Mean High Water Contour Determination for the Beaches of the Carteret County Shore Protection Surveys

Prepared for:

Caretet County Shore Protection Office
www.ProtectTheBeach.com

Prepared by:

Geodynamics LLC.
310 A Greenfield Drive
Newport, NC 28570
www.GeodynamicsGroup.com

May 12, 2017

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 PREFACE & INTRODUCTION

1.1 Purpose

Analysis of the Mean High Water (MHW) contour determination along the beaches studied by the Carteret County Shore Protection Office (Shackleford Banks, Bogue Banks and Bear Island) was performed in order to update the MHW contour elevation and provide documention on the process of identifying a single MHW contour elevation for each beach (Figure 1). Various shoreline change analysis and coastal geomorphology studies may directly reference the MHW contour and therefore a guideline to the most current and "useful" MHW contour determination was deemed necessary.

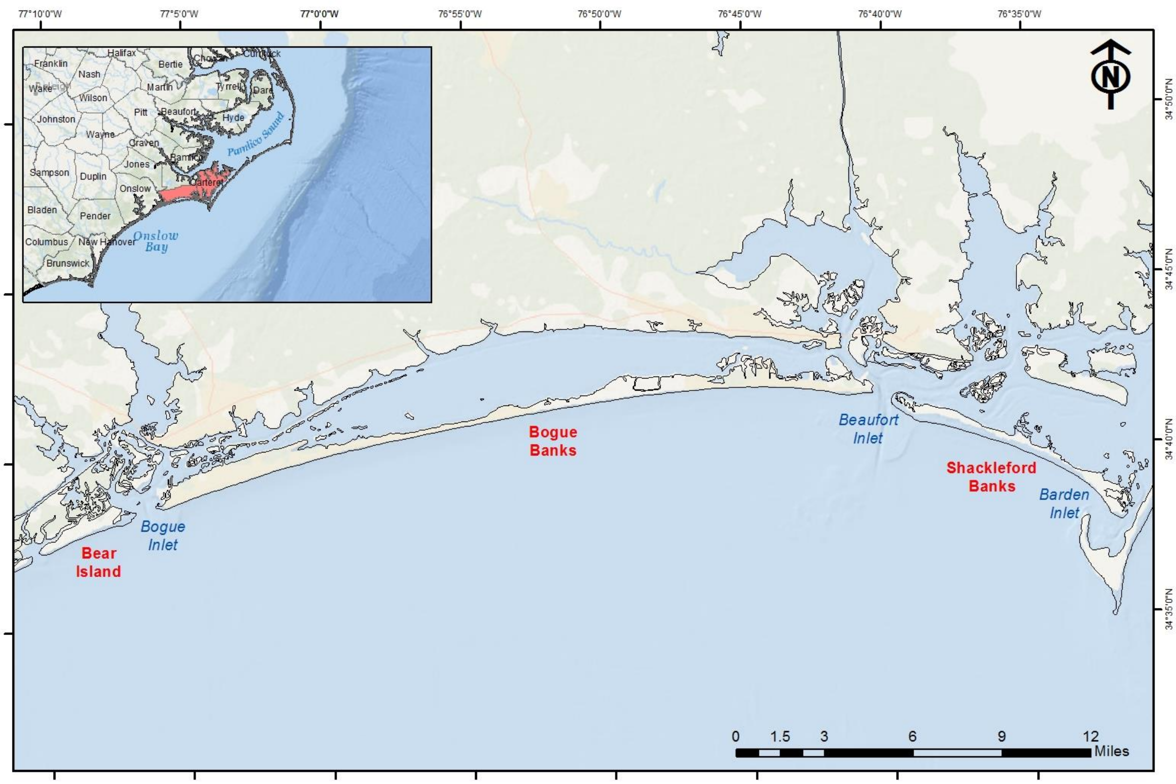

Figure 1. Map showing the location of Carteret County, NC (inset) and the islands studied by the CCSPO.

1.2 Introduction

As a means to study the changes and health of a given coastline, "the shoreline" is typically used as an indicator. While there has been extensive work and debate as to what "the shoreline" might be (wet-dry line, datum-derived contour or vegetation line for example), each project, analysis and shoreface might benefit from one shoreline definition or another (Figure 2). Carteret County Shore Protection Office's (CCSPO's) beach studies have historically used the MHW contour, a datum-derived shoreline, as an indicator of beach change.

Figure 2. Illustrated photograph showing various shoreline position indicators.

Over 2 decades ago, the MHW contour was defined as the contour of 1.1 ft in the North American Vertical Darum of 1988 (NAVD88). At that time, it appeared that the contour value was selected based on information from one single tidal datum station (865-6502, Morehead City Harbor) (Figure 3). Also at that time, there was little knowledge of other published tidal datum stations and no tidal datum models that exist for public use.

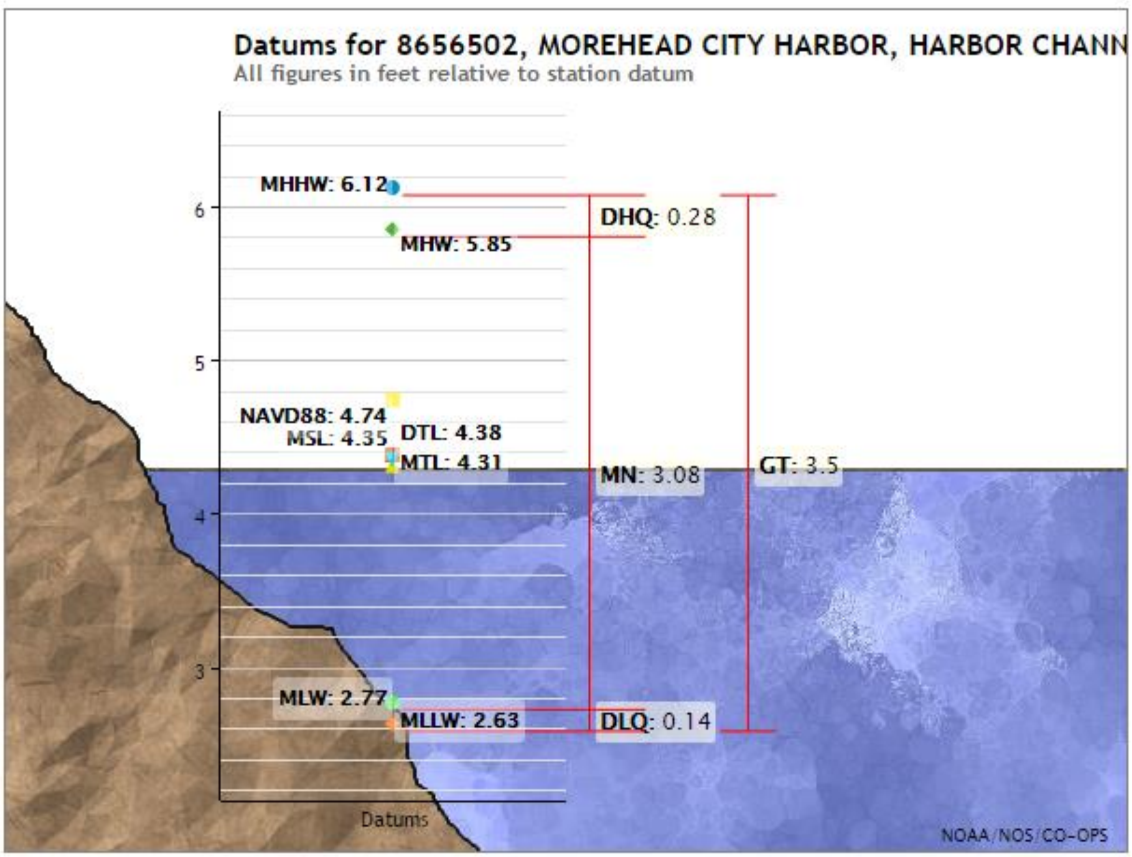

Figure 3. Diagram showing the datum separations for NOAA station 865-6502 (Morehead City Harbor)

Now, with advancements in tidal datum modeling, the addition of tidal datum stations and improved datum relationships, a better understanding of the spatial variations in the MHW contour elevation exists. Therefore, to improve the overall understanding of the datum-derived MHW contour shoreline, this determination project was initiated. This project was accomplished in 3 main stages:

1. Review and research the spatial variation of the MHW datum across each study area.
2. Determine a single elevation MHW contour value.
3. Convert historic shoreline datasets to the new MHW value.

The following sections of this document are intended to provide a general understanding of terminology and concepts related to datum-derived shorelines. These sections will outline the method by which the MHW contour value was determined and document the tools and processes utilized in each of the 3 main stages of the project listed above.

2.0 Tidal and Geodetic Datums

A vertical datum is technicallya surface of zero elevation to which heights of various points are referred such that those heights be in a consistent system. More broadly, a vertical datum is the entire system of the zero elevation surface and methods of determining heights relative to that surface. Over the years, many different types of vertical datums have been used. The most prevailing types today are tidal datums and geodetic datums (Vertical Datums, 2017). For more information, visit the National Geodectic Survey (NGS) website.

2.1.1 Tidal Datums

A tidal datum is a standard elevation defined by a certain phase of the tide. Tidal datums are used as references to measure local water levels and should not be extended into areas having differing oceanographic characteristics without substantiating measurements. In order that they may be recovered when needed, such datums are referenced to fixed points known as bench marks. Tidal datums are also the basis for establishing privately owned land, state owned land, territorial sea, exclusive economic zone, and high seas boundaries. Figure 4 below shows an illustration of various tidal datums and shoreline-related boundary locations. Below (Table 1) are definitions of tidal datums maintained by the Center for Operational Oceanographic Products and Services (NOAA Tides and Currents Online, 2017).

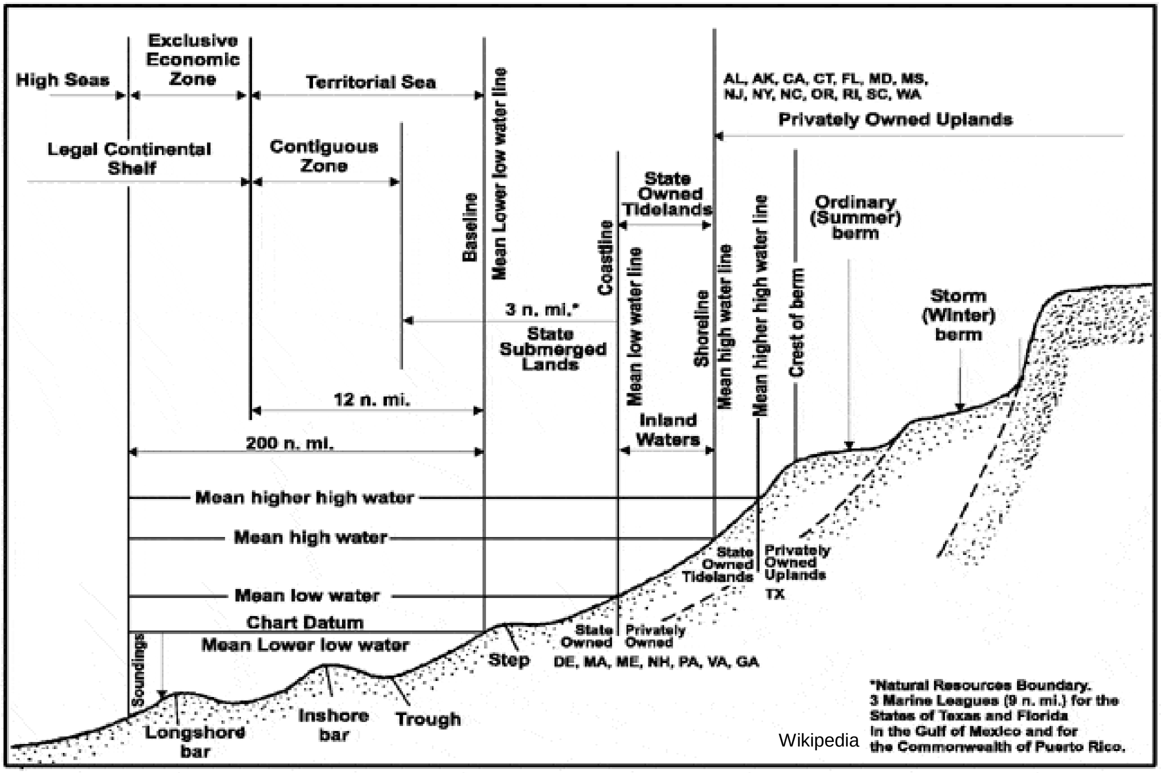

Figure 4. Diagram showing various water level datums and shoreline-related boundry locations.

Table 1. Table listing water level datums.

Highest Astronomical Tide (HAT)	The elevation of the highest predicted astronomical tide expected to occur at a specific tide station over the National Tidal Datum Epoch.
Mean Higher High Water (MHHW)	The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
MHW Mean High Water (MHW)	The average of all the high water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
Diurnal Tide Level (DTL)	The arithmetic mean of mean higher high water and mean lower low water.
Mean Tide Level (MTL)	The arithmetic mean of mean high water and mean low water.
Mean Sea Level (MSL)	The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. Shorter series are specified in the name; e.g. monthly mean sea level and yearly mean sea level.
Mean Low Water (MLW)	The average of all the low water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
Mean Lower Low Water (MLLW)	The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
Lowest Astronomical Tide (LAT)	The elevation of the lowest astronomical predicted tide expected to occur at a specific tide station over the National Tidal Datum Epoch.
Great Diurnal Range (GT)	The difference in height between mean higher high water and mean lower low water.
Mean Range of Tide (MN)	The difference in height between mean high water and mean low water.
Mean Diurnal High Water Inequality (DHQ)	The difference in height of the two high waters of each tidal day for a mixed or semidiurnal tide.
Mean Diurnal Low Water Inequality (DLQ)	The difference in height of the two low waters of each tidal day for a mixed or semidiurnal tide.
Greenwich High Water Interval (HWI)	The average interval (in hours) between the moon's transit over the Greenwich meridian and the following high water at a location.

Greenwich Low Water Interval (LWI)	The average interval (in hours) between the moon's transit over the Greenwich meridian and the following low water at a location.
Station Datum	A fixed base elevation at a tide station to which all water level measurements are referred. The datum is unique to each station and is established at a lower elevation than the water is ever expected to reach. It is referenced to the primary bench mark at the station and is held constant regardless of changes to the water level gauge or tide staff. The datum of tabulation is most often at the zero of the first tide staff installed.
National Tidal Datum Epoch	The specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present NTDE is 1983 through 2001 and is actively considered for revision every 20-25 years. Tidal datums in certain regions with anomolous sea level changes (Alaska, Gulf of Mexico) are calculated on a Modified 5-Year Epoch.

2.1.1 Geodetic Datums

Geodetic datums are predominantly determined through a process of surveying known as geodetic leveling, determining the height differences between points in the ground known as bench marks. These height differences can only yield actual heights at the benchmarks if at least one datum origin point is chosen to serve as the absolute level of the vertical datum. It is frequently the practice of those responsible for defining a geodetic datum, to choose a datum origin point that is also at a tide gage so a relationship between the tidal and geodetic datums exists, though this is by no means a requirement (NGS Vertical Datums, 2017).

North American Vertical Datum of 1988 (NAVD 88) consists of a leveling network on the North American Continent, ranging from Alaska, through Canada, across the United States, affixed to a single origin point on the continent:

- Tide Station & Location = Pointe-au-Pere,Rimouski, Quebec, Canada
- PID = TY5255
- GSD* Designation = 54L071 (* Geodetic Survey of Canada = GSD)
- Bench Mark = 1250 G
- Ht above LMSL(Meters) = 6.271

In 1993 NAVD 88 was affirmed as the official vertical datum in the National Spatial Reference System (NSRS) for the Conterminous United States and Alaska (see Federal Register Notice (FRN)). Although many papers on NAVD 88 exist, no single document serves as the official defining document for that datum (NGS Vertical Datums, 2017).

2.1.2 MHW Contour Datum Determination

Throughout the process of determining the single usable MHW contour elevation value for each island, the primary datums utilized were NAVD88 and MHW. As previously mentioned, making a direct relationship between the two datums can only happen when each datum is defined at a finite location. For this project, a few specific bench mark locations yielded existing and up-to-date datum relationships. These stations are listed below (Figure 5)and detailed information for each station can be accessed throught the NOAA Tides and Currents website (https://tidesandcurrents.noaa.gov/).

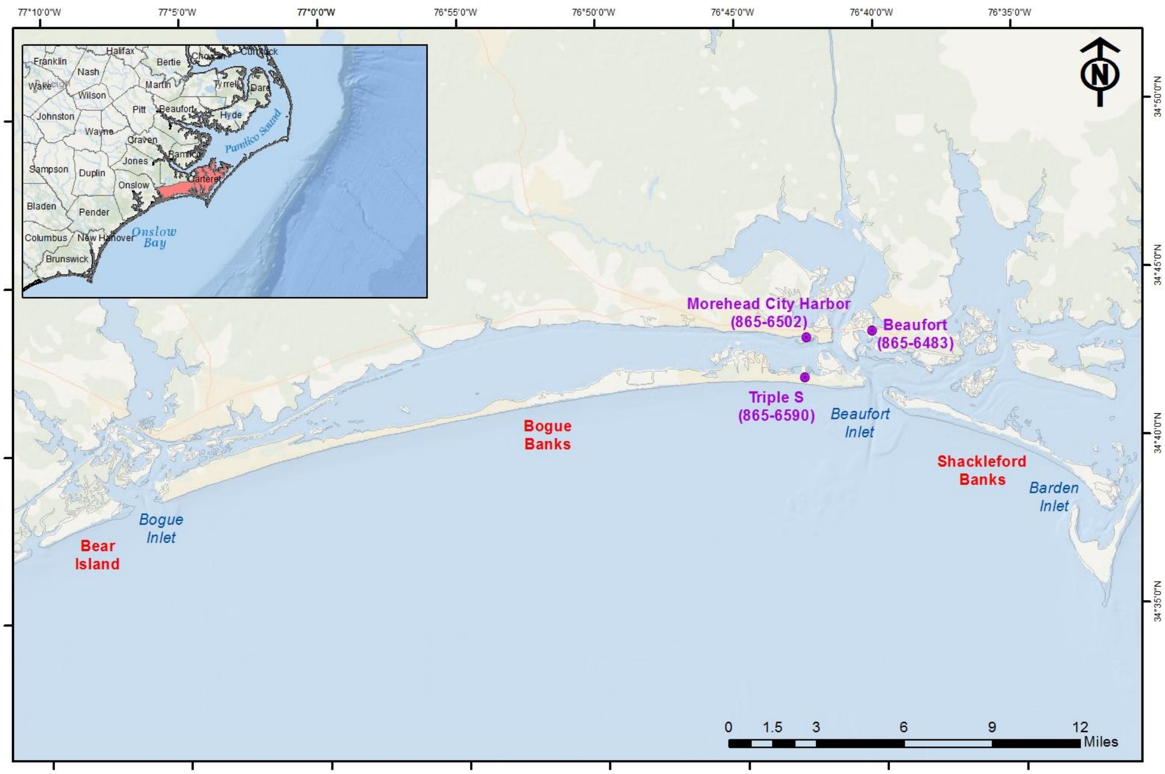

Figure 5. Map showing the location of each NOAA tide station with NAVD88-MLLW datum separations.

3.0 DATA SOURCES

In order to accomplish this project and update the existing database of county shorelines, data from a variety of sources needed to be assimilated. Information on the the datum relationships were obtained from NOAA while background into the previous MHW determiniation was acquired from the Carteret County Shore Protection Office. Geodynamics provided the information and data to develop the updated MHW contour determination, produce the updated shoreline GIS files, and contribute to this report.

3.1 NOAA

VDatum is a free software tool being developed jointly by NOAA's National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS). VDatum is designed to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums - allowing users to convert their data from different horizontal/vertical references into a common system and enabling the fusion of diverse geospatial data (NOAA VDatum, 2016).

3.2 Carteret County Shore Protection Office

The Carteret County Shore Protection Office serves as the main point-of-contact for all beach restoration/shore protection activities in Carteret County, directly interfacing with the local municipalities and County Board of Commissioners and provides staff support and guidance to the Carteret County Beach Commission. The CCSPO also performs the following role(s):

- Serve as principle liaison with the U.S. Army Corps of Engineers, federal Bureau of Ocean Energy Management, N.C. Division of Coastal Management, N.C. Division of

Water Resources, and other resource/permitting agencies regarding beach restoration/shore protection projects the County and local municipalities are undertaking.
- Where appropriate, represent the County on State, federal, and Non-Government Organization advisory boards and panels concerning matters pertaining to beach restoration, technology, and policy.
- Help oversee/coordinate County policy and legislative affairs, lobbying efforts, and communications with federal and State elected and appointed officials regarding all elements of coastal policy, including interactions with the County Board of Commissioners.
- Oversee monitoring efforts associated with permit compliance; and to ascertain the overall condition of the County's beaches for nourishment and inlet maintenance project planning while fulfilling FEMA's monitoring/maintenance requirements for engineered beaches.
- Serve as an information clearinghouse for science and policy matters related to beach restoration/shore protection in Carteret County and abroad.

3.3 Geodynamics, LLC

As a contractor for the CCSPO, Geodynamics performs yearly profile monitoring surveys, detailed site-specific surveys, maintains an online web mapping portal and consults with the CCSPO, the Beach Commision, and community on various coastal issues. As part of the yearly monitoring surveys, Geodynamics collects data in addition to the standard beach profiles to support mapping the Mean High Water (MHW) Contour across Bogue Banks. On Shackleford Banks and Bear Island, only profiles are collected. The shoreline data and profiles are gridded into a digital elevation model (DEM) from which the MHW contour is extracted. For more information on the survey and development of the MHW contour, please contact the CCSPO or Geodynamics to obtain a descriptive survey report. Geodynamics was tasked with this project as a means to update the MHW shoreline component of the yearly monitoring surveys and the existing database. Geodynamics performed the spatial assessment of the MHW-NAVD88 datum relationship using a GIS-based approach (see section 4.2). Once the datum relationship was developed, existing MHW contour shapefiles were updated to the proper MHW value.

4.0 CARTERET COUNTY MHWC SHORELINE ASSESSMENT

4.1 Methods

The assessment and determination of the MHWC relative to the NAVD88 datum was accomplished by an analysis primarily using NOAA's VDatum tool (integrated in Hypack 2014) and ESRI's GIS software. VDatum, as detailed in section 4.1, is a software tool that vertically transforms geospatial data among different datums. ESRI's Arc 10.5 software is a full GIS software platform for designing and managing solutions through the application of geographic knowledge and data (ESRI, 2017). The following section will describe, step-by-step, the method by which the MHWC was determined.

4.2 MHW-NAVD88 Determination

The following steps describe how a single value for the MHWC was determined for each island (Bogue Banks, Shackleford Banks and Bear Island):

1. Hypack 2014 with VDatum was used to extract an XYZ datum separation file, where X and Y are NC State Plane Coordinates (NAD83(2011), sft) and Z is the difference between NAVD88 and MHW in survey feet. The XYZ file was extracted to the extents of a Hypack border file encompansing each islands' shore face, including inlets. Each XYZ node produced from the VDatum extraction was spaced from 150 to 180 feet.

2. The XYZ file was then displayed in ArcGIS and color-coded based on datum separation values. It was determined that the majority of each island had a fairly steady/stable MHW separation value, but each end close to the inlets the separation was a minimum (east) and maximum (west) along each entire island (Figure 6).

3. The XYZ datum separation file was then reduced to the main portions of the islands, such that determining a single MHWC value would not be overly skewed by the separation range seen around the inlets.

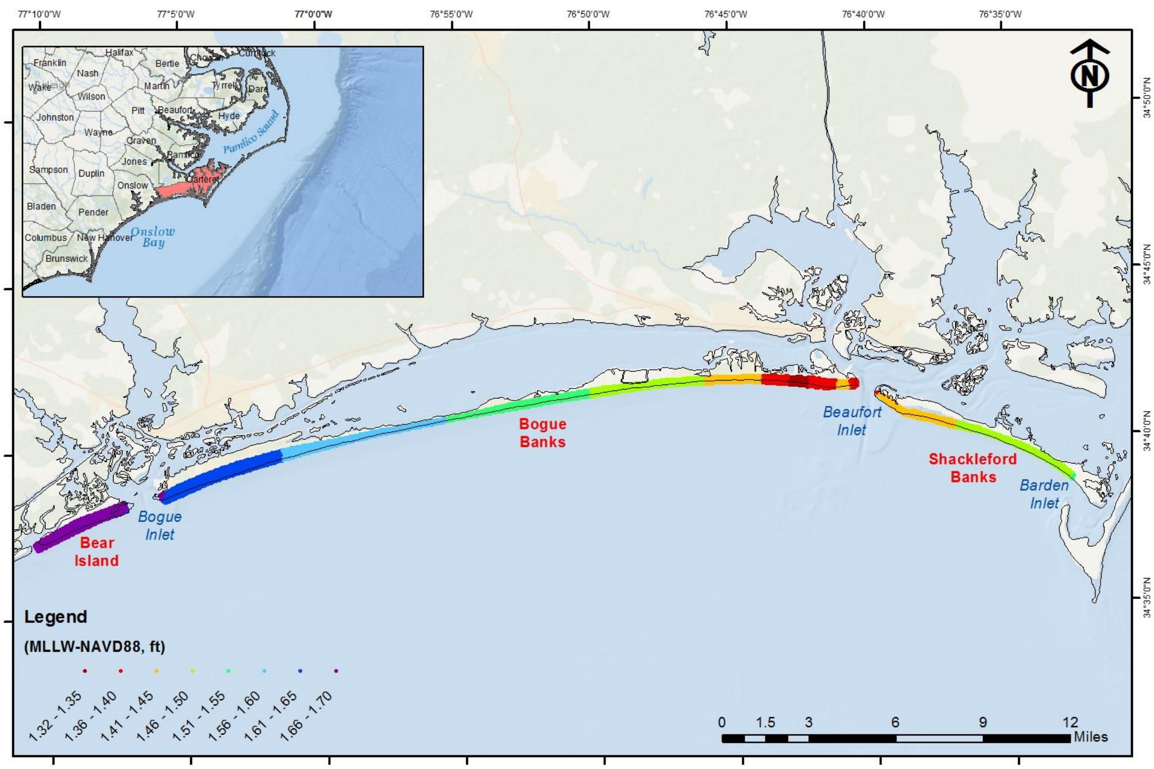

Figure 6. Map showing the NAVD88-MLLW datum separation as derived by NOAA's VDatum software.

4. A standard set of statistics was generated from the XYZ separation points, resulting in a single MHWC value for each island.
5. To ensure accuracy in the extraction of datum separation values using the Hypack with VDatum method, a set of XYZ data points were extracted and compared directly to the datum separation relationship at nearby NOAA tide stations with formulated datum separations (Table 2).

Table 2. Comparison of MHW datum values from computed from the tide station(s) and VDatum for three local tide stations.

Location	Station Name	NOAA Co-Ops	VDatum
Morehead City Harbor	865-6502	5.85	5.8488
Beaufort	865-6483	5.09	5.1358
Triple S	865-6590	9.07	9.0748

4.3 MHWC Uncertainty

The uncertainty of the MHWC along each island is mainly a function of 1) the spatial variability and accuracy in the datum separation along the island 2) the data and methods of rendering the MHWC from the survey data and 3) the slope of the beachface where the MHWC intersects. Since the overall intent of maintaining a database of MHWC data is to assess trends in shoreline change for coastal geomorphology studies, rather than use that data for defining a shoreline boundary in any legal sense, quanitifying uncertainty is not part of this assessment. If there is any need to determine the uncertainty of the MHWC at a specific location, please contact the CCSPO or Geodynamics to discuss the request.

4.4 Results

Based on the datum separtation information provided from VDatum and the geospatial/statistical approach developed for this study, we were able to determine a single MHWC value for each island. It should be noted again that due to hydrodynamics and geomorphology around coastal inlets, the MHWC separation values are more dynamic and therefor not included in this work. Listed below in Table 3 are the results of the geospatial datum separation analysis and the determined MHWC elevation for each island. The determined MHWC elevation relative to NAVD88 was rounded to the nearest tenth of a foot for two reasons; 1) the general accurancy of GNSS instrumentation used to survey the MHWC is repeatable to +/- 0.1 ft and 2) contours generated to the nearest hundredth of a foot for any given project would not be necessary.

Table 3. Results of the geospatial/statistical analysis performed in order to determine a single MHWC for each isalnd monitored by the CCSPO.

Location	# of Data Points in Analysis	Min. Separation	Max. Separation	Avg. Separation	St. Dev	Determined MHWC (NAVD88)
Bear Island	1212	1.65	1.69	1.667	0.008	**1.7 ft**
Bogue Banks	6481	1.32	1.66	1.526	0.089	**1.5 ft**
Shackleford Banks	1415	1.40	1.51	1.461	0.019	**1.5 ft**

Upon determination of the MHWC value for each island, the database of MHWC shapefiles for each island was updated for the CCSPO. This was accomplished by extracting the respective contour from the previously modeled DEM surface for each island. Seen below in Figure 7 is an example of the MHWC's along a portion of Bogue Banks.

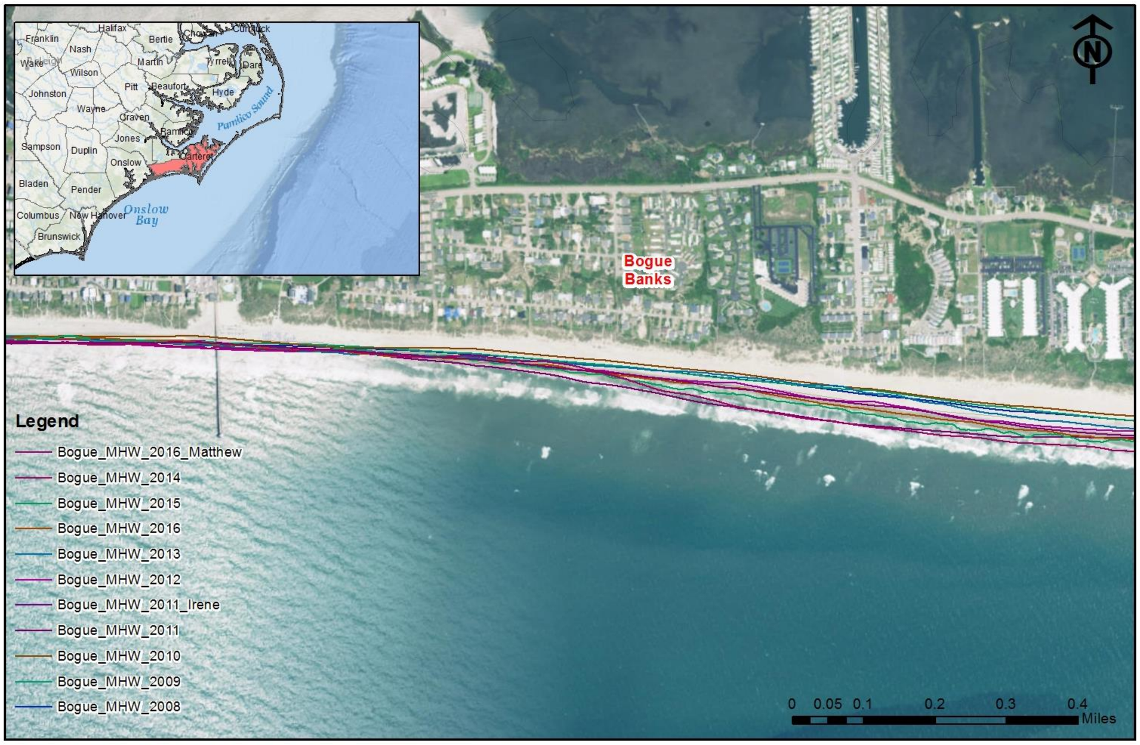

Figure 7. Map showing the MHWC shapfiles along a portion of Bogue Banks.

4.5 Conclusions

After almost a decade of shoreline surveys and studies sponsored by the Carteret County Shore Protection Office, it was recognized that the MHWC commonly used for shoreline change assesments did not adequately represet the modern datum separation information now available. Advancements in tidal and datum separation modeling and survey techniques have now allowed for a more comprehensive assessment and determiniation of the MWH-NAVD88 datum separation. NOAA's VDatum has become a staple in better utilizing water level datums and datum separations in a more realiable manner.

For this study, the three-phased approach (Section 1.2) to determine and update the local MHWC dataset proved successful and may serve as a guideline for future updates to MHW separation and legacy datasets. Throughout this project, it was found the small range of datum separation and the spatial distribution of that range of separation across each island combined with the accuracies and methods by which the MHWC is surveyed does not warrant creating MHWC's of different separation values across an island (ie…a changing MHWC elevation along a stretch of island). The modern MHWC elevation values determined for each island are considered adequate and accurate for coastal science studies of shoreline change. Property boundary issues/concerns involving the MHW boundary location should be directed to a professional surveyor with extensive knowledge of water level datums. To properly maintain a series of shorelines for any particular scientific study, it's recommended that the datum separations be "monitored" for changes. This can be done by performing calculation checks in Vdatum over the course of a given study. The separation might change when more tidal control is integrated into NOAA's models or geodetic datum components change over time. For any additional information pertaining to this study or the studies and/or surveys performed for the Carteret County Shore Protection Office, please contact the CCPSO directly.

5.0 REFERENCES AND USEFUL INFORMATION

About ArcGIS, *http://www.esri.com/arcgis/about-arcgis*. ESRI, 5 Aug. 2016. Web. 5 April 2017.

Tides and Currents Online, *https://tidesandcurrents.noaa.gov*. Center for Operational Oceanographic Products and Services, National Oceanographic and Atmospheric Administration, 15 Oct. 2013. Web. 26 April 2017.

VDatum, *https://vdatum.noaa.gov*. National Geodetic Survey, Center for Operational Oceanographic Products and Services, Office of Coast Survey, National Oceanographic and Atmospheric Administration, 8 Dec. 2016. Web. 24 April 2017.

Vertical Datums, National Geodetic Survey, National Ocean Service, 16 April 2017. Web. 26 April 2017.

Other Useful References

1. *User's Guide for the Installation of Bench Marks and Leveling Requirements for Water Level Stations*, NOAA/NOS, dated October 1987.

2. *User's Guide for Writing Bench Marks Descriptions*, NOAA/NOS, March 1998.

3. *User's Guide for Electronics Levels*, NOAA/NOS, Draft December 1997.

4. *Manual of Tide Observations*, U.S. Department of Commerce, Publication 30-1, Reprinted 1965.

5. *Tidal Datum Planes*, U.S. Department of Commerce, Special Publication No.135, Marmer 1951.

6. *Tide and Current Glossary*, U.S. Department of Commerce, NOAA, NOS, October 1989. https://tidesandcurrents.noaa.gov/publications/glossary2.pdf

7. NOAA Technical Report NOS 64 "*Variability of Tidal Datums and Accuracy in Determining Datums from Short Series of Observations*", Swanson, 1974.

8. *Tidal Datums and Their Applications*, NOAA Technical Report NOS CO-OPS 1, U.S. Department of Commerce, NOAA, NOS, December 1998.

9. *Computational Techniques for Tidal Datums*, NOAA Technical Report NOS CO-OPS 2, U.S. Department of Commerce, NOAA, NOS, DRAFT December 1998.

10. *Guidelines for Establishing GPS-Derived Ellipsoid Heights* (Standards: 2CM and 5CM) Version 4.3, NOAA Technical Memorandum NOS NGS-58, November 1997.

11. *Geodetic Leveling*, NOAA Manual NOS NGS 3, U.S. Department of Commerce, NOAA, National Ocean Survey, August, 1981.