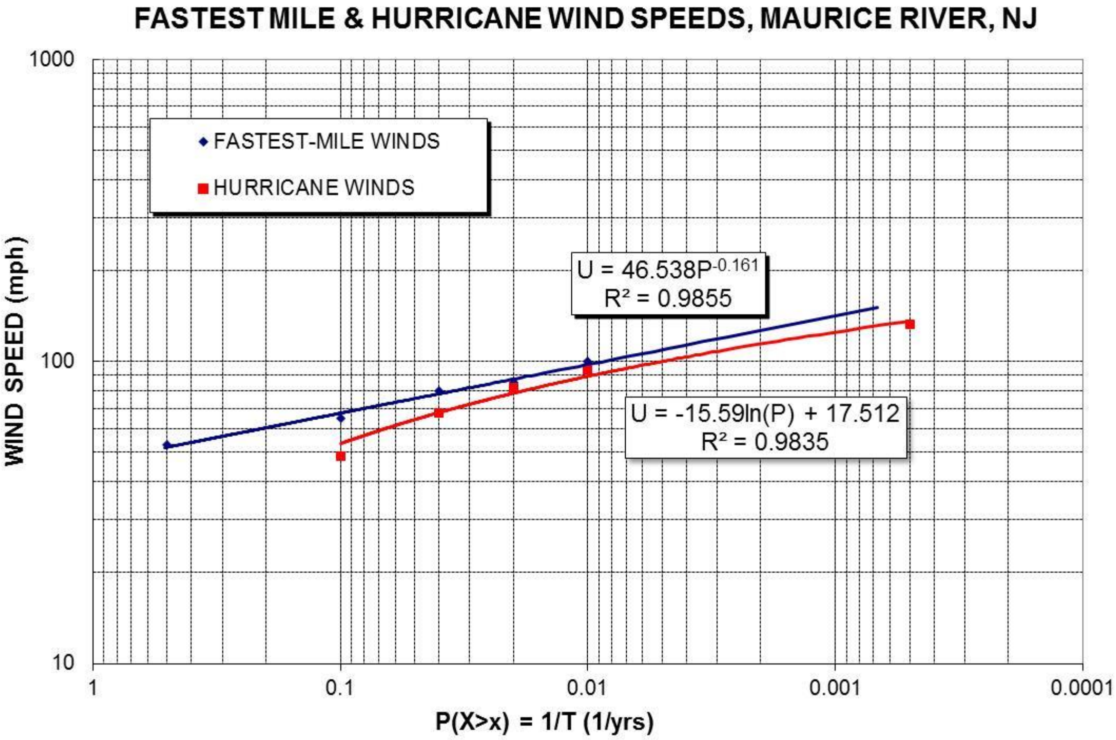

Figure 11 Extreme Winds at Maurice River Entrance, Delaware Bay, NJ.

## Extreme Winds and Estimated Maximum Waves

Extreme wind speeds at the Maurice River are shown in Figure 11. Hurricane wind speeds were determined from Batts, et al. (1980) while the maximum wind speeds from all sources were determined from Thom (1968). These winds are fastest-mile winds. Their duration is the time it takes the wind to travel one mile; hence, a 60-mph wind's speed will be averaged over 1 minute and a 30-mph wind over 2 minutes, etc. At the Maurice River, the 100-year hurricane wind speed is 89.3 mph while the100-year wind speed from all sources is 98 mph. No direction is specified for these wind speeds.

While no direction is specified, the wave height and period based on the 98-mph wind was calculated assuming it blows along the longest effective fetch. The resulting significant wave height is 10.9 feet and the period 7.15 s. An estimate of the statistics of these extreme waves is given in Figure 12. An estimate of the probability of the 10.9-foot high wave generated by wind with a return period of 100 years is 1/100 = 0.01 times the probability the wind will come along the longest fetch from the south. The probability the wind will be from the south is 0.0935; hence the exceedance probability associated with the 10.9-foot high wave will be (0.01)(.0935) = 0.000393.

Waves break when they move into shallow water so that the maximum wave height will be limited to 78% of the water depth; thus, the 10.9-foot high extreme wave will break in water 14.0 feet deep.

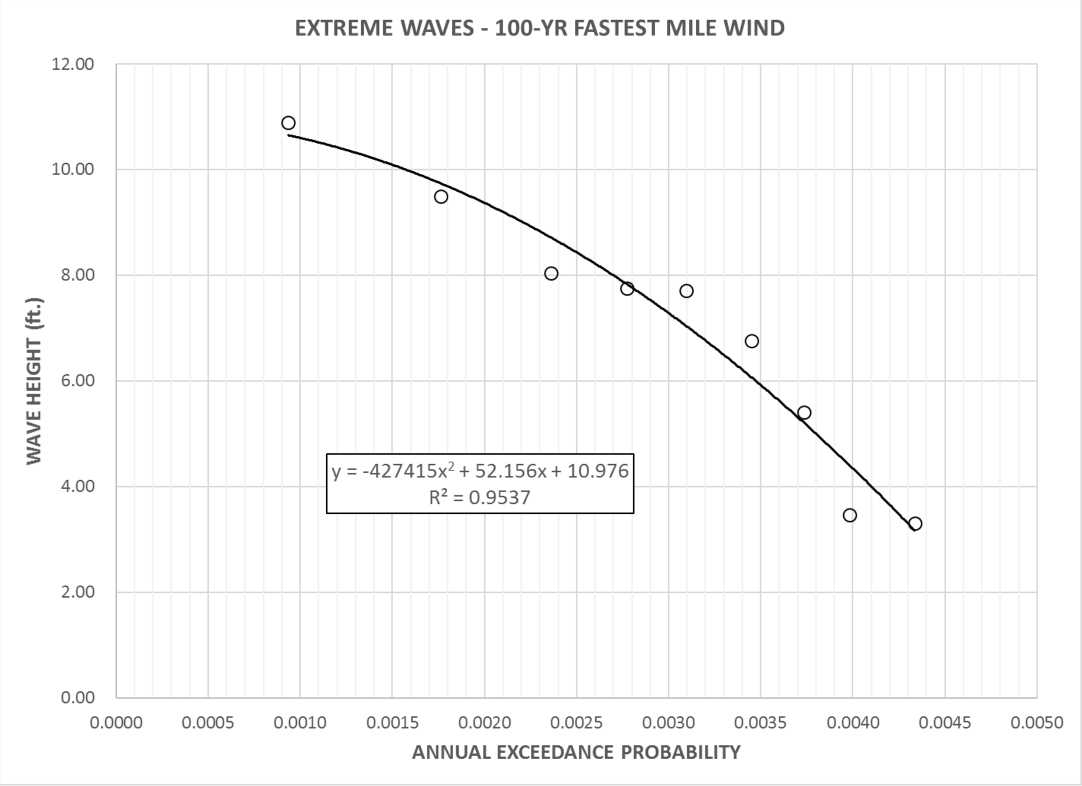

Figure 12 Estimated Statistics of Extreme Waves at Basket Flats.

## Table 2 Wave Heights and Period for Winds from 16 Cardinal Compass Directions at the Maurice River, NJ.

| | East | | East Southeast | | Southeast | | South Southeast | | South | | South Southwest | | Southwest | | West Southwest | | West | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind Speed | H | T | H | T | H | T | H | T | H | T | H | T | H | T | H | T | H | T |
| (mph) | (ft) | (s) | (ft) | (s) | (ft) | (s) | (ft) | (s) | (ft) | (s) | (ft) | (s) | (ft) | (s) | (ft) | (s) | (ft) | (s) |
| 5 | 0.23 | 1.10 | 0.30 | 1.25 | 0.37 | 1.40 | 0.39 | 1.47 | 0.45 | 1.61 | 0.44 | 1.57 | 0.42 | 1.53 | 0.42 | 1.52 | 0.36 | 1.41 |
| 10 | 0.57 | 1.63 | 0.75 | 1.92 | 0.97 | 2.18 | 1.14 | 2.39 | 1.64 | 2.89 | 1.48 | 2.74 | 1.33 | 2.59 | 1.29 | 2.54 | 1.01 | 2.23 |
| 15 | 0.88 | 1.95 | 1.12 | 2.33 | 1.51 | 2.65 | 1.84 | 2.94 | 2.74 | 3.68 | 2.42 | 3.44 | 2.14 | 3.22 | 2.06 | 3.15 | 1.62 | 2.72 |
| 20 | 1.17 | 2.19 | 1.44 | 2.62 | 2.01 | 3.00 | 2.51 | 3.35 | 3.73 | 4.24 | 3.28 | 3.94 | 2.87 | 3.67 | 2.76 | 3.59 | 2.20 | 3.09 |
| 25 | 1.44 | 2.39 | 1.72 | 2.87 | 2.46 | 3.29 | 3.15 | 3.68 | 4.65 | 4.69 | 4.07 | 4.35 | 3.54 | 4.04 | 3.40 | 3.95 | 2.76 | 3.40 |
| 30 | 1.69 | 2.56 | 1.97 | 3.07 | 2.87 | 3.54 | 3.75 | 3.96 | 5.49 | 5.07 | 4.80 | 4.69 | 4.16 | 4.36 | 4.00 | 4.26 | 3.29 | 3.66 |
| 35 | 1.92 | 2.72 | 2.19 | 3.25 | 3.26 | 3.76 | 4.32 | 4.22 | 6.28 | 5.40 | 5.49 | 5.00 | 4.73 | 4.63 | 4.55 | 4.53 | 3.79 | 3.89 |
| 40 | 2.14 | 2.86 | 2.39 | 3.41 | 3.60 | 3.95 | 4.86 | 4.44 | 7.01 | 5.69 | 6.13 | 5.27 | 5.26 | 4.88 | 5.06 | 4.77 | 4.27 | 4.10 |
| 45 | 2.35 | 2.98 | 2.58 | 3.56 | 3.92 | 4.12 | 5.38 | 4.65 | 7.70 | 5.96 | 6.72 | 5.52 | 5.76 | 5.11 | 5.54 | 4.99 | 4.70 | 4.28 |
| 50 | 2.54 | 3.10 | 2.76 | 3.70 | 4.23 | 4.28 | 5.86 | 4.84 | 8.36 | 6.21 | 7.29 | 5.75 | 6.24 | 5.32 | 6.00 | 5.20 | 5.12 | 4.45 |
| 55 | 2.73 | 3.21 | 2.94 | 3.82 | 4.51 | 4.43 | 6.31 | 5.02 | 8.97 | 6.44 | 7.83 | 5.96 | 6.68 | 5.51 | 6.43 | 5.39 | 5.51 | 4.61 |
| 60 | 2.90 | 3.32 | 3.10 | 3.94 | 4.79 | 4.58 | 6.74 | 5.18 | 9.56 | 6.66 | 8.34 | 6.16 | 7.11 | 5.70 | 6.84 | 5.57 | 5.89 | 4.76 |
| 65 | 3.07 | 3.41 | 3.25 | 4.05 | 5.05 | 4.71 | 7.15 | 5.34 | 10.12 | 6.87 | 8.83 | 6.35 | 7.51 | 5.87 | 7.21 | 5.73 | 6.25 | 4.90 |
| 70 | 3.23 | 3.51 | 3.40 | 4.16 | 5.30 | 4.84 | 7.54 | 5.48 | 10.66 | 7.06 | 9.29 | 6.52 | 7.89 | 6.03 | 7.57 | 5.88 | 6.60 | 5.04 |
| 75 | 3.39 | 3.60 | 3.55 | 4.26 | 5.54 | 4.96 | 7.92 | 5.62 | 11.18 | 7.24 | 9.74 | 6.69 | 8.25 | 6.18 | 7.92 | 6.03 | 6.93 | 5.17 |
| 80 | 3.54 | 3.68 | 3.69 | 4.36 | 5.77 | 5.07 | 8.29 | 5.75 | 11.68 | 7.42 | 10.18 | 6.86 | 8.60 | 6.32 | 8.26 | 6.17 | 7.26 | 5.29 |
| 85 | 3.68 | 3.76 | 3.82 | 4.45 | 5.99 | 5.18 | 8.64 | 5.88 | 12.16 | 7.59 | 10.59 | 7.01 | 8.94 | 6.46 | 8.58 | 6.30 | 7.57 | 5.41 |
| 90 | 3.82 | 3.84 | 3.96 | 4.54 | 6.21 | 5.29 | 8.98 | 6.00 | 12.63 | 7.75 | 10.98 | 7.15 | 9.26 | 6.59 | 8.89 | 6.43 | 7.87 | 5.52 |
| 95 | 3.96 | 3.92 | 4.09 | 4.62 | 6.42 | 5.39 | 9.31 | 6.12 | 13.09 | 7.90 | 11.36 | 7.29 | 9.58 | 6.72 | 9.20 | 6.56 | 8.16 | 5.63 |
| 100 | 4.09 | 3.99 | 4.21 | 4.71 | 6.63 | 5.49 | 9.63 | 6.24 | 13.53 | 8.05 | 11.73 | 7.42 | 9.89 | 6.84 | 9.49 | 6.68 | 8.44 | 5.73 |
| 105 | 4.22 | 4.06 | 4.34 | 4.79 | 6.83 | 5.58 | 9.94 | 6.35 | 13.96 | 8.20 | 12.09 | 7.55 | 10.19 | 6.96 | 9.78 | 6.79 | 8.72 | 5.84 |
| 110 | 4.35 | 4.13 | 4.46 | 4.86 | 7.02 | 5.67 | 10.25 | 6.45 | 14.37 | 8.33 | 12.45 | 7.68 | 10.48 | 7.07 | 10.06 | 6.90 | 8.99 | 5.93 |
| 115 | 4.47 | 4.19 | 4.58 | 4.94 | 7.22 | 5.76 | 10.54 | 6.56 | 14.76 | 8.47 | 12.79 | 7.80 | 10.77 | 7.18 | 10.34 | 7.01 | 9.25 | 6.03 |
| 120 | 4.59 | 4.26 | 4.69 | 5.01 | 7.40 | 5.85 | 10.83 | 6.66 | 15.15 | 8.59 | 13.13 | 7.92 | 11.05 | 7.29 | 10.61 | 7.12 | 9.51 | 6.12 |
| 125 | 4.70 | 4.32 | 4.81 | 5.08 | 7.59 | 5.94 | 11.12 | 6.76 | 15.53 | 8.72 | 13.46 | 8.03 | 11.32 | 7.40 | 10.87 | 7.22 | 9.76 | 6.21 |
| 130 | 4.82 | 4.38 | 4.92 | 5.15 | 7.77 | 6.02 | 11.39 | 6.85 | 15.91 | 8.84 | 13.78 | 8.14 | 11.59 | 7.50 | 11.13 | 7.32 | 10.00 | 6.30 |
| 135 | 4.93 | 4.44 | 5.03 | 5.22 | 7.95 | 6.10 | 11.67 | 6.94 | 16.27 | 8.95 | 14.10 | 8.25 | 11.86 | 7.60 | 11.39 | 7.42 | 10.24 | 6.39 |
| 140 | 5.04 | 4.50 | 5.14 | 5.28 | 8.12 | 6.18 | 11.93 | 7.03 | 16.63 | 9.07 | 14.41 | 8.35 | 12.12 | 7.69 | 11.64 | 7.51 | 10.48 | 6.47 |
| 145 | 5.15 | 4.56 | 5.24 | 5.34 | 8.29 | 6.25 | 12.19 | 7.12 | 16.98 | 9.18 | 14.71 | 8.46 | 12.37 | 7.79 | 11.88 | 7.60 | 10.71 | 6.55 |
| 150 | 5.26 | 4.61 | 5.35 | 5.41 | 8.46 | 6.33 | 12.45 | 7.21 | 17.33 | 9.29 | 15.01 | 8.56 | 12.63 | 7.88 | 12.13 | 7.69 | 10.94 | 6.63 |
| 155 | 5.36 | 4.67 | 5.45 | 5.47 | 8.63 | 6.40 | 12.71 | 7.29 | 17.67 | 9.39 | 15.31 | 8.65 | 12.88 | 7.97 | 12.36 | 7.78 | 11.16 | 6.71 |
| 160 | 5.47 | 4.72 | 5.56 | 5.53 | 8.79 | 6.47 | 12.95 | 7.38 | 18.01 | 9.50 | 15.60 | 8.75 | 13.12 | 8.06 | 12.60 | 7.87 | 11.38 | 6.79 |
| 165 | 5.57 | 4.77 | 5.66 | 5.58 | 8.95 | 6.54 | 13.20 | 7.46 | 18.34 | 9.60 | 15.89 | 8.84 | 13.36 | 8.15 | 12.83 | 7.95 | 11.60 | 6.86 |
| 170 | 5.67 | 4.83 | 5.76 | 5.64 | 9.11 | 6.61 | 13.44 | 7.54 | 18.67 | 9.70 | 16.18 | 8.94 | 13.60 | 8.23 | 13.06 | 8.03 | 11.81 | 6.94 |
| 175 | 5.78 | 4.88 | 5.86 | 5.70 | 9.27 | 6.68 | 13.68 | 7.62 | 19.00 | 9.80 | 16.46 | 9.03 | 13.84 | 8.31 | 13.29 | 8.12 | 12.02 | 7.01 |
| 180 | 5.88 | 4.93 | 5.95 | 5.75 | 9.43 | 6.74 | 13.92 | 7.69 | 19.32 | 9.89 | 16.73 | 9.12 | 14.07 | 8.40 | 13.51 | 8.20 | 12.23 | 7.08 |
| 185 | 5.98 | 4.98 | 6.05 | 5.81 | 9.58 | 6.81 | 14.15 | 7.77 | 19.63 | 9.99 | 17.01 | 9.20 | 14.30 | 8.48 | 13.73 | 8.27 | 12.43 | 7.15 |
| 190 | 6.08 | 5.03 | 6.15 | 5.86 | 9.73 | 6.87 | 14.38 | 7.84 | 19.94 | 10.08 | 17.28 | 9.29 | 14.52 | 8.55 | 13.95 | 8.35 | 12.64 | 7.22 |
| 195 | 6.18 | 5.08 | 6.24 | 5.91 | 9.88 | 6.93 | 14.60 | 7.91 | 20.25 | 10.17 | 17.55 | 9.37 | 14.75 | 8.63 | 14.16 | 8.43 | 12.84 | 7.28 |
| 200 | 6.28 | 5.13 | 6.33 | 5.96 | 10.03 | 6.99 | 14.83 | 7.98 | 20.56 | 10.26 | 17.81 | 9.45 | 14.97 | 8.71 | 14.38 | 8.50 | 13.03 | 7.35 |

## WATER LEVELS

### Sea Level Rise

Sea levels are rising globally. Historical sea levels at Cape May, NJ have been rising at an average rate of about 4.63 mm per year. See Figure 13. At this rate, sea level will be 0.76 feet or 9.1 inches above current levels in 50 years.

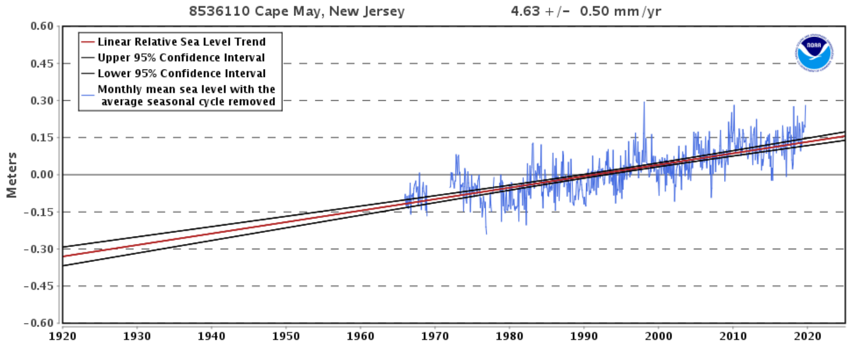

Figure 13 Historical Sea Levels at Cape May Ferry Terminal, Cape May, NJ.

### Astronomical Tides

Tidal data were obtained from NOAA's web site for Station 8536931 at Fortescue Creek, NJ. Tidal datums are shown in Figure 14. Mean Lower Low Water (MLLW) is 3.22 feet below the North American Vertical Datum of 1988 (NAVD88) while Mean Higher High Water (MHHW) is 3.2 feet above NAVD88. The mean range is 5.85 feet and the spring range is 6.42 feet. Mean Sea Level (MSL) is 0.03 feet below NAVD88.

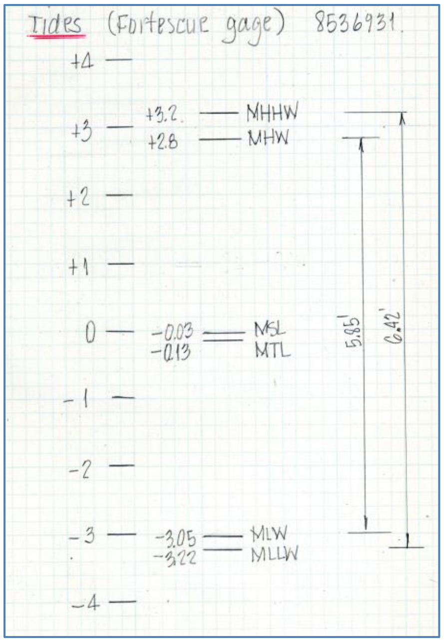

Figure 14 Tidal Datums at Fortescue Creek, NJ.

**Storm Tides**

Storm surge data for various return periods were obtained from FEMA from the Cumberland County Flood Insurance Study (FEMA, 2016). They are based on a post-hurricane *Sandy* analysis. Surge levels are summarized in Figure 15. The water level with 1% chance of being exceeded in any year (a return period of 100 years) is +8.6 feet above NAVD88. Table 3 presents surge levels interpolated from the regression equation given on Figure 15.

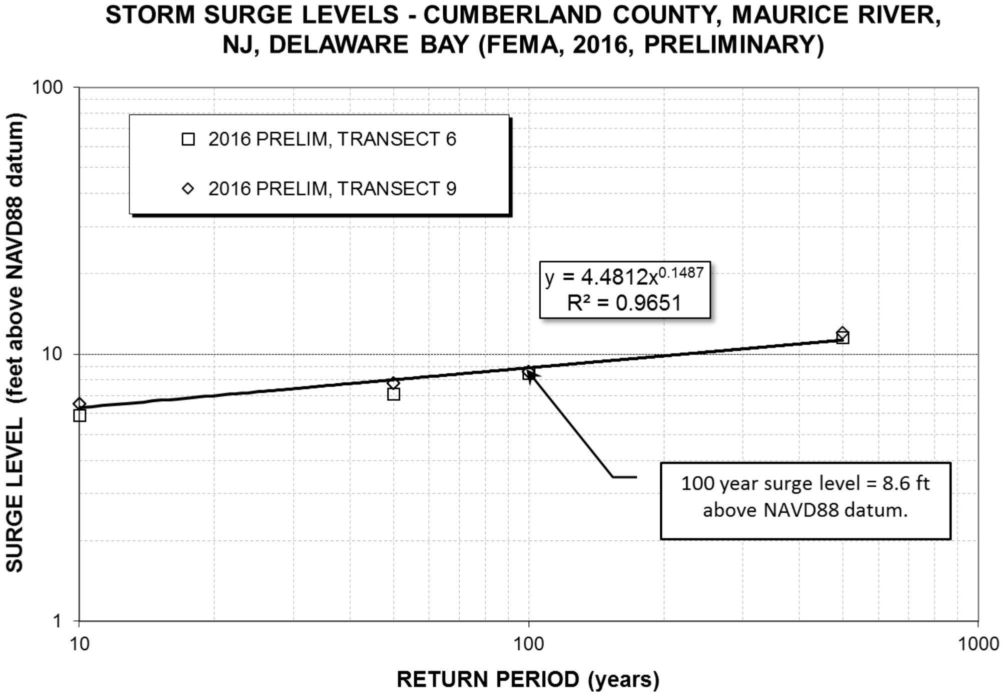

Figure 15 Predicted Storm Surge at Basket Flats, Maurice River. (Data from Cumberland County Flood Insurance Study, Transects 6 &9, FEMA, 2016.)

Table 3 Interpolated Surge Levels at Basket Flats, Maurice River (based on Transects 6 & 9, Cumberland County Flood Insurance Study, FEMA, 2016.)

| Return Period (years) | Surge Level (feet above NAVD88 datum) |
|---|---|
| 1 | 4.48 |
| 2 | 4.97 |
| 5 | 5.69 |
| 10 | 6.31 |
| 20 | 7.00 |
| 50 | 8.02 |
| 100 | 8.88 |

## PROFILES

Profiles across Basket Flats were obtained by the Stockton University Coastal Research Center. The location of the profiles are shown in Figure 16 and the profiles are shown in Figure 17. A composite profile constructed to approximate lines 7+00, 12+00, 17+00 and 21+00 is also shown on Figure 17.

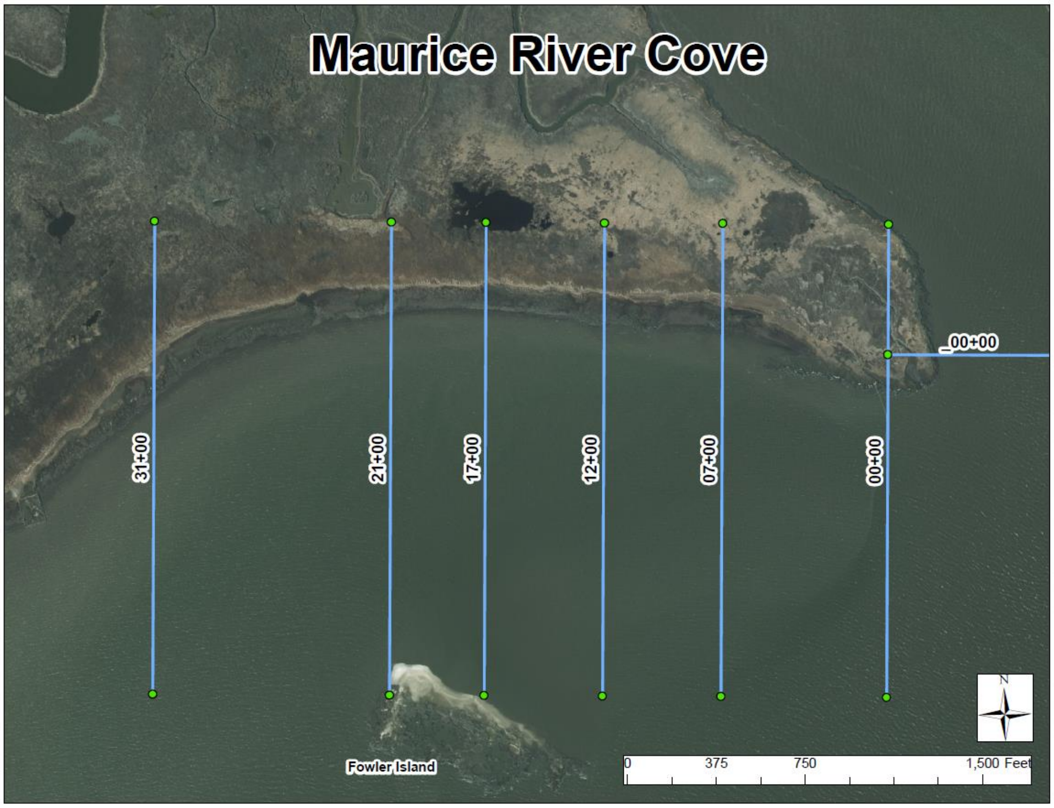

Figure 16 Location of Basket Flats Profiles.

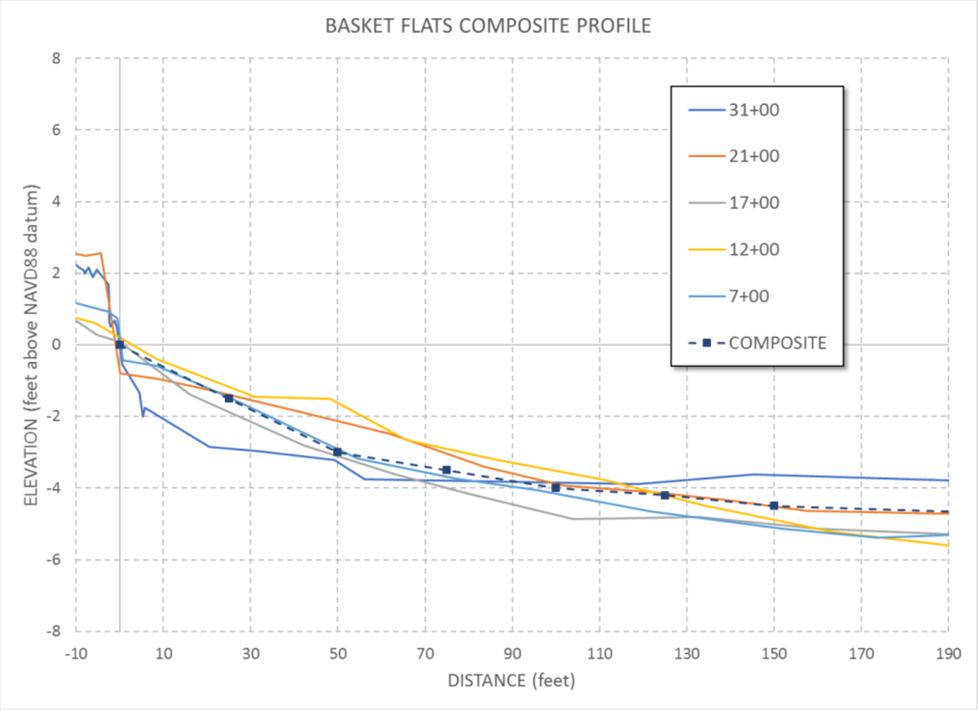

Figure 17 Basket Flats Profiles.

# BREAKWATER AND REVETMENT DESIGNS

## Breakwater Concept Design

Reef-type breakwaters are comprised of a relatively uniform size stone. In contrast to layered rubble mound structures, reef breakwaters are easier to construct since they are stone simply dumped onto a foundation mat. They are also easier to repair in the event of damage. The cross-section of a reef breakwater will deform and the crest elevation will be lowered when design wave conditions are exceeded; however, they continue to provide some protection albeit wave transmission is increased. A typical reef breakwater cross-section is shown in Figure 18.

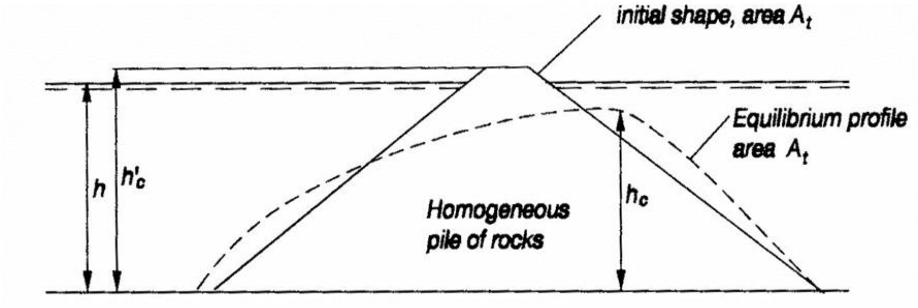

Figure 18 Typical Reef Breakwater Showing Initial and Deformed Cross-Sections.

In the present design the foundation for a series of detached nearshore breakwaters will be provided by a Tensar® mat. See Figure 19. Like gabions, Tensar® mats are stone filled containers; however, the containers are plastic geogrids filled with stones approximately 3 inches in diameter. As a foundation they are usually constructed with a geotextile filter on the bottom. They are about 1 foot thick, 10 feet wide and 20 feet long although they can be constructed to most any size area. Their size is usually constrained by the construction equipment needed to place them.

Figure 19 Tensar® Mat Being Installed.

The nearshore reef breakwaters will be 200 feet long with 25-foot-wide gaps between them. They will be 100 feet offshore of the original shoreline. See Figure 20 for the proposed breakwater layout. Their purpose is to provide shore protection and prevent erosion so that salt marsh vegetation can be established and maintained behind them. Such breakwater systems also can provide protection to sandy beaches that are conducive to horseshoe crab breeding. The rock can provide a substrate for oysters. The sheltered area behind the breakwaters also can be layered with shell fragments to provide oyster substrate.

The stone size selected for the breakwaters was based on the maximum size opening between the stones. A maximum opening of 0.5 feet precludes horseshoe crabs from becoming trapped. Assuming spherical stones, the largest stone weight providing a 0.5-foot opening is about 285 lbs. A spherical stone weighing 285 lbs. has a diameter of about 1.2 feet. Assuming the 285 lb. stone is at the upper end of a typical allowable stone size distribution, the median stone size will be 230 lbs. Thus,

$$0.75(230) \text{ lbs} < W < 1.25(230) \text{ lbs.}$$

$$170 \text{ lbs.} < W < 285 \text{ lbs.}$$

in which $W$ = the weight of the stone in pounds and the coefficients 0.75 and 1.25 are an allowable range of stone weights. In terms of size, the diameters will range between 1.0 to 1.2 feet or 12 to 14.5 inches.

Figure 20 Layout of Detached Offshore Reef Breakwaters, Basket Flats.

The cross-section of the proposed reef breakwater is shown in Figure 21. The foundation will be at about -4.0 NAVD88 with the base of the reef at -3.0. The location of the breakwaters on the prevailing beach profiles is shown in Figure 22. The crest elevation initially will be at +4.0. That crest elevation will be lowered depending on the level of wave action the reef experiences.

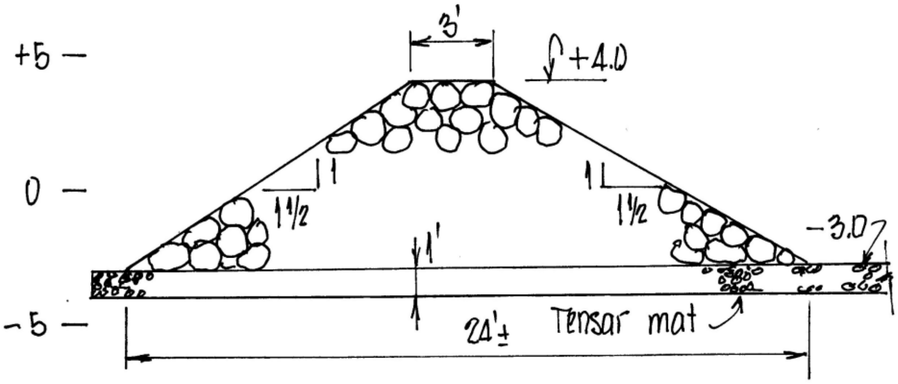

Figure 21 Typical Reef Breakwater Cross-Section.

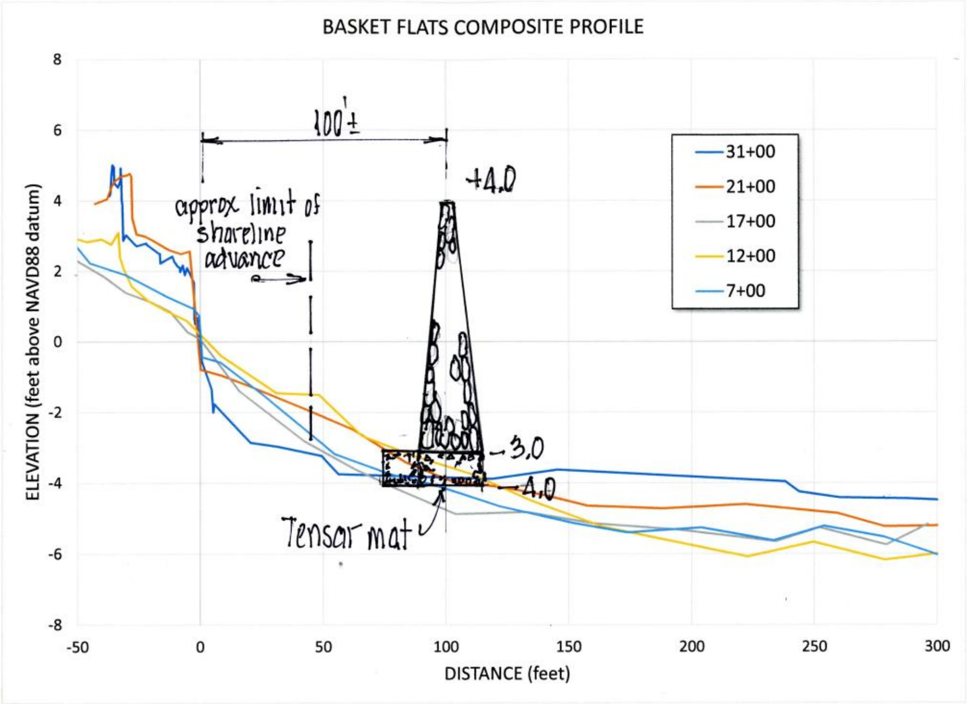

Figure 22 Breakwater Cross-Section Shown on Basket Flats Profiles.

The response of the shoreline to the breakwaters is shown in Figure 23. The shoreline will reorient itself in response to wave energy passing through the gaps. The breakwater/gap system will intercept 89% of the incident wave energy. Behind the breakwaters the shoreline will move out to form a salient while behind the gaps the shoreline will recede. Initially no beach or marsh material will be added to the system; consequently, the amount of accretion behind the breakwaters will balance the amount of recession behind the gaps. The method of Suh and Dalrymple (1987) (as presented in USACE, 1993) was used to determine how far the salient will extend from the original shoreline. The maximum distance selected for design was for it to be less than ½ the distance of the breakwaters from the original shoreline; the selected breakwater length/gap configuration results in a salient that extends 46 feet from the original shoreline. This leaves sufficient area in the lee of the breakwaters for future marsh planting and/or oyster bed establishment.

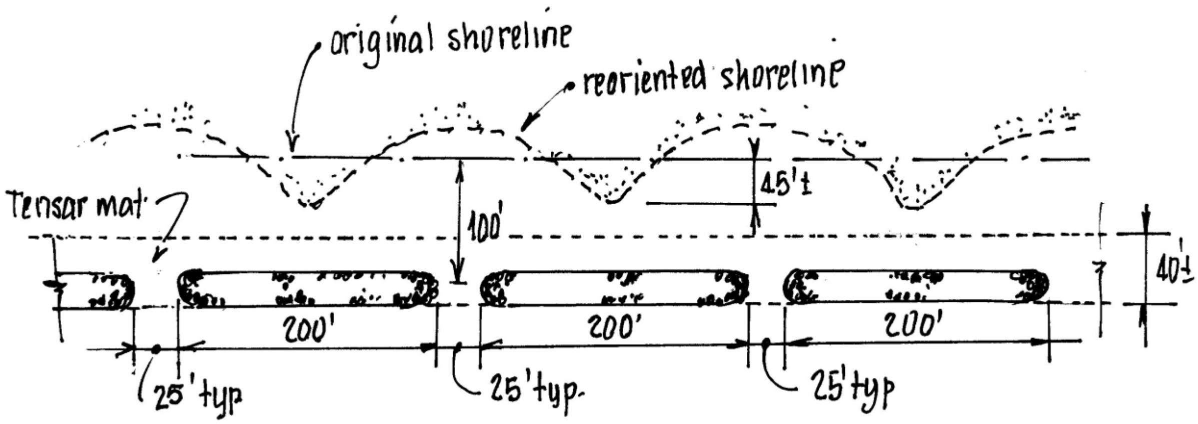

Figure 23 Layout Configuration of Detached Breakwaters.

Design for rare or unusual events is cost prohibitive; hence, wave and water level conditions for a range of water levels were evaluated for the design. For example, the 10-year event has a probability of 1 in 10 or 10% of occurring in any one year; however, the probability (risk) it will occur at least once a 10-year period is about 65%. Therefore, the proposed breakwater system will likely experience some damage during its lifetime. However, rubble mound structures are resilient and continue to provide protection even after sustaining some damage. They are also relatively simple to repair should it become necessary.

The response of the proposed reef breakwater to wave action was calculated using the analysis proposed by van der Meer (1990) as presented in the Corps' *Coastal Engineering Manual* (USACE, 2011). The method provides the reduction in crest elevation resulting from a given level of wave action. Wave transmission over the breakwaters was calculated using three methods: van der Meer (1991), Wiegel (1960) and Powell & Allsop (1985). Figure 24 presents the results for a wave period $T$ = 5 seconds and stone weighing 220 lbs. Wave heights on the figure are the maximum height sustainable for the given water depth. Waves break in shallow water when their height exceeds about 78% of the water depth; thus, a wave travelling in water 10 feet deep will have a maximum height of 7.8 feet. The prevailing water level therefore determines the maximum wave height. The 10-year water level in Maurice River Cove is about +6.3 feet NAVD88. If the breakwater base is founded at MLLW (-3.2 feet NAVD88) the 10-year water depth will be (6.3 + 3.2) = 9.5 feet and the maximum wave height will be 7.4 feet. Intermediate water depths will also occur as the water level increases up to the 10-year level. Figure 24 shows that for the 10-year water level of 6.3 feet, the incident wave height is about 7.3 feet. The original structure height of 7 feet is reduced to about 6 feet and the transmitted wave height is about 3.5 feet. (Note that the Powell & Allsop (1985) wave transmission value is used since it more closely describes the rubble structure type than the thin flat plate of the Wiegel (1960) structure.) Performance of the structure at 20-year and 50-year water level conditions is also good.

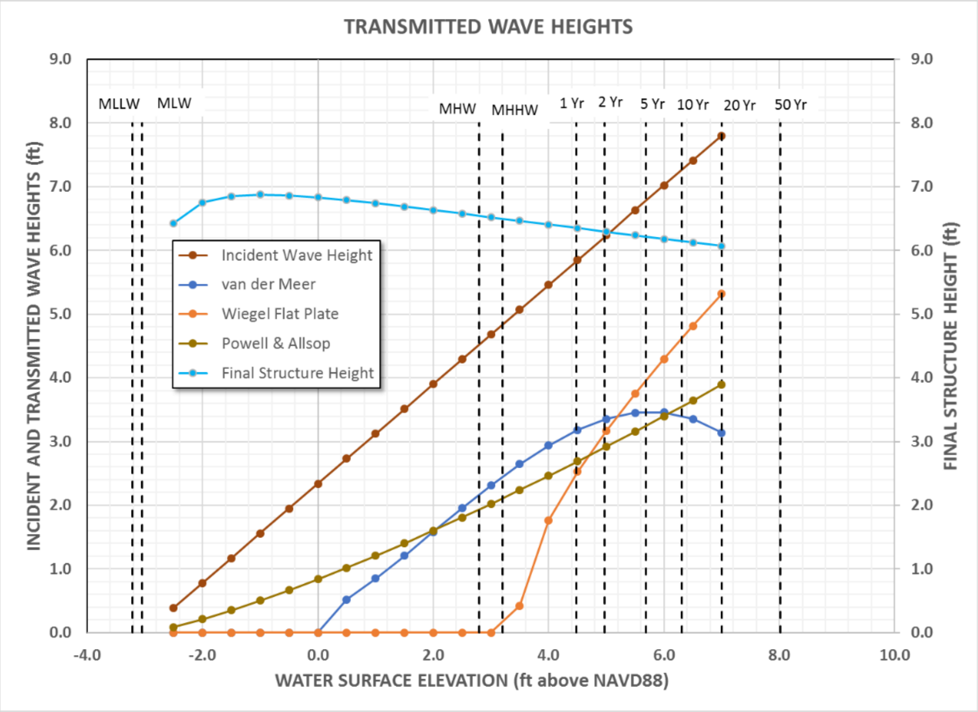

Figure 24 Behavior of Reef Breakwater for Various Levels of Wave Attack, $T$ = 5 sec, $W$ = 220 lbs.

## Revetment Design

To prevent erosion and stabilize the easterly end of Basket Flats, armoring by a revetment is proposed. Erosion of the end of Basket Flats would expose the town of Bivalve to direct attack by waves from the south – the longest fetch producing the largest waves. Figure 25 shows a cross-section of the proposed revetment. The toe is at elevation -6.0 NAVD88 datum. The crest is at +8.0. The design water level is the 20-year storm tide level of +7.0; hence, the design water depth is 13 feet yielding a breaking wave height of $H_{max}$ = 0.78(13.0) = 10.1 feet. This wave height is rare and would be associated with hurricane winds blowing from the south; it thus provides a conservative design. The revetment is shown on the prevailing profile in Figure 26.

Figure 27 presents the results of a stability analysis. Two procedures were used to calculate the weight of the armor stone needed to withstand design wave conditions. The Hudson (1974) equation (USACE, 2011) was applied for conditions when the water level is below the breakwater crest. Breaking wave heights associated with the shallower depths were used. The van der Meer (1991) procedure (USACE, 2011) was used for an overtopped and/or submerged structure. Figure 27 shows that the maximum armor stone weight of 8,000 pounds (4 tons) is needed for a water level of about +5.0 feet – about 2 feet below the design level. Note however, that as water levels increase during a storm the water level will pass through the critical +5.0-foot level.

The underlayer is comprised of stone weighing $W/10$ = 800 lbs. and a geotextile filter is provided beneath the structure. The range of stone weights is,

$$3 \text{ tons } < W < 5 \text{ tons}$$

or $$3.3 \text{ ft.} < d < 3.9 \text{ ft.}$$

The range of underlayer stone weights is,

$$0.3 \text{ ton } < W/10 < 0.5\, ton$$

or $$1.5\, ft < d_u < 1.8\, ft$$

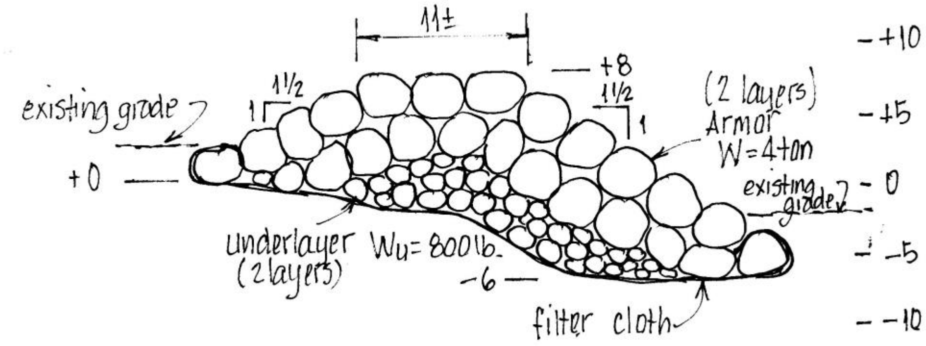

Figure 25 Typical Revetment Cross-section.

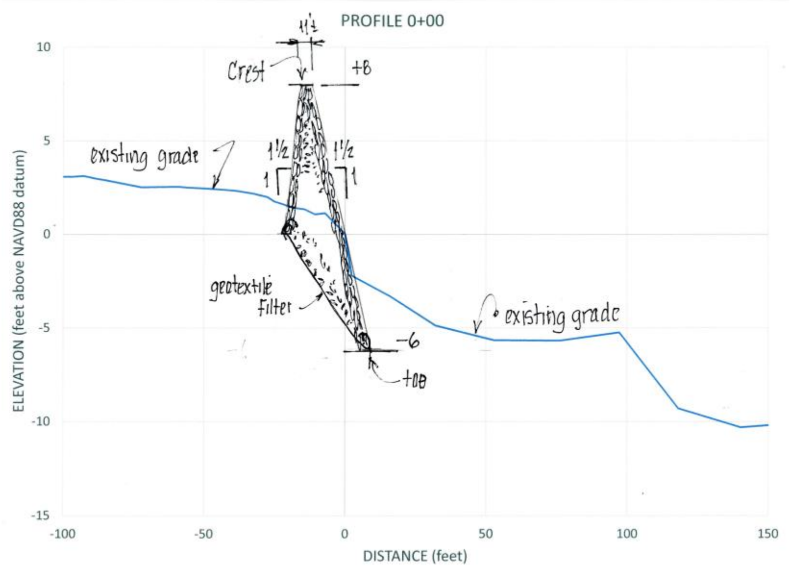

Figure 26 Typical Revetment Cross-Section and Prevailing Profile

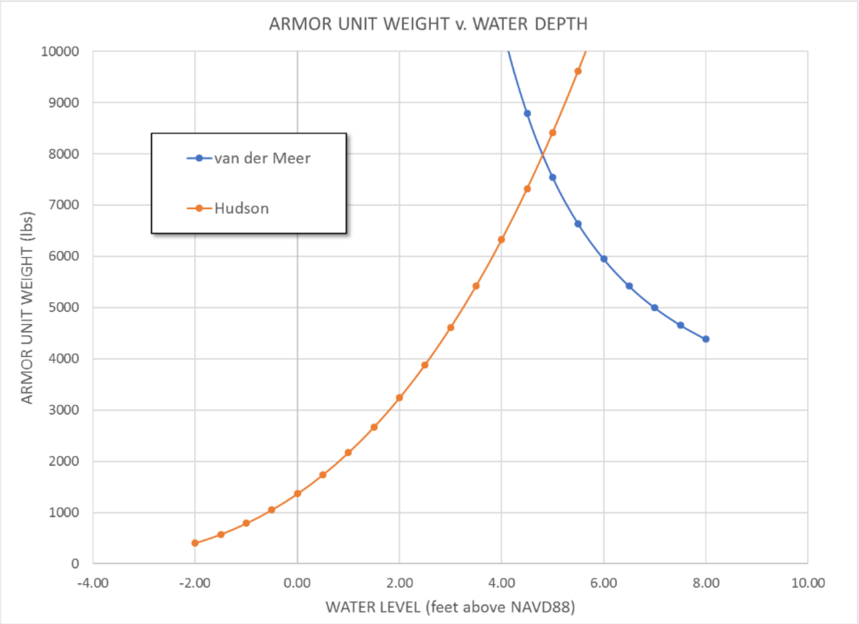

Figure 27  Revetment Armor Stone Weight v. Water Level.

The easterly revetment end is subject to wave action that could unravel the structure; consequently, a conical head is proposed with a flatter 1:2 slope. See Figure 28. A reinforced concrete sheet pile core will prevent the head from unraveling due to ebb and flood currents in the Maurice River. The breakwater head superimposed on the prevailing profile is shown in Figure 29. Note that the toe of the revetment head is at -8.0 NAVD88 while the toe of the revetment itself is at -6.0 NAVD88. The layout of the revetment and head are shown in Figure 30. Note that the revetment extends approximately 400 feet along the Basket Flats shoreline until it transitions into the area protected by the detached breakwaters. A detail of the breakwater head is shown in Figure 31.

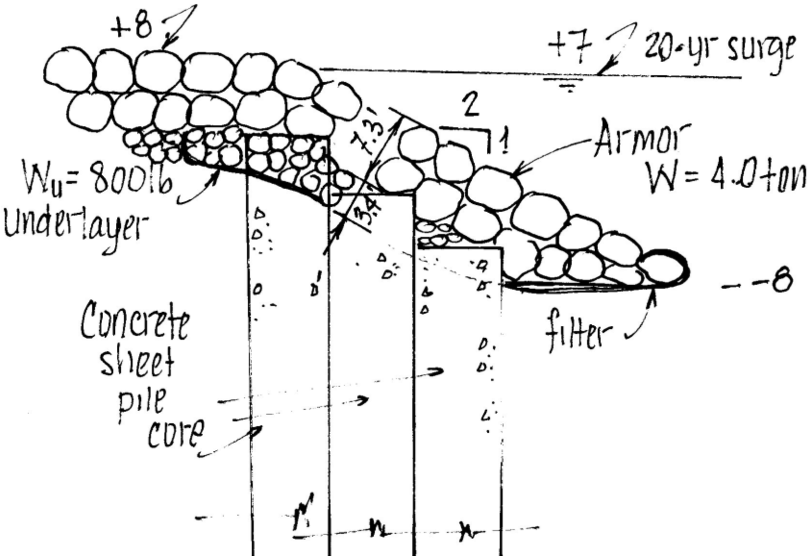

Figure 28 Typical Section Through Revetment Head.

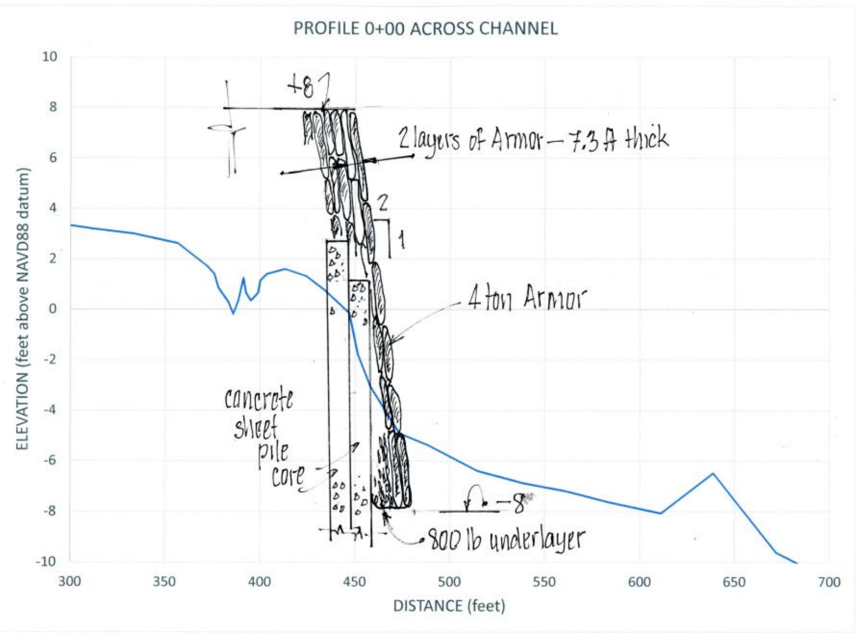

Figure 29 Revetment Head with Prevailing Cross-Section.

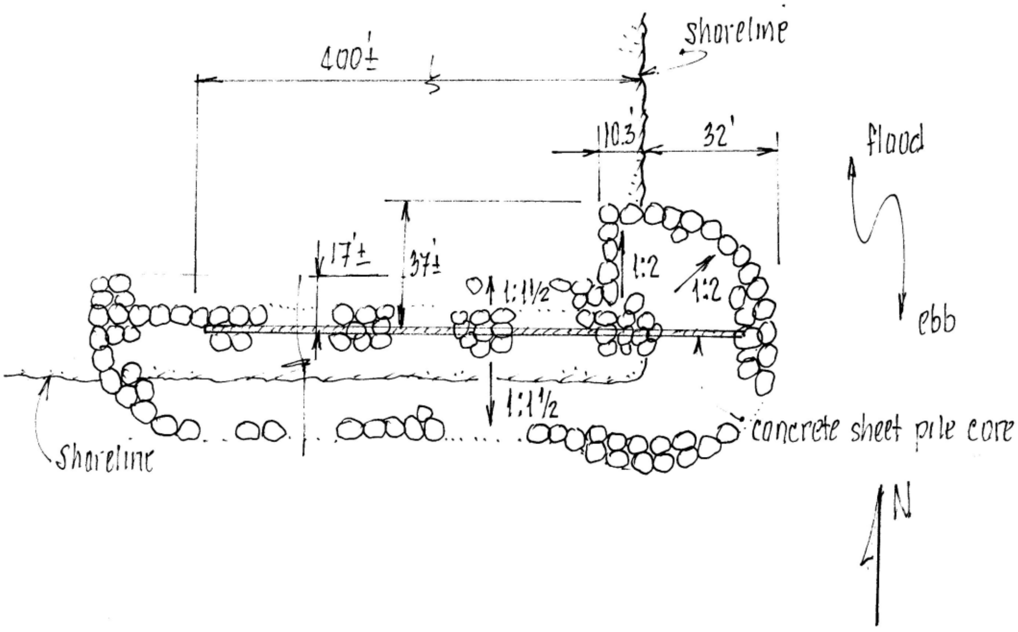

Figure 30 Layout of Revetment and Revetment Head

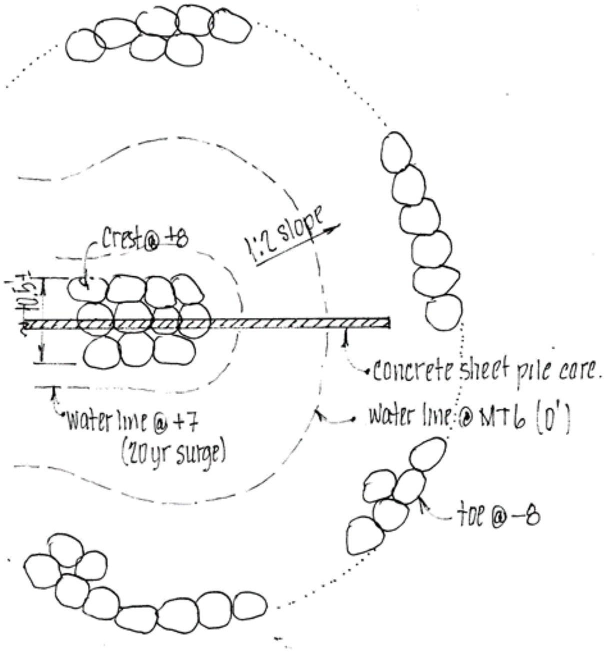

Figure 31 Detail of Plan View of Revetment Head.

Because the revetment crest is at +8.0 it will be overtopped during high water level events. Figure 32 provides an estimate of the wave heights in the lee of the revetment. The van der Meer (1991) wave transmission equation gives slightly higher transmitted wave heights than those based on a layered rubble structure. Figure 32 indicates that the transmitted wave height on top of the Basket Flats marsh on the leeward side of the revetment will be 6.0 feet during the 20-year surge. During this event, water on the leeward side of the revetment will be about 6.0 feet deep; hence transmitted waves will be “cushioned” by the water.

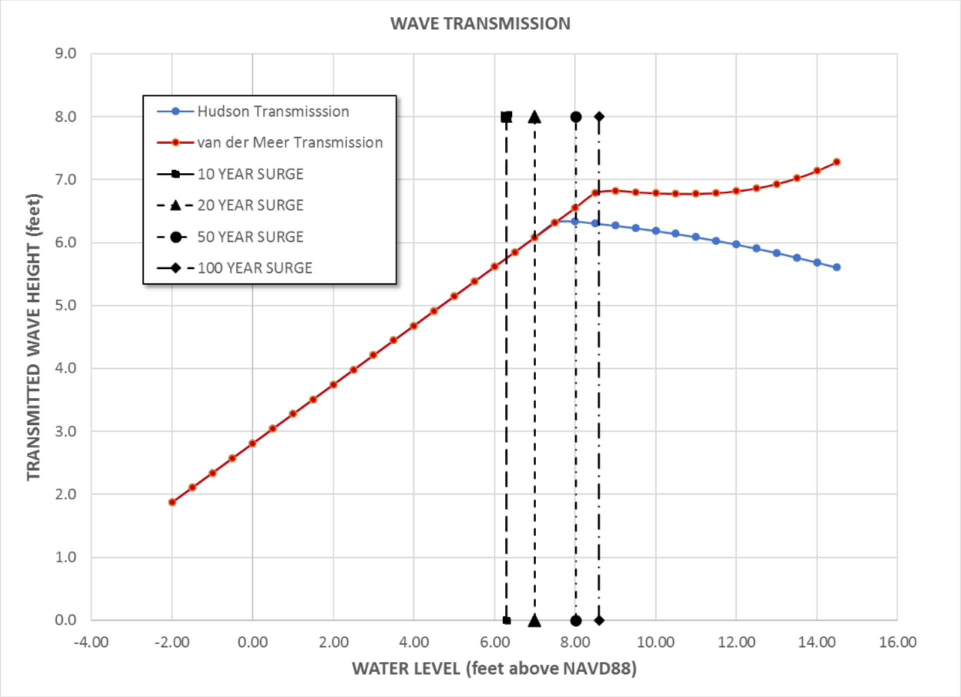

Figure 32 Wave Transmission over Revetment.

## Channel Side of Basket Flats

The channel side of Basket Flats is subject to river currents and consequently to erosion. Five profile lines across the channel were obtained by the Stockton University Coastal Research Center as shown in Figure 33. The lines do not extend onto land. The location of the profiles is shown in Figure 33 and the profiles are shown in Figure 34. The deep main channel is close to the Basket Flats side and the profiles are steep there. Details of the profiles on the Basket Flats side of the channel are shown in Figure 35. Moving eastward toward the tip of Basket Flats (Line 1 toward Line 5) the nearshore slopes become steeper: Line 1, $\Delta y/\Delta x = 0.222$; Line 2, $\Delta y/\Delta x = 0.169$; Line 3, $\Delta y/\Delta x = 0.116$; Line 4, $\Delta y/\Delta x = 0.0955$ and Line 5, $\Delta y/\Delta x = 0.0527$. Consequently, the channel side of Basket Flats shows more erosion at its westward end. While the present project does not propose protection for the channel side of Basket Flats, it may prove necessary in the future.

Figure 33 Maurice River Channel Survey Lines (Lines 1 through 5 from Left to Right)

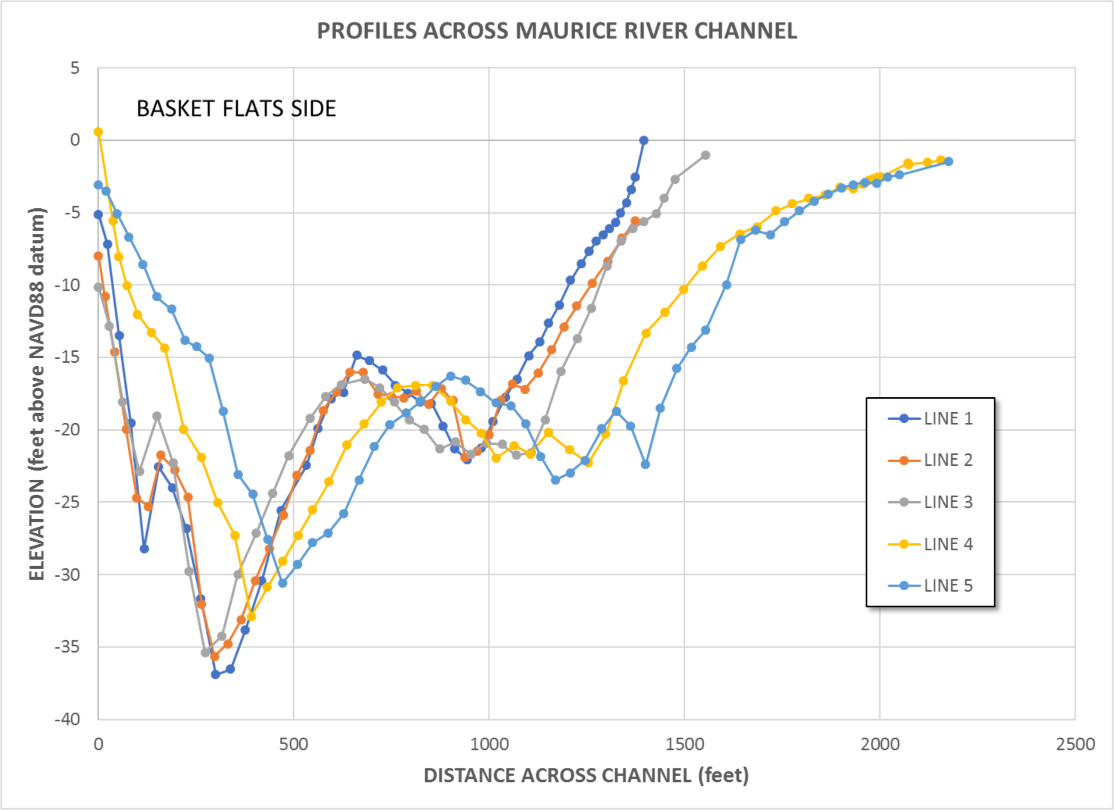

Figure 34 Profiles Across Maurice River Channel Behind Basket Flats.

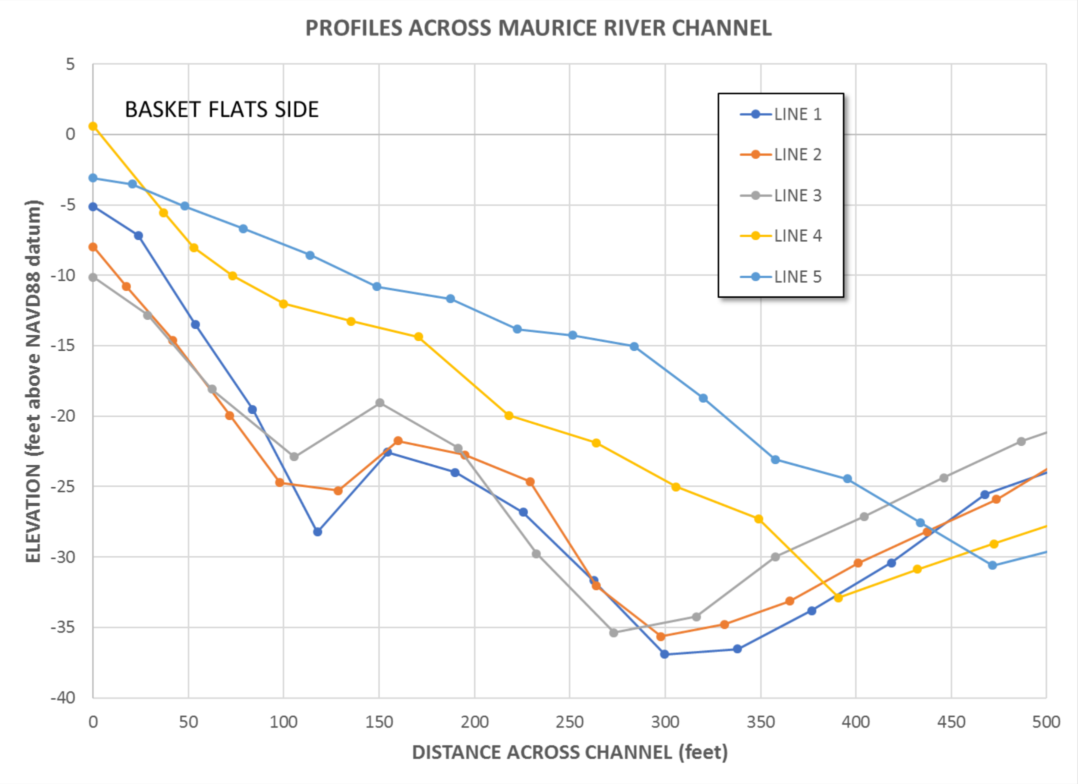

Figure 35  Detail of Profiles Across Maurice River Channel Behind Basket Flats.

## SUMMARY AND CONCLUSION

To prevent further erosion of Basket Flats and to provide for future marsh enhancement, a series of nine nearshore, detached breakwaters is proposed. The detached breakwaters would be constructed of uniform size rock weighing about 230 lbs. (170 lbs. < *W* < 285 lbs.) founded on Tensar® mats. The opening between stones will be less than about 0.5 foot to preclude horseshoe crabs from getting trapped. The breakwaters would be 200 feet long with 25-foot wide gaps between them. Their crest elevation will be at +4.0 feet NAVD88 datum. The base of the breakwaters will be at -3.0 feet. The base of the Tensar® mats beneath the breakwaters will be at -4.0 feet.

To protect the easterly end of Basket Flats a revetment is proposed. A revetment is necessary to prevent erosion of the easterly end of the Basket Flats spit. If Basket Flats erodes further, the town of Bivalve will be vulnerable to severe wave attack by waves from the south - the longest fetch. The rubble mound revetment will have a two-layer cross-section with 4-ton (3 ton < *W* < 5 ton) armor underlain with 800 lb. stone. The crest elevation will be +8.0 feet and the bottom at -6.0 feet. The revetment will be overtopped by waves during high water events; however, the water depth on the leeward side (about 6.0 feet) will cushion the marsh of the impact by overtopping waves. The base of the revetment head will be at -8.0 NAVD88 datum.

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