

Inlet Hazard Area Boundary, 2019 Update:

Science Panel Recommendations to the
North Carolina Coastal Resources Commission

February 12, 2019

NC Coastal Resources Commission's Science Panel on Coastal Hazards
& NC Division of Coastal Management



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Acknowledgments

The Inlet Hazard Area (IHA) boundaries in use today were adopted in 1979. The North Carolina Coastal Resources Commission's (CRC) Science Panel on Coastal Hazards first recommended the need to update the IHA boundaries in 1999 and an earlier report was prepared and presented, but not adopted, in 2010. This present effort responds to a CRC 2016 request to update the IHA boundaries. It is a result of a close collaborative effort between the Science Panel and the Division of Coastal Management (DCM). The Science Panel members provided their inlet knowledge and experience and guided the development of the final methodology used. The DCM, led by Mr. Ken Richardson, developed all the statistics and maps, kept track of the changes and prepared the first draft of the report. His efforts were supported by the DCM staff, including Mr. Mike Lopazanski, Mr. Tancred Miller and Dr. Braxton Davis. Members of the Science Panel include: Mr. Steve Benton (DCM retired); Mr. Bill Birkemeier (USACE Field Research Facility retired, Science Panel Co-Chair); Dr. Bill Cleary (UNC Wilmington emeritus); Mr. Tom Jarrett, PE (Coastal Planning and Engineering); Dr. Margery Overton (Science Panel Co-chair, NC State University); Dr. Charles "Pete" Peterson (UNC Chapel Hill Institute for Marine Sciences); Mr. Spencer Rogers (NC Sea Grant); Mr. Greg "Rudi" Rudolph (Carteret County Shore Protection Office); and Dr. Beth Sciaudone, PE (NC State University).

The authors also extend gratitude to the NC Department of Transportation Photogrammetry Unit whose collaborative efforts provided much of the historical aerial orthophotos necessary to study historical shoreline trends.

The authors also extend appreciation to the numerous and diverse stakeholders that contributed ideas and concepts that added to the quality and accuracy of what this report intends to achieve. Finally, the authors wish to thank the past and current members of the CRC, whose unending support of their staff (DCM) and overall guidance on coastal policy and issues continues to protect and preserve the North Carolina coast for current and future generations.

NC Coastal Resource Commission's July 2016 Scope of Work for the Science Panel:

The CRC presented three tasks to the Science Panel:

- 1) Develop inlet shoreline change rate calculation methodology.
- 2) Re-evaluate points along the oceanfront shoreline where inlet processes are the dominant influence over shoreline position.
- 3) Present results at CRC meeting.

Executive Summary

The first North Carolina Inlet Hazard Areas (IHA) were developed in 1978 to recognize that shorelines adjacent to inlets are more dynamic than those along the oceanfront. At the time, the novel shoreline analysis methodology used the historic migration of inlet shorelines along the coast to define IHAs. Since that time, research has shown that in addition to inlet migration, the oscillations of ocean shoreline adjacent to the inlet are also a significant threat to development. Forty years later, some of the inlets have significantly changed. Several inlets (Mad Inlet, Old Topsail Inlet, and New/Corncake Inlet) have closed completely with little chance of reopening. Others (New Topsail and Shallotte Inlets) have moved outside the limits of the original IHA boundaries. In 2004, the Science Panel on Coastal Hazards began working on revising the IHA methodology, which led to initial recommendations in 2010. Most recently in 2016, the Panel was retasked by the North Carolina Coastal Resources Commission to develop an inlet shoreline change rate calculation methodology and update the IHAs.

Inlet shorelines behave differently than oceanfront shorelines not influenced by inlets. Although dynamic and locally unique, most inlets can be classified as either *migrating* in the net longshore sand transport direction, *oscillating* around a general location, or both. The shorelines inside the inlet, between the two islands, can migrate much faster than most other landforms. New Topsail Inlet has been moving south approximately 90 feet per year since the 1930s. Mason Inlet was moving at 365 feet per year before it was relocated and stabilized.

Inlet oscillations occur both directly on the inlet shoreline, between the two islands, and on the ocean shorelines near the inlet. The locations of the inlet shorelines and the width of the inlet are constantly modified by changes in wave height/direction, storms and other factors. In 2013-2014, Tubbs Inlet between Sunset Beach and Ocean Isle Beach widened from around 560 feet to more than 1700 feet, widening by a factor of 3 in less than 2 years. The inlet width has since been narrowing and is likely to return to its previous width.

Oceanfront shorelines near inlets have long-term erosion rates approximately 5 times greater than other oceanfront shorelines. Much larger oscillations in the oceanfront shoreline near inlets can also occur over several years or decades. These fluctuations are most often caused by movements in the primary ebb channel through the offshore bar. As the channel moves closer to one island, sections of that shoreline accrete while the other island erodes near the inlet. When the channel shifts by natural processes or dredging, the oceanfront process reverses. The island previously losing then gains, while the other side of the inlet loses what it previously gained and sometimes more. The oscillations may not contribute to the long-term erosion rate but can be a short-term threat to coastal development.

In 2010, the Panel developed draft IHAs for each of the developed inlets. Public comments criticized the effort in part because then-present IHA rules were not appropriate for the much larger redefined areas. Also, no proposed rule changes were presented to accompany draft boundary updates. The 2010 drafts were also criticized because of the increased size of the draft IHAs, and the fact that inlet risk within the areas varied considerably. In comparison, when

defined as a simple box along the shoreline, the Ocean Erodible Area (OEA) component of the Ocean Hazard Area (OHA) is like the IHA. However, the published erosion rates within the OHA identify the relatively higher risk closer to the shoreline.

In response to the public comments on the 2010 IHA drafts, the panel developed the Inlet Hazard Area Method (IHAM) to define the IHA and to identify two risk lines that are calculated similarly to the CRC's OEA mapping. Away from inlets, the existing vegetation line can be a useful indicator of the long-term erosion trend, offering several advantages in defining the Ocean Hazard Area. However, the migrations and oscillations near the inlets make the vegetation line too volatile to be an effective management tool. A primary finding of this report is that the vegetation line is not a reliable reference feature for certain management purposes near inlets. The dynamic oscillations near inlets were found to be better represented by a fixed, Hybrid-Vegetation Line based on the most landward limits of all vegetation lines over the study period. The Science Panel recommends fixed IHA development boundaries, like the Static Vegetation and Development lines used for large-scale (>300,000 cubic yards) beach nourishment projects.

The IHAM defines the landward limit of the IHA by multiplying 90 years times the annual inlet-shoreline erosion rate, measured landward from the Hybrid-Vegetation Line. This calculation is like that already applied in defining the landward limit of the Ocean Erodible Area and Ocean Hazard Area outside the IHA. A second line, the 30-Year Risk Line, has been mapped similarly to the minimum oceanfront setback distance of 30 times the erosion rate for identifying higher-risk areas. Because inlet shorelines behave differently than non-inlet areas, there are several important differences in how the erosion rates are measured and how they are applied in mapping compared to the non-inlet shorelines:

- The alongshore boundary of the IHA is identified by an increase in shoreline change variability compared to adjacent shoreline that is not influenced by the inlets.
- The erosion rates were analyzed using linear regression, a statistical method that takes advantage of the growing database of North Carolina shorelines and that better reflects the dynamic nature of inlets (rather than the endpoint method used in the OEA).
- Time periods for analysis were selected on an inlet-by-inlet basis, based on the available shoreline images that best represented the recent history of the inlet shoreline.
- The IHAM assumes homogeneous, erodible sediments. In areas where the IHAM does not reflect the influence of underlying geology and dune topography, the Panel used professional judgement and their knowledge of each inlet to aid in the delineation of the landward IHA boundary.

The maps in this report present the Panel's recommended IHA for each of the developed inlet shorelines where the inlet risk is equal to or more important than the long-term erosion and storm impacts. Because inlet oscillations make the existing vegetation line a poor indicator of future conditions, the proposed boundaries are fixed relative to the Hybrid-Vegetation Line. The Science Panel on Coastal Hazards recommends that the CRC consider updating subsequent IHA boundaries every five years, to coincide with updates to oceanfront erosion rates and Ocean Erodible Area boundaries. This 2019 report is submitted as a replacement for the 2010 report on the panel's recommendations.

1.0 Introduction

Ocean and inlet shorelines represent the dynamic interface between sea and land. Inlet shorelines are constantly moving under the combined and powerful influences of nature (tide, wind, current and waves) and engineering practices (dredging, beach nourishment, inlet closure/relocation, erosion control structures). Tidal inlets are an important and dynamic feature of barrier island coasts. They connect ocean to sound, promote habitat, facilitate navigation, improve water quality and support recreation. Inlets may open and close or migrate with the alongshore sediment transport. Although inlets are each locally unique, they can be separated based on dynamics – some inlets migrate along the coast while others oscillate back and forth around a central position. In some instances, an inlet will oscillate over the short-term as it migrates over the long-term.

- *Migrating Inlets* move alongshore with the prevailing longshore current and sand transport, persistently accreting on one side and forcing the other inlet shoreline to erode. Migration rate will vary with the conditions and may reverse in direction.
- *Oscillating Inlets* can be identified by a multi-year reversing pattern of erosion on one side and accretion on the other. Over a period of years or decades the erosion patterns may reverse. What was previously eroding recovers while the previous accretion disappears. Oscillations are most often caused by shifts in the alignment of the channel through the offshore bar as it naturally oscillates from one side of the inlet to the other. An Oscillating Inlet remains in the same general location because of various reasons, which may include a natural balance in sediment transport, underlying geology scoured by relic river channels or manmade dredging.

These migrations and oscillations affect not only the inlet shorelines between the two islands but also oceanfront shorelines near the inlets, sometimes seemingly distant from the inlet. Primary influences on the oceanfront are the size of the inlet's offshore shoal and the dynamic locations of the tidal channels through the bar. In general, the ocean shorelines near the inlets have higher long-term erosion rates than other ocean shorelines. In an analysis of the DCM 70-year shoreline database, Rogers (2015) examined shoreline change rates inside and outside the Panel's draft Inlet Hazard Area (IHA) boundaries statewide. Of North Carolina's 310 miles of shoreline, 77 percent of the shoreline was outside the IHAs and 23 percent within. The non-inlet oceanfront shorelines were eroding at a median rate of 0.9 feet per year, while the inlet shorelines were eroding at 4.3 feet per year, or approximately five times faster than the non-inlet oceanfront. Ocean inlet systems are highly dynamic balances, with waves and currents attempting to fill the gap in the islands, being opposed by daily tidal currents and periodic storms attempting to enlarge the opening.

One way to appreciate just how dynamic inlets are is to examine their movement through time. While difficult to show in a print report, it is easy to visualize online using the historic inlet atlas animation developed by North Carolina Sea Grant and available using the following link:

<https://ncseagrant.ncsu.edu/program-areas/coastal-hazards/inlet-atlas/>

Shorelines inside the inlet can migrate much faster than other oceanfront shorelines. New Topsail Inlet has been migrating south at around 90 feet per year since the 1930s. Mason Inlet was migrating at 365 feet per year before it was relocated and stabilized in 2002. Inlet shorelines also oscillate much faster than non-inlet shorelines. In 2013-4, Tubbs Inlet between Sunset Beach and Ocean Isle Beach widened from around 560 feet to more than 1700 feet, widening by a factor of 3 in less than two years. The inlet width has since been narrowing and is likely to return to its previous width. These oscillations do not necessarily increase the long-term erosion rate but still add to the short-term risk to development. The IHA is designed to identify these dynamic inlet areas.

1.1 Establishment of Inlet Hazard Areas

The establishment of Areas of Environmental Concern (AECs) as authorized under the NC Coastal Area Management Act (CAMA) of 1974 (GS 113A) forms the foundation of the North Carolina Coastal Resources Commission's (CRC) permitting program for regulating coastal development. Rules define the Ocean Hazard Area AEC, including three components: 1) Ocean Erodible; 2) Inlet Hazard; and 3) Unvegetated Beach (NCAC 15A 07H.0304). The Inlet Hazard Area (IHA) AEC is defined as locations that "are especially vulnerable to erosion, flooding and other adverse effects of sand, wind, and water because of their proximity to dynamic ocean inlets." [NCAC 15A 07H.0304(2)]

The IHA maps in use today are based on analysis by Priddy and Carraway (1978). They utilized aerial photographs spanning 1940 through 1977 to analyze 23 inlets, of which 19 are still active. The number of photos at each inlet ranged from 6 to 32. Measurements were made on the photos themselves with a spatial resolution of 300 feet alongshore. An inlet shoreline change rate was computed using both linear and quadratic equations to determine the best-fit shoreline change rate for each inlet. A landward limit to the IHA was established at the point where the 1% chance that shoreline position would exceed the defined hazard area at any time within the decade (1978-1988). At inlets where the regression methods could not be used, the IHA boundaries were established by using the methods of Fisher (1962, 1967) to map previous inlet territory. IHA boundaries were not designated for Masonboro Inlet, Drum Inlet, the southwestern side of Ocracoke Inlet, and Oregon Inlet because they were excluded from requirements listed in the NC Coastal Plan (NC Department of Natural Resources and Community Development, 1977). The Inlet Hazard Areas developed for the 19 developed inlets in the study by Priddy and Carraway were presented to the CRC as IHA boundary recommendations and adopted in 1979. Minor amendments followed in 1981.

In 1998, the CRC Science Panel on Coastal Hazards identified the need to update the methodology for defining the IHA (Oct 21, 1998 Science Panel meeting minutes) and in their short-term recommendations to the CRC (Fisher, 1999) stated:

Inlet Hazard Areas are coastal zones that are especially vulnerable to migration, erosion, flooding, and other adverse effects of sand, wind, and water because of

their proximity to dynamic tidal inlets. Each of North Carolina's inlets is unique and there are distinct differences in the history and behavior of inlets in different coastal compartments of the state. Current Inlet Hazard Areas are based upon original studies conducted over twenty years ago. The Inlet Hazard Areas need revision to incorporate updated knowledge.

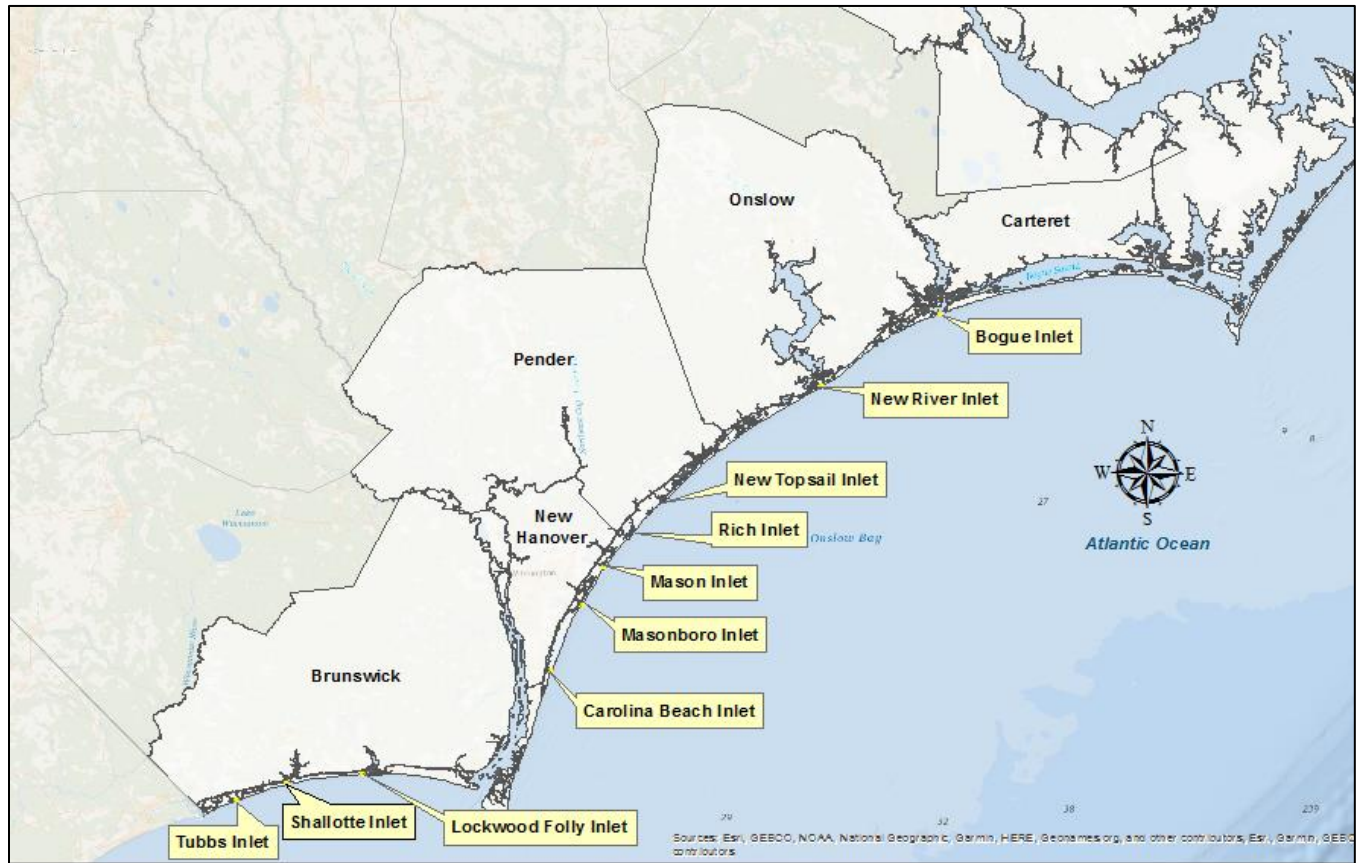
The Panel recommends that the delineation of the Inlet Hazard Areas be revised after a review of site-specific studies of each inlet by a group of experts. The hazard zone delineation shall consider such factors as previous inlet territory, structurally weak areas along migration pathways, unusually low and narrow sections of barriers prone to breaching, external influences such as jetties and channelization, and increased erosion extending along adjacent shorelines.

Later research has shown that in addition to inlet migration addressed in the original IHA analysis, the oscillations in the ocean shoreline adjacent to the inlet have also been a significant threat to development (Cleary, 1999). After 40 years some of the inlets significantly changed. Three of the tidal inlets from the 1978 study have closed naturally: Mad Inlet, Old Topsail Inlet and New/Corncake Inlet. New Topsail and Shallotte Inlets have moved outside the limits of the original IHA boundaries. Little River Inlet, located in South Carolina just over the SC/NC border has since been stabilized and no longer requires an IHA for the NC side.

In 2004, the Science Panel on Coastal Hazards began working on revising the IHA methods leading to initial recommendations by DCM to the CRC in 2010. This effort stalled after extensive public comment, in part because existing IHA rules were perceived as being overly restrictive in the larger redefined areas. Public comments on the 2010 draft also questioned the increased IHA size and raised concerns that inlet risk within the IHA varied considerably. The Science Panel, DCM and CRC have agreed that IHA rules should be revised to better accommodate the oceanfront expansions proposed in the latest draft maps.

In 2016, the Science Panel on Coastal Hazards was again asked by the Coastal Resources Commission to develop an updated methodology to delineate inlet hazard areas. The purpose of this report is to present that new methodology, the Inlet Hazard Area Method (IHAM), and to recommend revised IHA boundaries for the ten active and developed tidal inlets in North Carolina. The inlets considered include Tubbs, Shallotte, Lockwood Folly, Carolina Beach, Masonboro, Mason, Rich, New Topsail, New River, and Bogue Inlets (Figure 1). The Cape Fear River Entrance and Beaufort Inlet are proposed to be separately managed in a new State Ports Inlet Management AEC and were not included in this report. The shorelines adjacent to Brown's, Bear, Barden, Drum, Ocracoke, Hatteras and Oregon inlets are publicly owned, with a low potential for future development. Thus, they were not included in this report.

Figure 1. Study area includes Tubbs, Shallotte, Lockwood Folly, Carolina Beach, Masonboro, Mason, Rich, New Topsail, New River and Bogue Inlets. At least one side of each inlet is developed.



To address public comments on the previously drafted 2010 IHAs, the Panel has developed the recommendations in this report to be similar to the management resources provided in the Ocean Erodible Area component of the Ocean Hazard Area. The OEA is defined by the long-term erosion rates that vary along the shoreline. The landward limit of the OEA is defined by a line determined by multiplying 90 times the local annual erosion rate (or 2 feet/year, 180 feet if greater) measured from the vegetation line at the time of construction. The largest buildings, greater than 100,000 square feet, are required to be landward of the OEA. To reflect the increased erosion hazard closer to the ocean, a seaward line is determined by multiplying 30 times the local erosion rate landward of the vegetation line and used as a setback line for buildings smaller than 5,000 square feet.

This report recommends similar 30- and 90-Year *Risk Lines* to define the IHA at each inlet. The Science Panel found that the vegetation line does not reflect long-term inlet changes, but that the *Hybrid-Vegetation Line*, which is mapped from the same historical aerial photography as the local erosion rates, can be used. The Hybrid-Vegetation Line is a fixed line allowing the 30- and 90-Year Risk Lines to be mapped as fixed lines like the present IHA boundaries and the various fixed management lines available when larger beachfill projects are constructed (Static

Vegetation Lines, Static Vegetation Lines Exceptions and Development Lines). The results cover a smaller area than proposed in 2010 and differentiate the risk with two lines in the IHA.

1.2 Report Organization

This report is organized in four chapters with three appendices. Chapter 2 describes the methodology used. Chapter 3 describes the analysis and the recommended IHA for each inlet. Chapter 4 provides recommendations.

Acronyms used in the report are listed in Appendix A. Appendix B lists definitions for key terms. Appendix C provides maps for each proposed IHA, which duplicate the IHA maps provided in Chapter 3 but are larger in scale.

2.0 Methodology

The Inlet Hazard Area Method (IHAM) was developed through close collaboration between the North Carolina Division of Coastal Management (DCM) and the Coastal Resources Commission's (CRC) Science Panel on Coastal Hazards. It defines a series of statistical and analytical steps to be used to develop an initial IHA. Those steps are then confirmed or modified based on additional knowledge of each inlet.

The IHAM major steps include:

- 1) Map historic vegetation lines and delineate a Hybrid-Vegetation Line that represents the landward-most position of all vegetation lines, for use as a reference line in determining the landward boundary of the IHA.
- 2) Map shorelines and generate change rate and standard deviation of shoreline position statistics.
- 3) Use the standard deviation to define the alongshore extent of inlet influence.
- 4) Compute the 30- and 90-Year Risk Lines, which are mapped relative to the Hybrid-Vegetation Lines.
- 5) Use professional knowledge of inlet processes, geomorphology and engineering activities to modify the IHA as needed.

2.1 Hybrid-Vegetation Line:

Away from inlets, the existing vegetation line is a useful reference feature for the long-term erosion trend. However, the dynamic oscillations or higher variability near inlets are not reflected in the most recent vegetation line and are better represented by a Hybrid-Vegetation Line, which is based on the landward limits of the historic vegetation lines over the period of study.

The Hybrid-Vegetation Line (HVL) represents the landward-most position of all vegetation lines mapped at each inlet (Figure 2). The HVL is most often a composite of landward-most segments from multiple dates, or in some instances may represent only a single date. The HVL is significant because in an inlet environment where erosion and accretion can occur rapidly, it represents the landward-most position of where the hazard once existed. A spatial 5-*transect* running average was applied to blend together different date segments by averaging each transect-HVL intersection with the two transects to the left and right. Figure 3 is an example of the HVL computation from Lockwood Folly Inlet at Holden Beach.

In addition to providing an improved reference feature for defining the IHA, the HVL was the most effective of several methods tested by the Panel to incorporate the higher variability of the inlet shorelines into the IHA boundaries.

Figure 2. The smoothed HVL (red line) is made up of landward-most segments of all vegetation lines (green line) by using a 5-transect running average statistical method to smooth the raw HVL (yellow line).

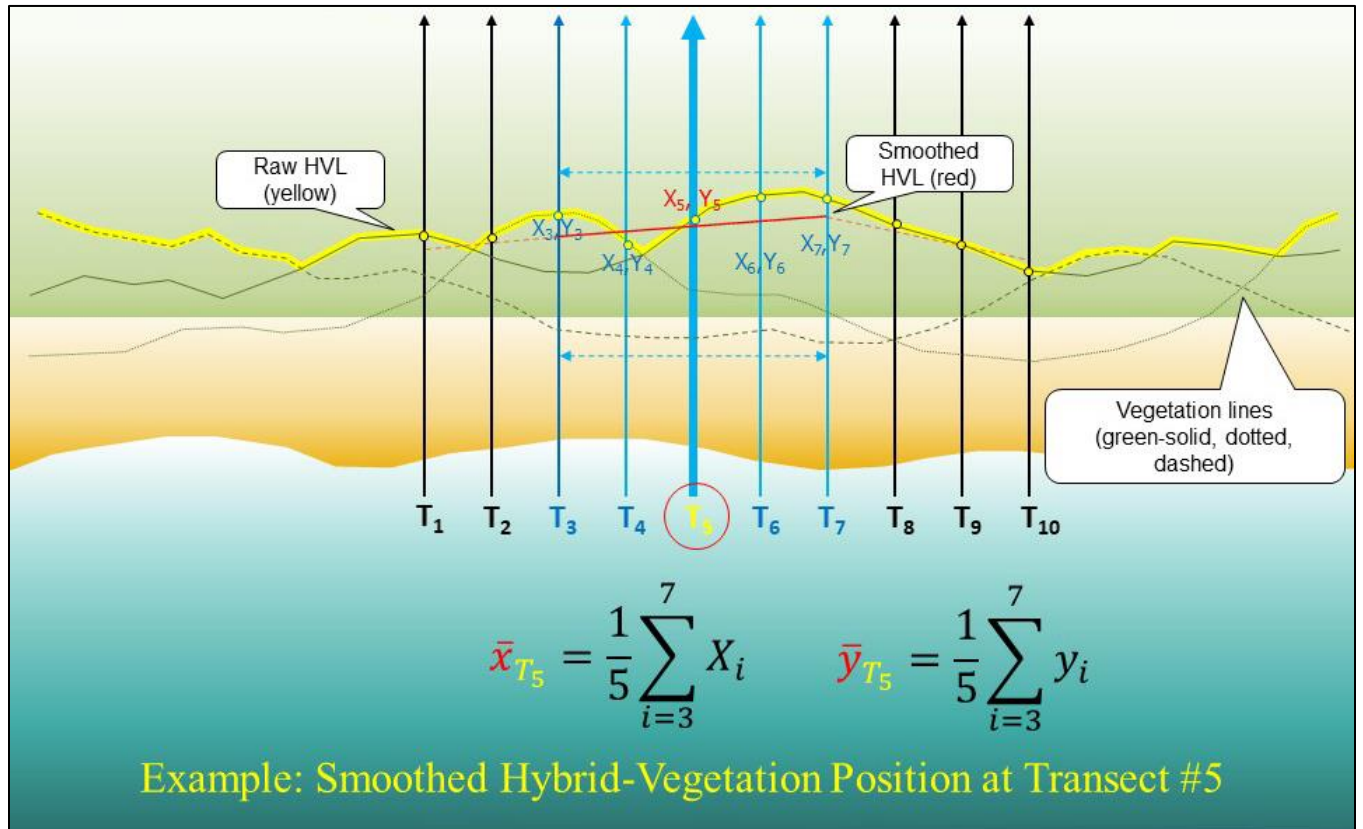
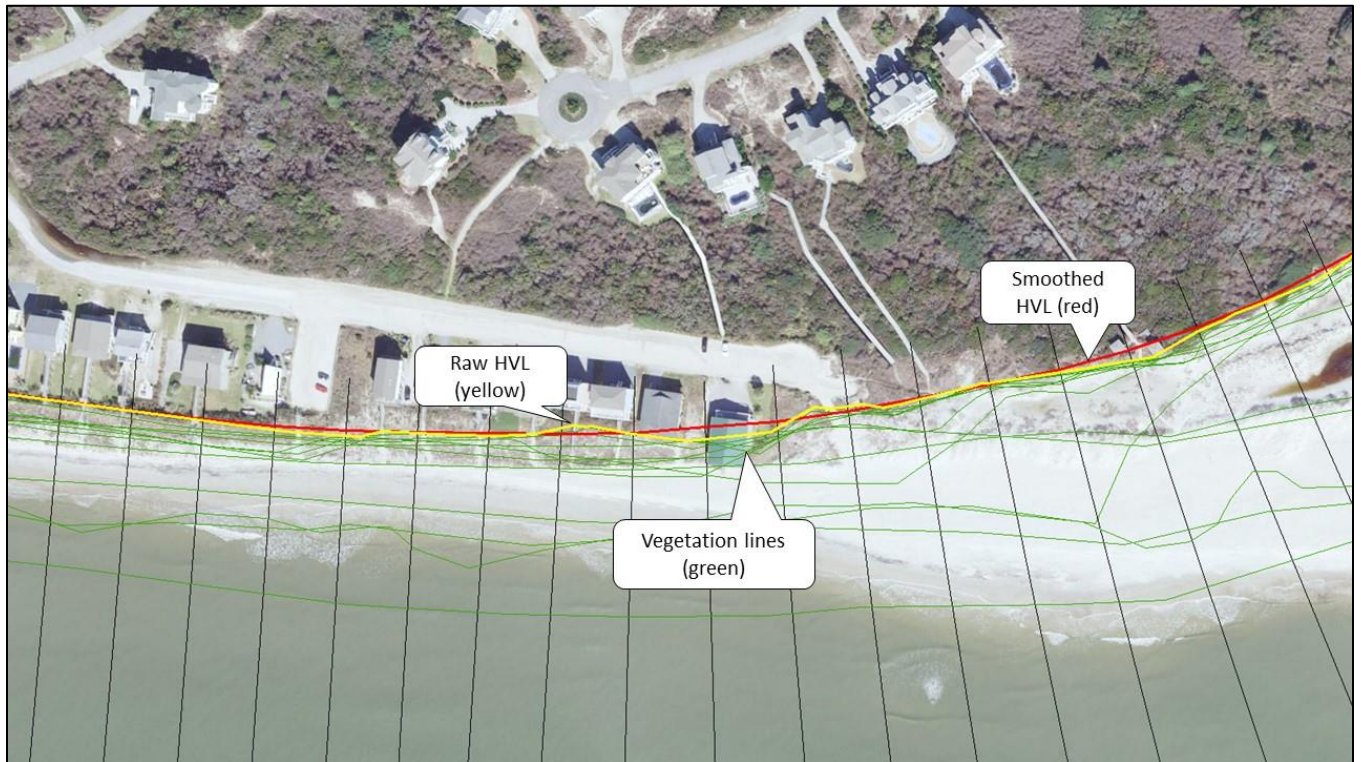


Figure 3. Example showing individual vegetation lines (dark-green lines), the raw Hybrid-Vegetation Line (yellow line), which is the landward-most position of all vegetation lines, and the smoothed Hybrid-Vegetation Line (red line) using a 5-point running average at Holden Beach at Lockwood Folly Inlet.



2.2 Shoreline Data

DCM's growing database of oceanfront and inlet shorelines facilitated this study by allowing many different approaches to be tried and tested. Most of the shorelines used were mapped using historic orthophotography to digitize the wet-dry line (Figure 4), considered a proxy for the Mean High Water (MHW) line. Three shorelines represented the location of MHW - either derived from lidar (1997 and 2004), or NOS T-Sheets (either from the 1930s or 1940s). Two studies carried out by DCM (Limber et al., 2007a; 2007b) indicated that the lidar-derived MHW line could be used interchangeably with the wet-dry shorelines.

Although shoreline data existed between 1930 and 2016, the temporal focus here is on shorelines between 1970 and 2016 for several reasons:

- The 1930 to 1940 shorelines were excluded at most inlets because of uncertainties on the hydrodynamics at each inlet associated with the construction and maintenance dredging of the Atlantic Intracoastal Waterway (AIWW) and other waterways. This specifically affected the inlets in the southern portion of the State, where one to four shorelines were excluded.

- Shorelines based on photography taken immediately or within one year after major storms or beach nourishment projects were excluded.
- The primary imagery used were NC DOT shoreline images between 1970 and 2000.

These criteria resulted in the number of shorelines used, ranging between 10 and 24 at each inlet.

Oceanfront and inlet shorelines were analyzed along a series of numbered, shore-perpendicular transects spaced at 25-meter (82-foot) intervals using USGS's Digital Shoreline Analysis System (DSAS) with ESRI's ArcGIS. Due to the curvature of inlet shorelines where there is a transition from the oceanfront into the inlet throat, transects were cast from an onshore baseline to create radial transects that retained shore-perpendicular orientation and spacing. These radial transects were used to compute shoreline changes inside the inlet.

Figure 4. Interpretation of the "wet-dry" shoreline using orthophotography.

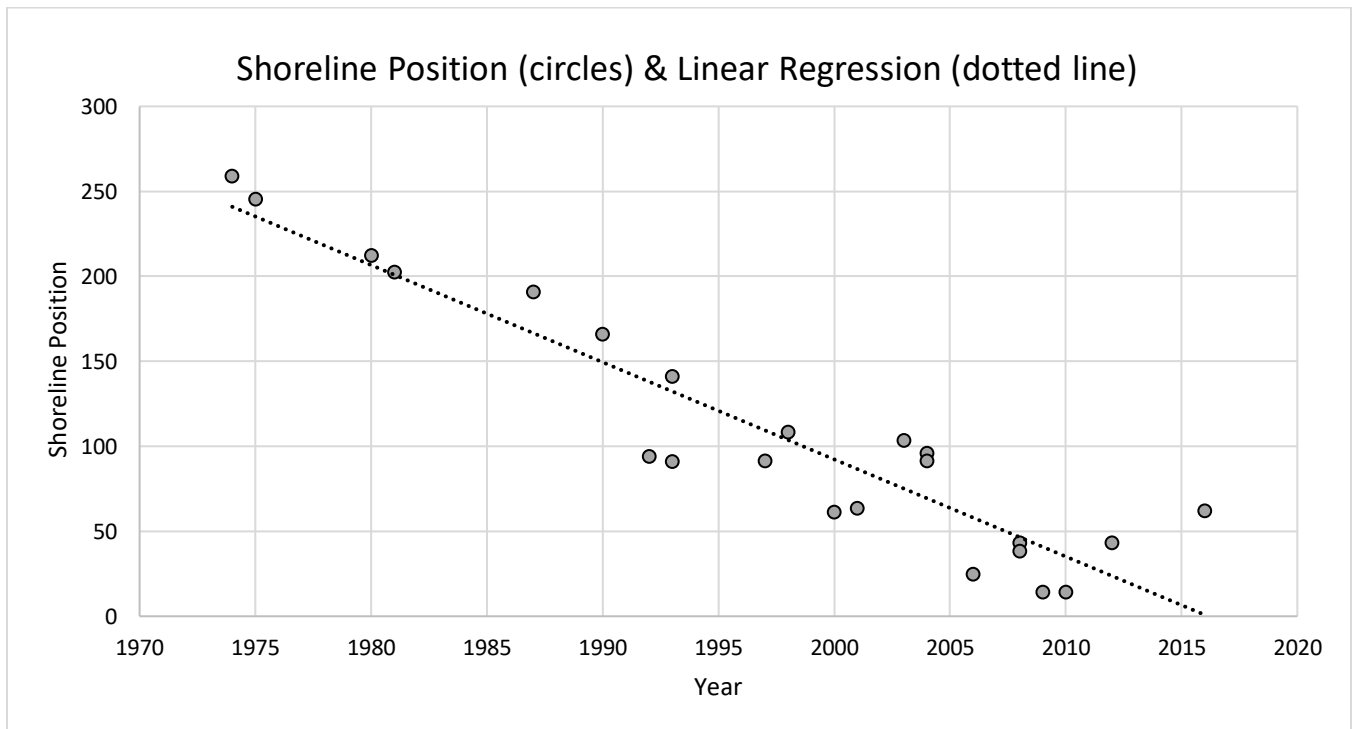


2.3 Shoreline Change Rates: Linear Regression

DCM has calculated long-term oceanfront shoreline change (erosion/accretion) rates since 1979 using the end-point method, which is based on the change between the earliest and most recent dates. Any short-term change between those dates, no matter how significant, is not directly captured. Because inlet shorelines are constantly moving and fluctuating in position, the end-point method is less effective in capturing the dynamics of an inlet or for quantifying its long-term trends. Instead, linear regression, a statistical measure using multiple shorelines, was used for this study (Thieler et al., 2009).

At each transect, there are a series of shoreline-transect intersections that represent the shoreline's position through time. Linear regression minimizes the distance between the known values (actual shoreline positions) and a best-fit regression line (Figure 5). The slope of this line is the Linear Regression Rate (LRR) of shoreline change or the local erosion or accretion rate.

Figure 5. Relative shoreline position as a function of time (circles). The slope of the best fit, dotted line is the linear regression rate (LRR) of shoreline change (in this case, it is eroding at 19 feet per year).



The benefits of linear regression include (Dolan et al., 1991):

- All data are used, regardless of changes in trend or accuracy.
- The method is purely computational.
- The calculation is based on accepted statistical concepts.
- The method is easy to employ.

Although the linear regression method is less sensitive to individual points, it is susceptible to outliers; it assumes that the computed trend is linear, and it tends to underestimate the rate of change relative to other statistics, such as the end-point rate (Dolan et al., 1991; Genz et al., 2007).

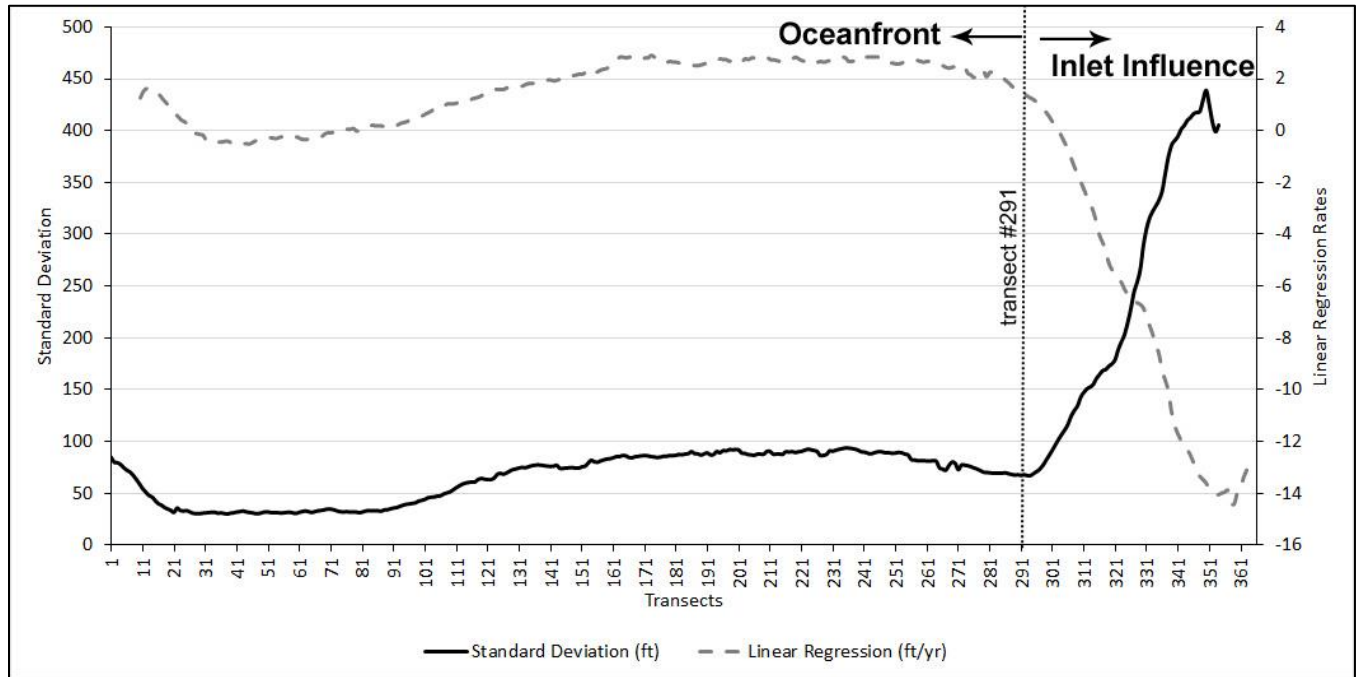
Once computed, the linear regression rate was then smoothed as described previously for the HVL (Figure 2); but instead of averaging 5 transects, a 17-transect running-average alongshore was used. This follows the DCM blocking computation used for the OEA shoreline rates and further smooths the alongshore variation in the shoreline change rate.

2.4 Using Standard Deviation of Shoreline Position to Identify the Alongshore IHA Boundary

The alongshore IHA boundary represents the location along the oceanfront shoreline where inlet related processes begin to have a dominant influence compared to other oceanfront processes. Since inlet shorelines are generally more dynamic than oceanfront shorelines, this boundary was identified by using the standard deviation of shoreline position and, to a lesser degree, the alongshore variation in the erosion/accretion rate (the LRR) between transects. The standard deviation of shoreline position is a measure of the extent of shoreline variation (i.e., the back and forth movement of the shoreline) at each transect.

Figure 6, which plots the alongshore variation in the Standard Deviation and the LRR, illustrates the methodology that was used. The inlet is on the right-hand side whereas the left-hand side of the graph represents the non-inlet oceanfront shoreline. For this location, transect-291 (vertical dashed line) represents a sharp change in both plotted lines. To the right of transect-291, the shoreline is dominated by inlet hydrodynamics, and to the left it is dominated by oceanfront processes. Therefore, transect-291 is identified as the alongshore boundary for the Inlet Hazard Area on the left side of this inlet.

Figure 6. The LRR and the standard deviation of shorelines plotted relative to the alongshore transect numbers. Transects are spaced 82 feet (25 meters) apart. The vertical dashed line at transect-291 separates inlet influence from the oceanfront.



2.5 The 30- and 90-Year Risk Lines:

The hazard risk varies within the IHA. To identify areas at greater risk, the 30- and 90-Year Risk Lines were developed based on the inlet-shoreline erosion rates, similarly to the minimum and maximum OEA boundaries, which are determined by multiplying 30 and 90 times a setback factor based on shoreline change rates, with a minimum rate of change of 2 feet of erosion/year. Within the IHA, the 90-Year Risk Line is used to define its landward extent. The location on each transect is measured landward of the Hybrid-Vegetation Line. The computation of the 90-Year Risk Line is based on the shoreline erosion rate (the LRR) or a minimum rate of -2 feet/year if the shoreline is accreting or eroding at a slower rate.

The 30-Year Risk Line is an intermediate line that defines a higher level of risk closer to the shoreline. It is computed similarly to the 90-Year Risk Line, but by using a multiplier of 30 and measured relative to the Hybrid-Vegetation Line.

2.6 Modifications to the Computed Inlet Hazard Area

The IHAM as described above worked well at most of the inlets, requiring no additional modification. However, as Priddy and Carraway (1978) and Overton and Fisher (2004) found in their studies, the IHA defined for some inlets required additional modifications based on how well the computed IHA fit the unique character of each inlet. This is not surprising considering that the IHAM is based only on historic shoreline positions, assumes uniformly erodible material and assumes that past shoreline changes can be used to estimate changes further landward. These are usually, but not always, good assumptions. Some of the issues considered included:

- the stabilizing impact of engineering activities including the AIWW;
- local geomorphology and underlying geology known to be less erodible;
- locations within an inlet where the minimum erosion rate of 2 feet per year was considered unrealistic;
- migrating, low-elevation, ephemeral swash bars, which overly magnify the dynamic nature of the inlet and unrealistically impact the 30- and 90-Year Risk Lines;
- instances where the radial transects within the inlet throat, when extended landward to mark the 30- and 90-Year Risk Lines, intersected with other transects, each with a different erosion rate;
- instances where the break in the standard deviation separating inlet influence from the oceanfront was not clear or occurred too close to the inlet based on other observations of coastal change; and
- cases where 30- and/or 90-Year Risk Lines were unrealistically mapped too far landward based on knowledge of the recent stability of the barrier island that was not reflected in the observed LRR.

In these cases, the Panel used their professional knowledge of each inlet to aid in the delineation of the IHA boundaries. In some cases, they refined the shoreline dates used in the analysis or moved the IHA boundary to a more appropriate location based on the underlying geology. Specific details are provided in the descriptions for each of the inlets.

3.0 Inlet Hazard Area Recommendations

This chapter delineates the Inlet Hazard Area recommendations for each inlet. The history of the inlet is briefly described. The relevant analysis details of the IHAM and any modifications are outlined for each side of the inlet. Maps locating the Panel's recommended Inlet Hazard Area for each side of the inlet are presented. Larger scale copies of these maps can be found in Appendix C.

3.1 Tubbs Inlet

Tubbs Inlet is a relatively small migrating inlet that was recognized on early 1700's maps. Throughout much of its early history the inlet migrated westward along an 8,600-foot pathway, at a rate between 50 and 65 feet per year. In January 1970, the inlet was relocated 3,200 feet eastward to a position that approximated its 1938 location. Following relocation, the inlet began migrating eastward toward Ocean Isle.

Causes of the migration reversal are complex, making the inlet difficult to predict. Around the time of relocation feeder channels behind both sides of the inlet were altered by dredging for land development. Other sections of the channels connecting to the AIWW shoaled and became hydraulically less efficient. More recently the inlet's migration may have been influenced by the 1980 construction of the dual navigation jetties at Little River Inlet, then 4 miles to the southwest, and the natural closing of Mad inlet in 1997, then 3 miles to the southwest. The inlet shoreline can be considered at least widely oscillating and may be establishing a migration to the northeast.

When the existing IHA boundary was established in 1979, shortly after the inlet was relocated, there was not enough data at the time to forecast how natural processes and adjacent shorelines would respond to the inlet's relocation, so the IHA boundary was simply mapped to encompass both the new and former locations of the inlet.

3.1a Sunset Beach side of Tubbs Inlet

Tubbs and Mad Inlets were presumed to have had a combined influence on making Sunset Beach one of a few accreting islands in North Carolina (Cleary & Marden, 1999). The northeastward migrating spit on Sunset Beach retreated 1100 feet around 2013 but was quickly recovering by 2017. There are no erosion control structures on Sunset Beach.

Because of the relocation and the dredging of feeder channels behind both Sunset Beach and Ocean Isle for land development around the time of the inlet relocation, 1970 and 1971 data were excluded, and only shoreline data after 1971 (starting with the 1981 data set) were used in

applying the IHAM (Figures 7, 8). The oceanfront shoreline boundary of inlet influence is inlet transect-210 (Figure 9). The 90-Year Risk Line is the recommended landward boundary (Figure 10).

Figure 7. Tubbs Inlet at Sunset Beach. Vegetation Lines mapped: 1981, 1992, 1993, 1998, 2003, 2004, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 1981, 1993, 1998, 2003, 2004.

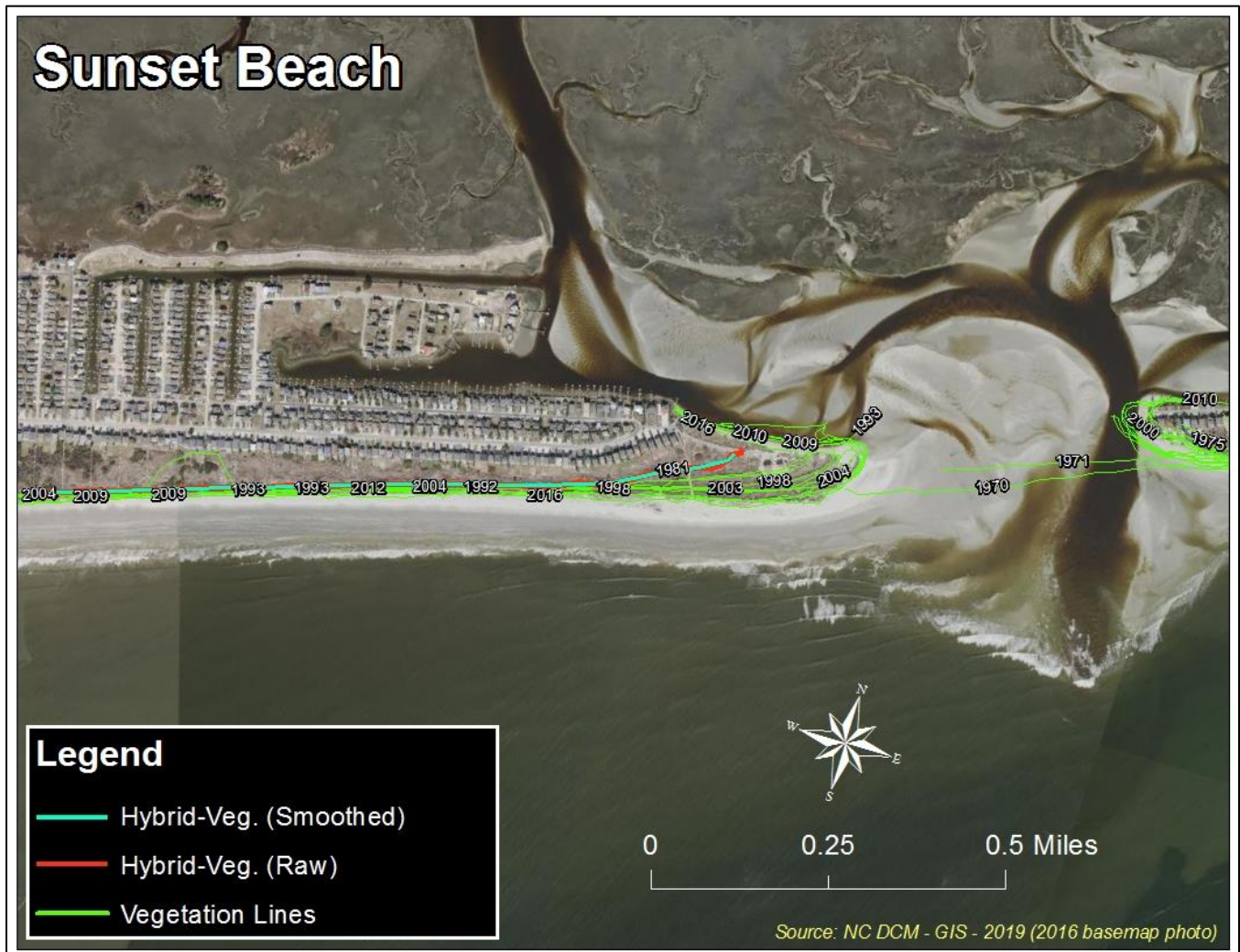


Figure 8. Tubbs Inlet at Sunset Beach. Shorelines included in the analysis: 1981, 1992, 1993, 1997, 1998, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016.



Figure 9. Based on standard deviation of shoreline position at Tubbs Inlet-Sunset Beach, transect-210 is recommended as the inlet-ocean transition boundary. Negative Linear Regression Rates indicate erosion, while positive values represent accretion (right axis).

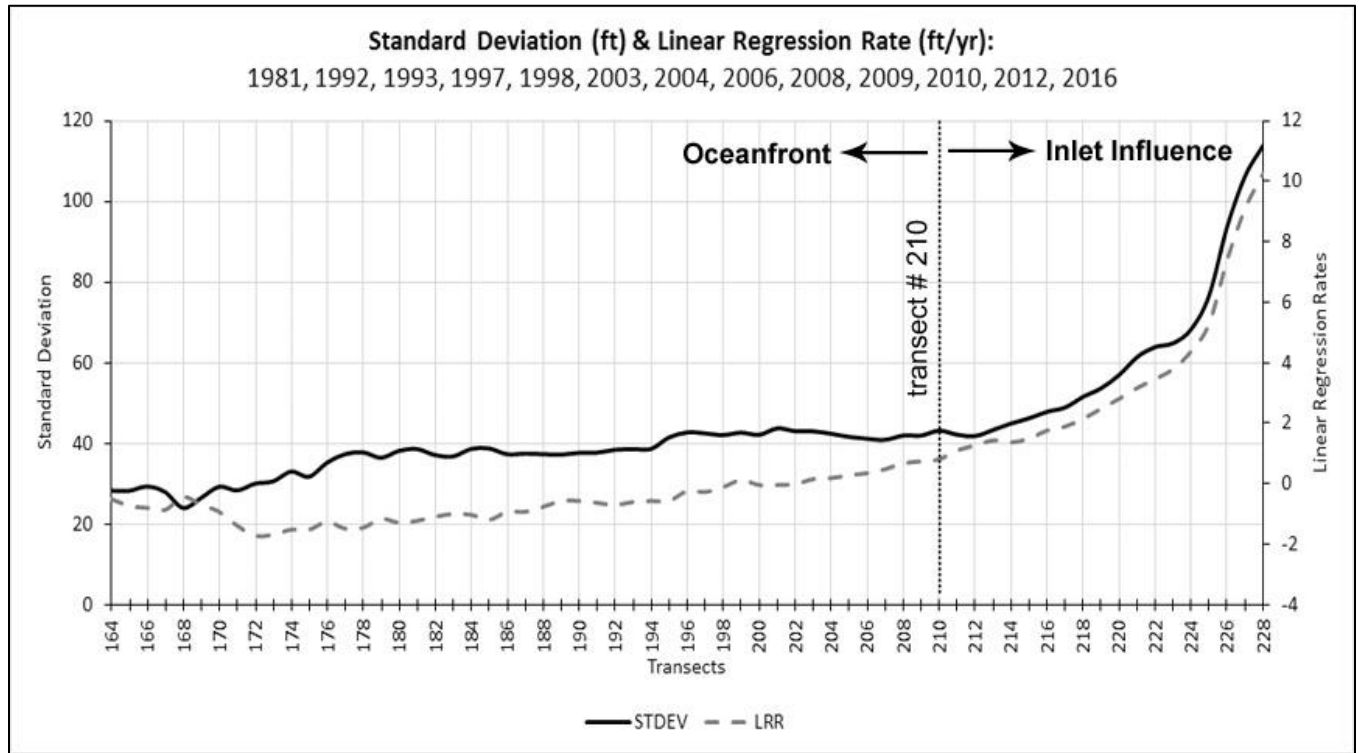
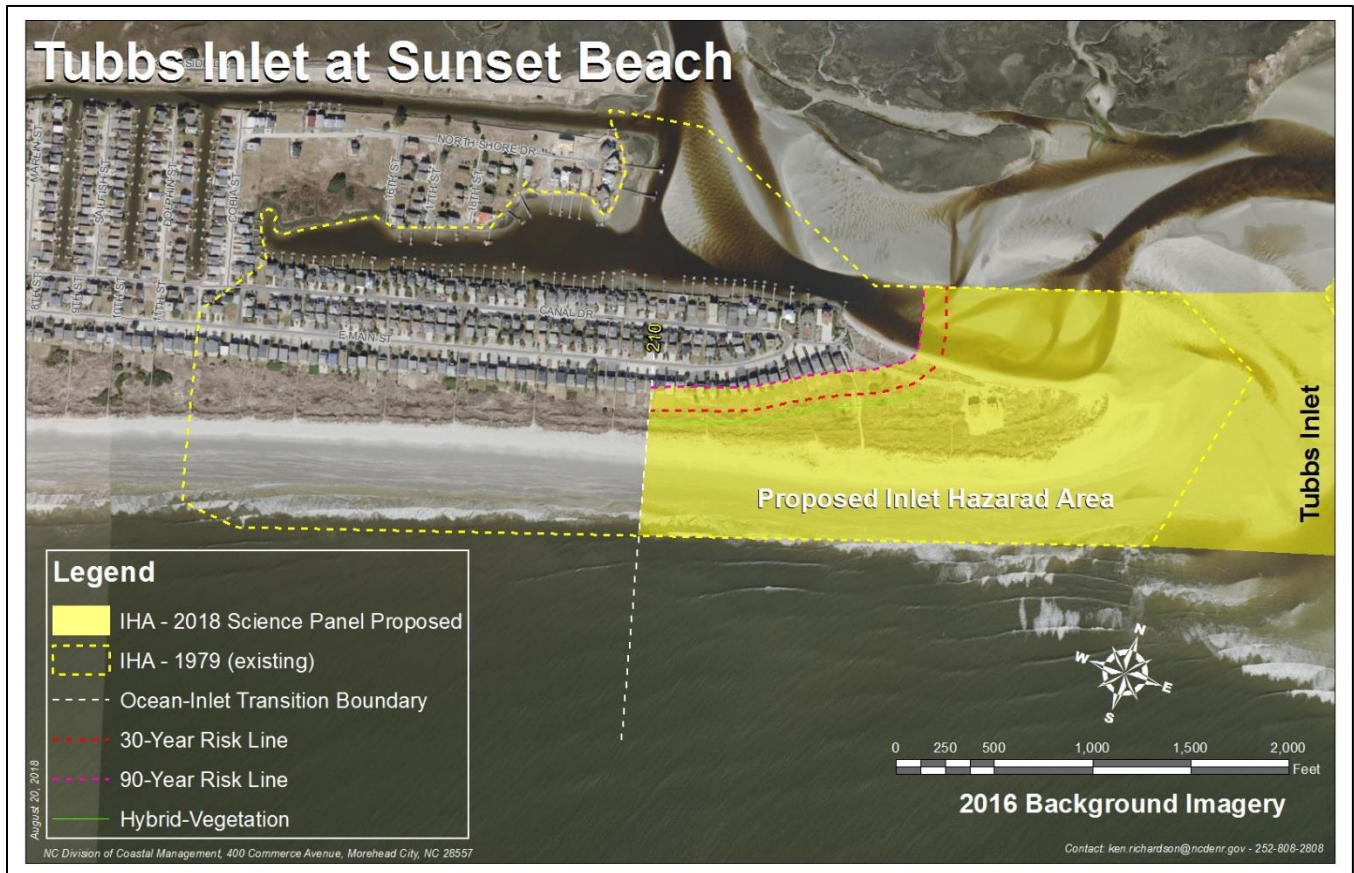


Figure 10. Tubbs Inlet at Sunset Beach Hybrid-Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.1b Ocean Isle side of Tubbs Inlet

Since relocation, Tubbs Inlet has been migrating toward Ocean Isle at a highly irregular rate. The inlet shoreline has been armored with sandbags. Farther northeast, the ocean shoreline has accreted following the relocation. The vegetation and shoreline data for Ocean Isle at Tubbs inlet are shown in Figures 11 and 12.

Using the IHAM, transect-28 is the boundary of inlet influence (Figure 13); the recommended landward boundary is the 90-Year Risk Line (Figure 14).

Figure 11. Tubbs Inlet at Ocean Isle. Vegetation Lines mapped: 1974, 1975, 1980, 1981, 1987, 1990, 1992, 1993, 1998, 2000, 2001, 2003, 2004, 2009, 2010, 2012, 2016. Vegetation line segments making up the hybrid-vegetation Line: 1980, 1981, 1990, 1993, 2000.



Figure 12. Tubbs Inlet at Ocean Isle. Shorelines included in the analysis: 1974, 1975, 1980, 1981, 1987, 1990, 1992, 1993, 1997, 1998, 2000, 2001, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016.



Figure 13. Based on standard deviation of shoreline position at Tubbs Inlet-Ocean Isle Beach, transect-28 is recommended as the inlet-ocean transition boundary along the shoreline. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

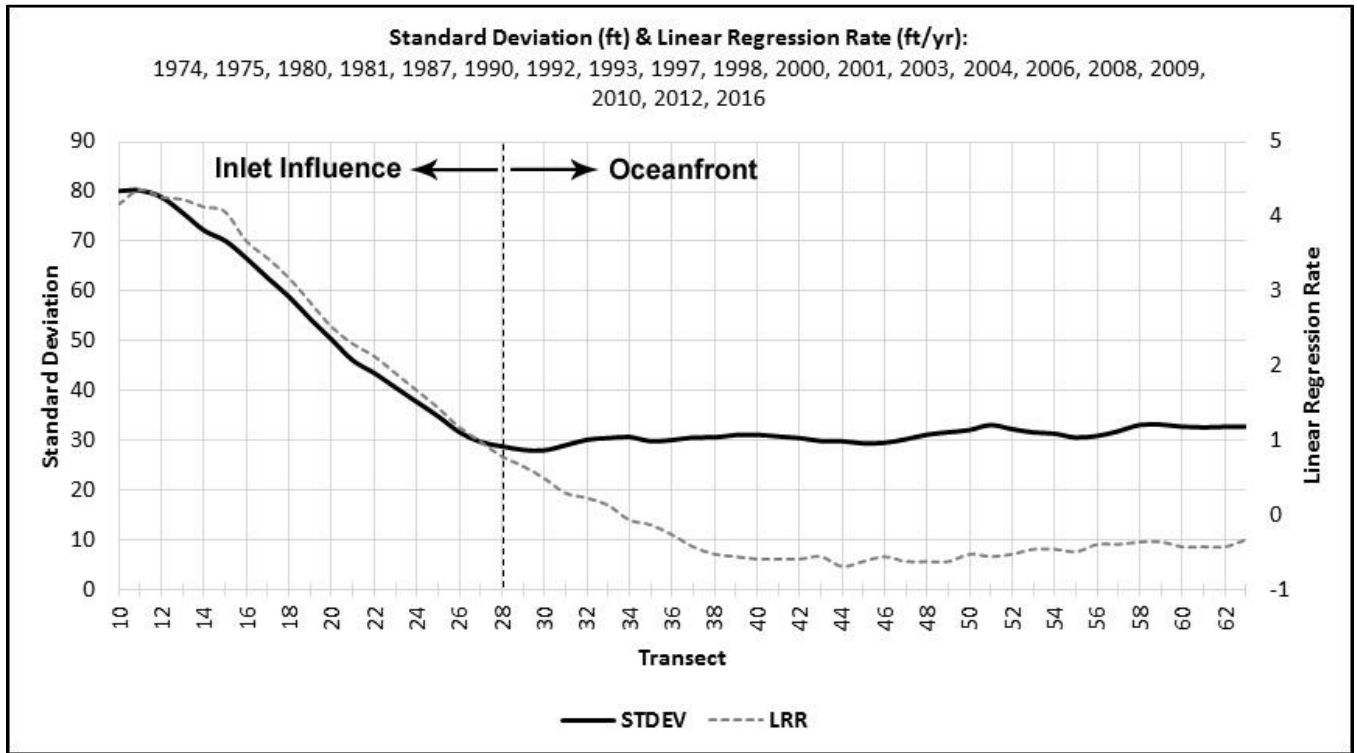
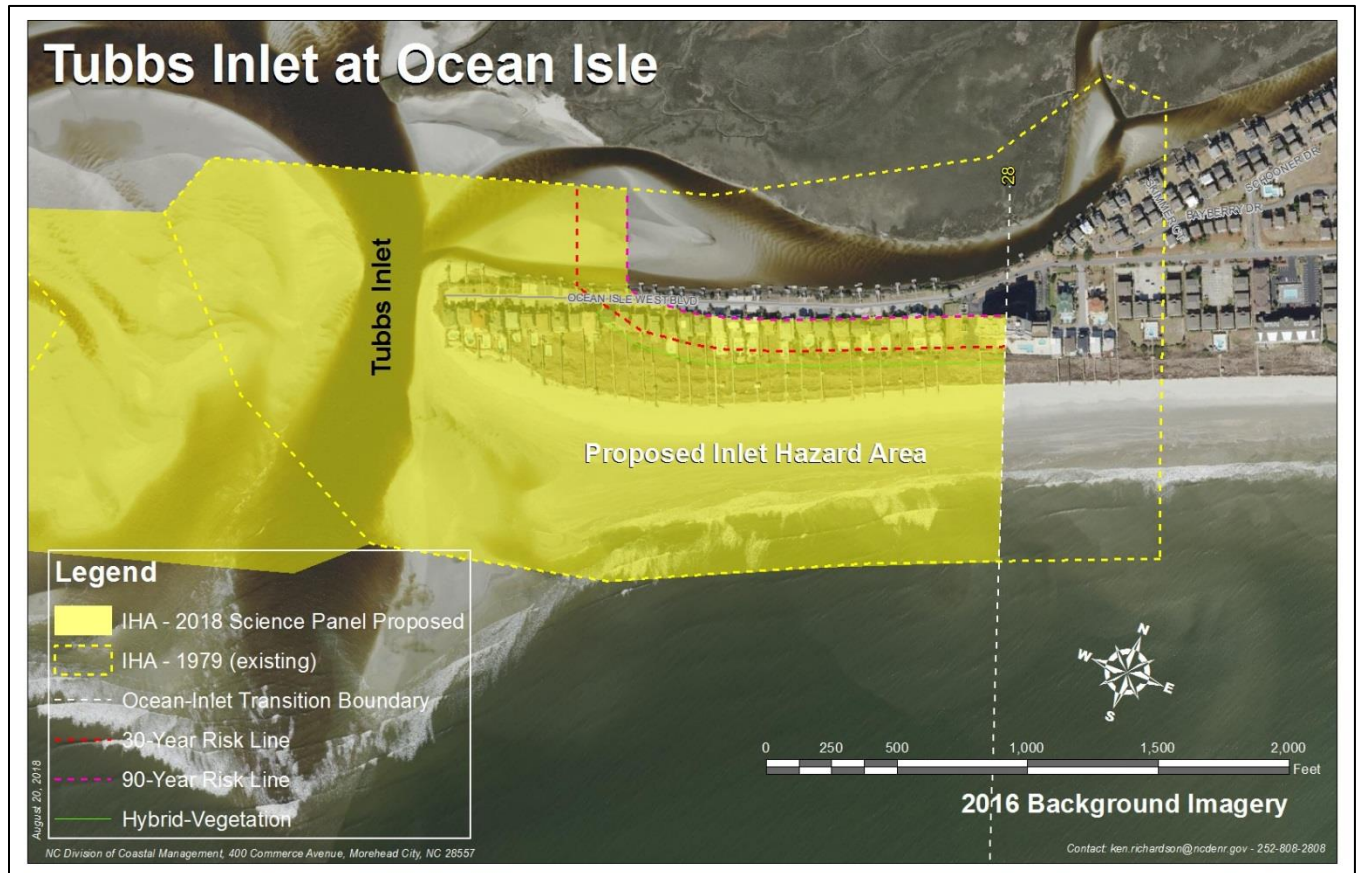


Figure 14. Map of Tubbs Inlet at Ocean Isle Beach Hybrid-Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.2 Shallotte Inlet

Shallotte Inlet has oscillating inlet shorelines with oscillating oceanfront shorelines on both sides of the inlet. It was charted as early as 1672. Seismic data from the nearshore area indicate the inlet is a permanent feature related to the paleo-channel of the ancestral Shallotte River. Since 1938 the throat position of the ebb (main) channel has shifted within a 900 feet wide corridor. Although the position of the ebb channel within the throat has not changed appreciably, its seaward portion across the ebb-tidal delta has shifted widely, approximately 13,000 feet across the offshore shoal.

The historic reorientation and repositioning of the outer bar channel from the southwest to the southeast facilitated changes in the shape of the ebb-tidal delta and its effect on the adjacent oceanfront shorelines. Since the late 1960's the ebb channel has generally been aligned in an SE-ESE direction, which has favored the accretion along the Holden Beach shoulder that has led to the bulbous shape of the western end of the island. By contrast, during the same interval, the Ocean Isle oceanfront shoreline has experienced chronic long-term erosion.

When the Shallotte inlet ebb channel orientation is positioned towards Holden Beach, the updrift shoulder of Ocean Isle experiences erosion (and vice versa). The bulbous shape of Holden Beach shoreline has been present since 1974. If the ebb channel becomes more westerly, then this accreted sand is expected to erode. Ocean Isle had the same bulbous shape between 1938 and 1958 before the ebb channel shifted and caused erosion at the eastern end of Ocean Isle. If the ebb channel once again re-orient itself toward Ocean Isle, the bulbous shape will return to Ocean Isle, and Holden Beach will erode.

In 2001, the US Army Corps of Engineers constructed a beach nourishment project along 17,000 feet of Ocean Isle Beach extending west from Shallotte Boulevard. Material used to construct the project was obtained from a borrow area in Shallotte Inlet that extended from near the AIWW, seaward to approximately the 17-foot depth contour. In essence, the borrow area created a new ebb channel oriented perpendicular to the adjacent shorelines. The location of the Shallotte Inlet channel was based on historic positions and alignments of the inlet's ocean bar channel, which seemed to have positive impacts on the east end of Ocean Isle Beach. The Shallotte Inlet borrow area has been used to provide sand for periodic nourishment of Ocean Isle.

3.2a Ocean Isle Beach side of Shallotte Inlet

Numerous sandbag revetments have been constructed along the 5,000 feet of developed shoreline adjacent to the inlet. Closest to the inlet the beach road is now 4th Street, 1st through 3rd Streets having been eroded.

Although the channel's midpoint has been relatively stable since 1938, the shoulders of both Ocean Isle Beach and Holden Beach have experienced erosion and accretion. The impact of Hurricane Hazel in 1954 caused the reorientation of the channel to move in a more easterly direction, which made Ocean Isle Beach experience accelerated erosion. Therefore, shoreline data beginning in 1933 was used for the statistical analysis (Figures 15, 16). Inlet transect-291 is the boundary along the oceanfront shoreline where erosion rates start to accelerate approaching the inlet, and inlet processes start to affect the shoreline's position (Figure 17)¹. Because of the high erosion rates near the inlet (upwards of ~15 ft/yr), the Panel decided, based on the underlying geology and surface dune topography, that the 90-yr Risk Line mapped using the IHAM fell too far inland, into an area where an increased inlet threat is unlikely. The Panel recommends moving the 90-Year Risk Line and establishing the landward limit of the recommended IHA closer to the 30-Year Risk Line (Figure 18).

¹ Updated on 04/27/2021 to add clarity to the selection of transect-291.

Figure 15. Shallotte Inlet at Ocean Isle. Vegetation Lines mapped: 1970, 1974, 1975, 1980, 1981, 1987, 1990, 1992, 1993, 1998, 2000, 2001, 2003, 2004, 2008, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 1998, 2000, 2001, 2003, 2004, 2008, 2009, 2010, 2012, 2016.



Figure 16. Shallotte Inlet at Ocean Isle. Shorelines included in the analysis: 1933, 1938, 1944, 1970, 1974, 1975, 1980, 1981, 1987, 1990, 1992, 1993, 1997, 1998, 2000, 2001, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016.

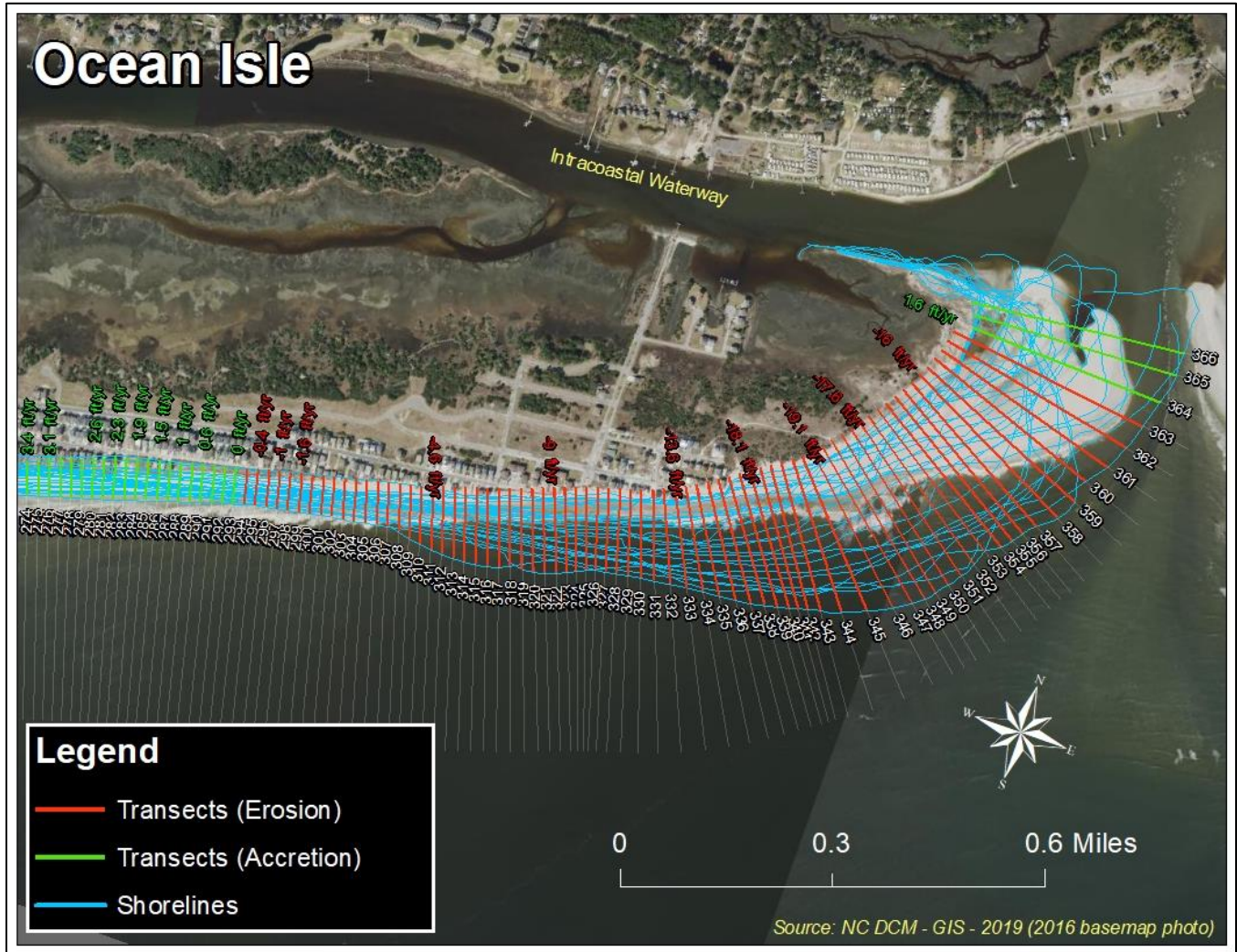
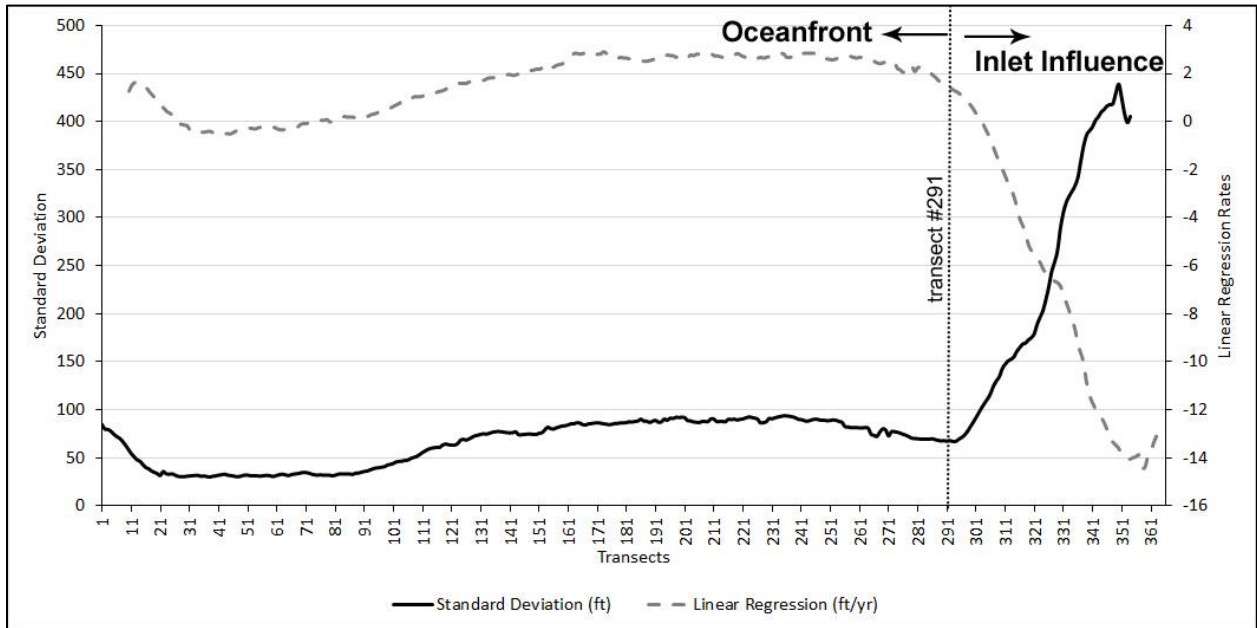
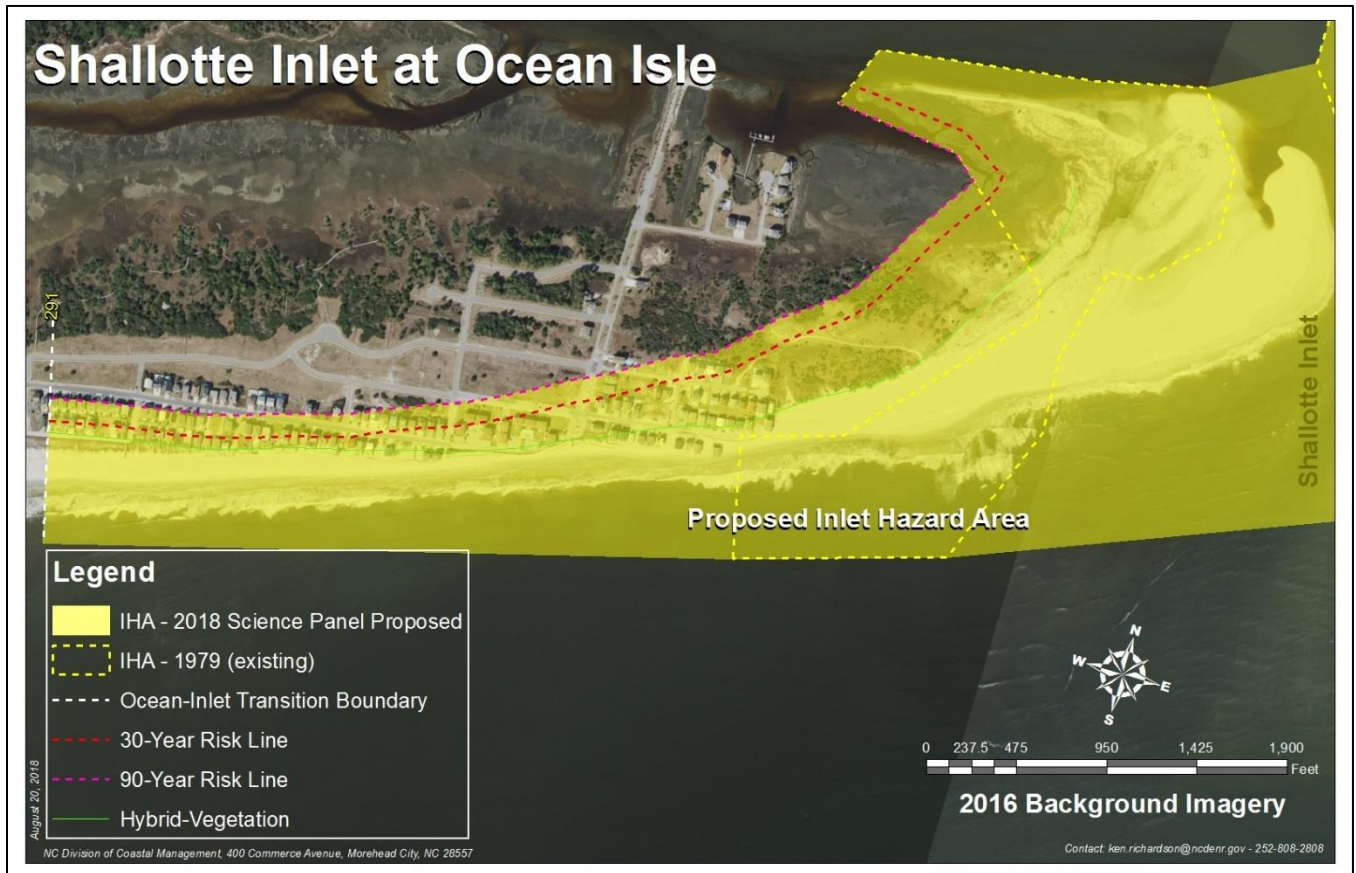


Figure 17. Based on the standard deviation of shoreline position, and linear regression of shoreline change at Shallotte Inlet-Ocean Isle Beach, transect-291 is recommended as the inlet-ocean transition boundary along the shoreline. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis)².



² Updated 04/27/2021 to correct graph labelling and include more details on selection of transect-291.

Figure 18. Shallotte Inlet at Ocean Isle Beach Hybrid-Vegetation Line and the recommended IHA boundary with the 30-Year Risk Line and modified 90-Year Risk Lines.



3.2b Holden Beach side of Shallotte Inlet

The vegetation and shoreline data for the Holden Beach side of Shallotte inlet are shown in Figures 19 and 20. Using the IHAM, transect-170 is the boundary of inlet influence along the oceanfront shoreline (Figure 21). The accretional cycle caused by the ebb channel alignment close to the Holden Beach shoreline, which began in the 1970s, results in an underestimate of the difference between the 30- and 90-Year Risk Lines closer to the inlet. To compensate for this, beginning at transect-90, the Panel adjusted the landward boundary to follow the existing IHA boundary and to connect with the inlet end of the 90-Year Risk Line (Figure 22).

Figure 19. Shallotte Inlet at Holden Beach. Vegetation Lines mapped: 1970, 1981, 1992, 1993, 1998, 2003, 2004, 2008, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 1970, 1981, 1992, 1993, 1998, 2003, 2004, 2008, 2009, 2010.

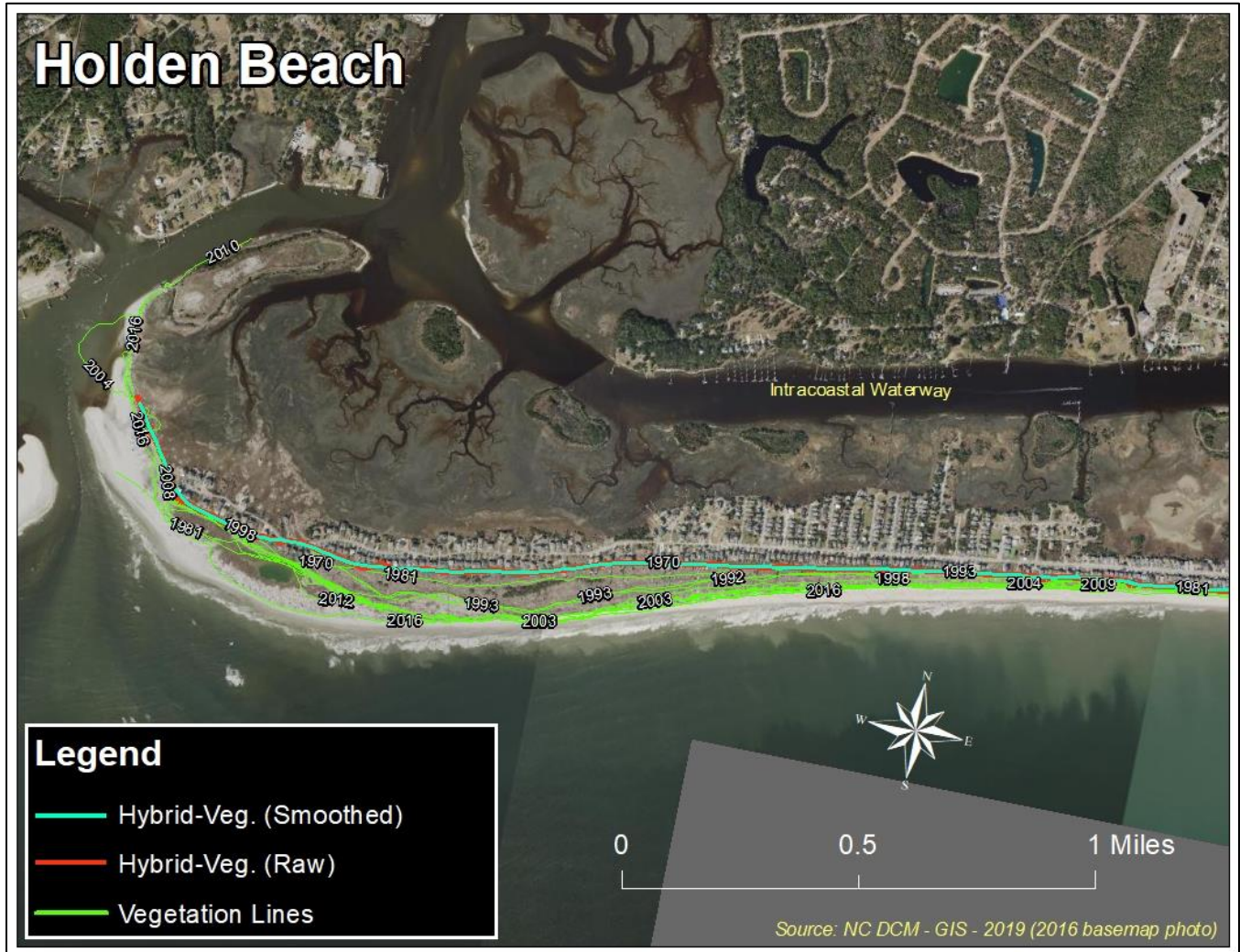


Figure 20. Shallotte Inlet at Holden Beach. Shorelines included in the analysis: 1970, 1981, 1992, 1993, 1997, 1998, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016.

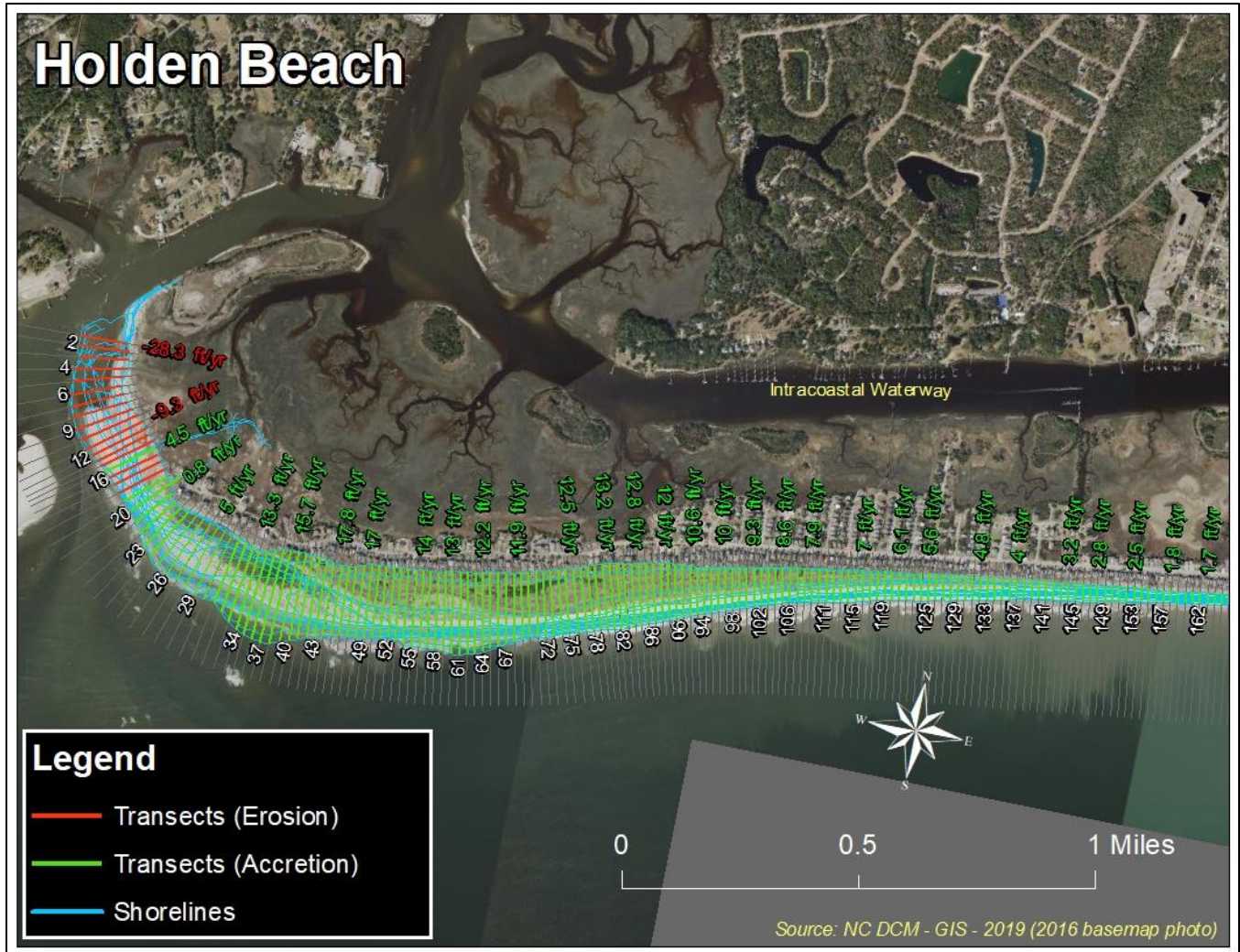


Figure 21. Based on the standard deviation of shoreline position at Shallotte Inlet-Holden Beach, transect-170 is recommended as the inlet-ocean transition boundary along the shoreline. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

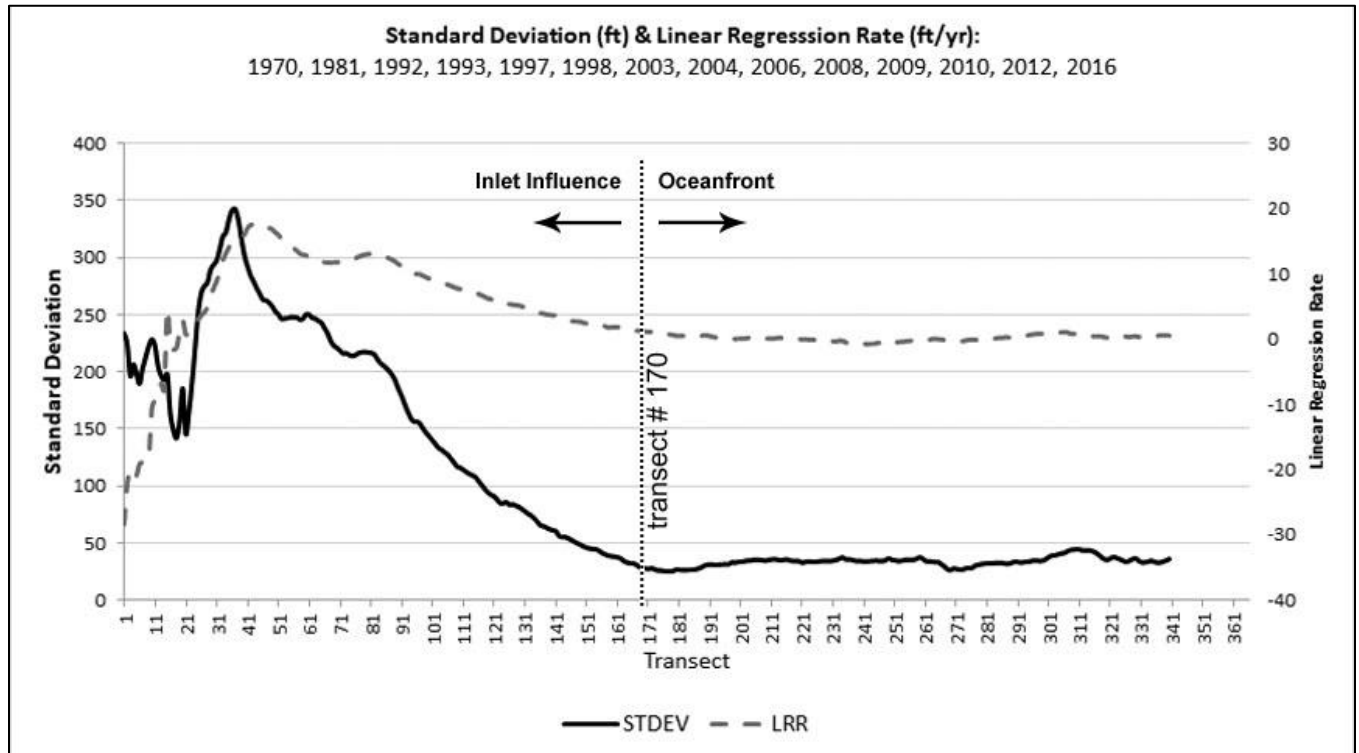
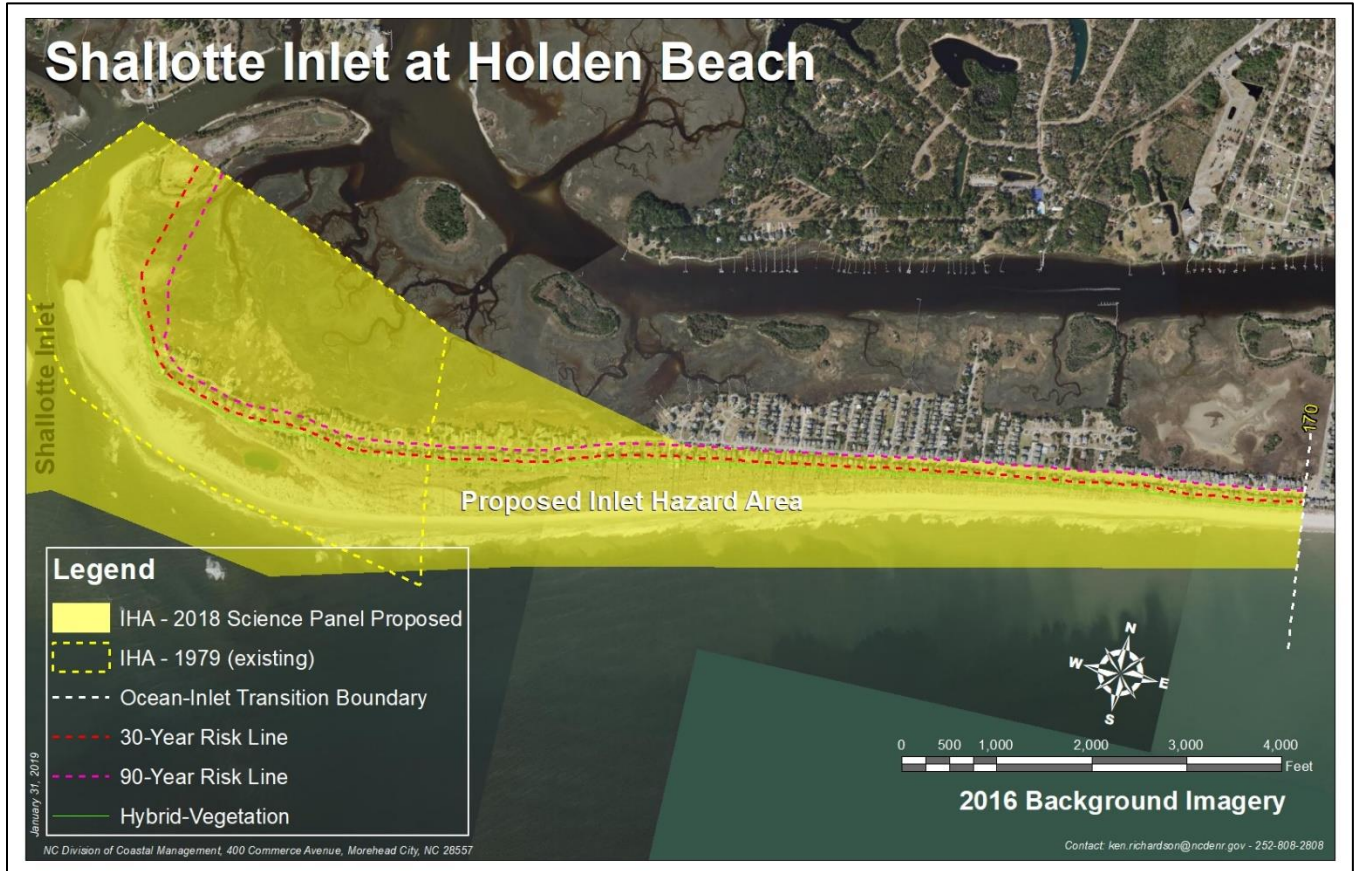


Figure 22. Shallotte Inlet at Holden Beach Hybrid-Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines. Black dashed line indicates Transect-90 where the IHA boundary was adjusted to match the existing IHA line (yellow dashed line).



3.3 Lockwood Folly Inlet

Lockwood Folly Inlet, like nearby Shallotte Inlet, is an oscillatory inlet with wide oscillations in the adjacent oceanfront shorelines. It was charted as early as 1672. Seismic data from the inner-continental shelf suggest the inlet is a permanent feature related to the paleo-channel of the ancestral Lockwood Folly River that extends across the hard bottom-dominated shoreface. Since 1938 the throat position of the ebb channel has shifted east and west within a 420 feet wide corridor. Although the throat segment of the ebb channel has been confined to a relatively narrow zone, the outer segment of the channel has migrated to the southwest and the southeast across a 7,250 feet wide length of the oceanfront shorelines. Because of the complex pattern of movement of the ebb channel across the outer bar, the symmetry of the ebb delta has continually been altered as has the protective wave-sheltering effect of the shoals on the ocean shorelines.

The contrasting patterns of change along the Holden Beach and Oak Island oceanfront shorelines directly reflect the influence of the ebb channel's position, its alignment and the attendant shape changes of the ebb-tidal delta. In general, the pre-dominant historic southeasterly alignment of

the ebb channel has promoted much of the long-term chronic erosion along Holden Beach involving hundreds of feet of shoreline retreat and by contrast the hundreds of feet of progradation along Oak Island.

Lockwood Folly Inlet is an authorized Federal shallow-draft navigation project. The navigation channel is periodically maintained by dredging.

3.3a Holden Beach side of Lockwood Folly Inlet

Vegetation and shoreline data between 1970 and 2016 illustrate the effects on the shoreline of low-elevation swash bars consistently welding onto the ocean shoreline near the inlet (Figures 23, 24). The shoreline more distant from the inlet has been eroding. Sandbag revetments have been installed to armor roads and houses along 2,000 feet of developed shoreline adjacent to the inlet.

Using the IHAM, transect-477 is recommended as the boundary of inlet influence along the oceanfront shoreline (Figure 25). Because use of the 17-point running average of the shoreline change rate can be problematic across a sharp transition between eroding and accreting sections, the Panel used the unsmoothed erosion rates starting at inlet transect-540 and ending at transect-547 to establish the Risk Lines. The recommended boundary of the IHA is the 90-Year Risk Line (Figure 26).

Figure 23. Lockwood Folly Inlet at Holden Beach. Vegetation Lines mapped: 1971, 1978, 1988, 1993, 1998, 2003, 2004, 2008, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 1971, 1988, 1993, 1998, 2003, 2004.

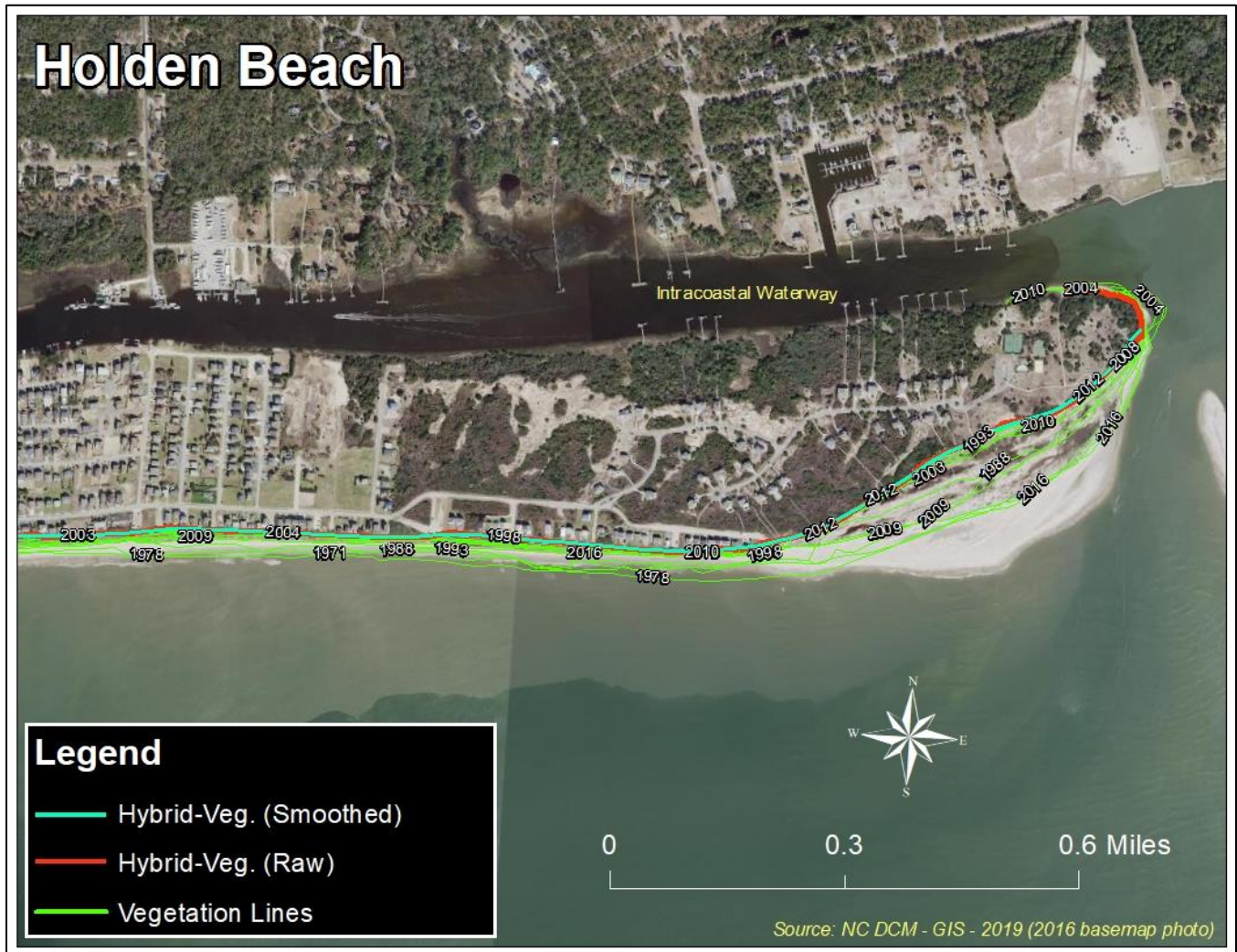


Figure 24. Lockwood Folly Inlet at Holden Beach. Shorelines included: 1970, 1971, 1978, 1988, 1993, 1997, 1998, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016.

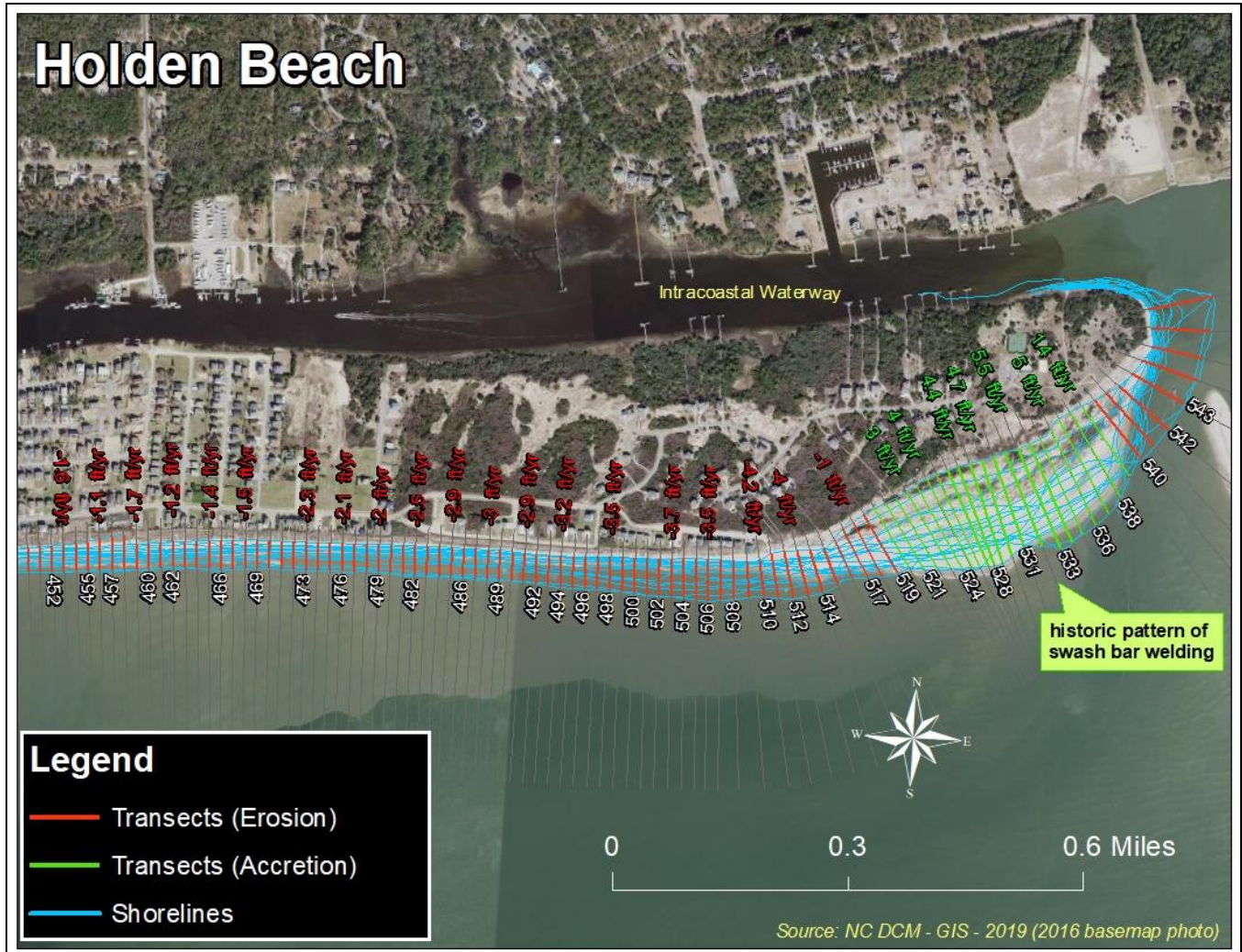
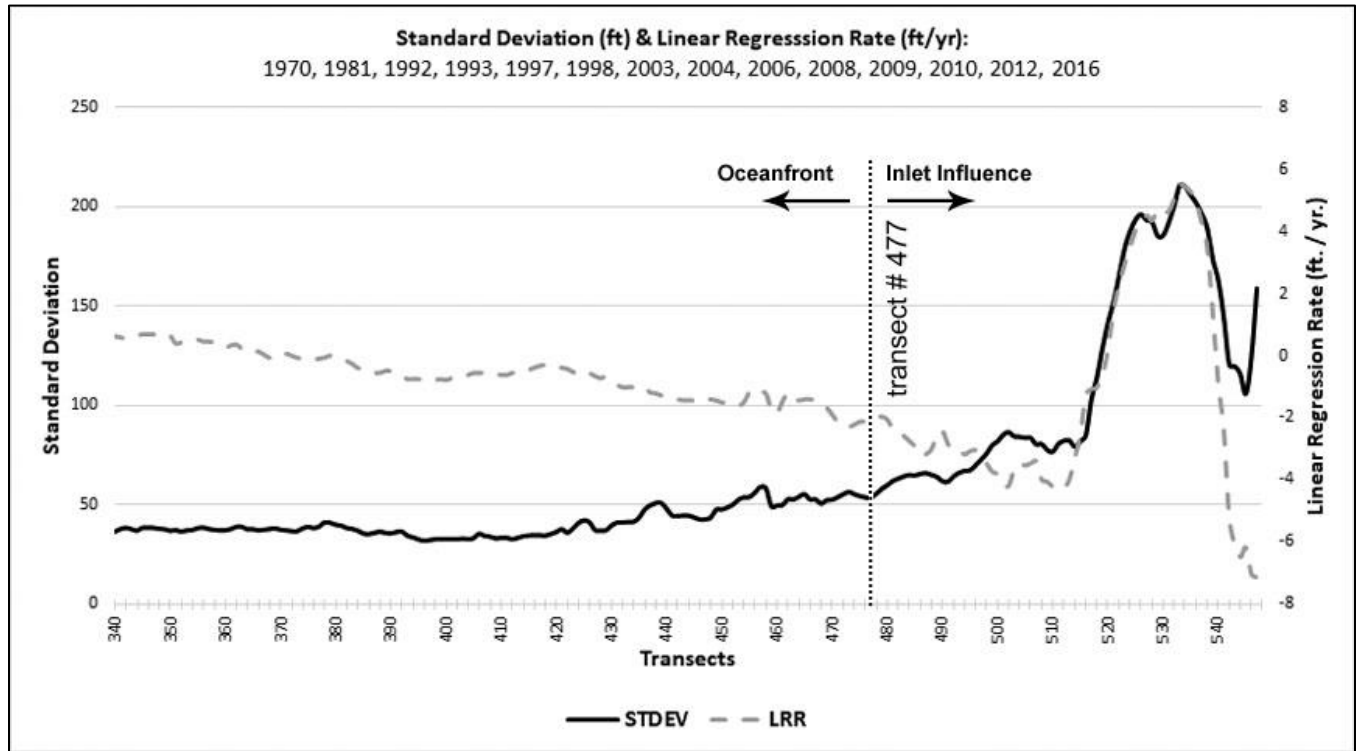
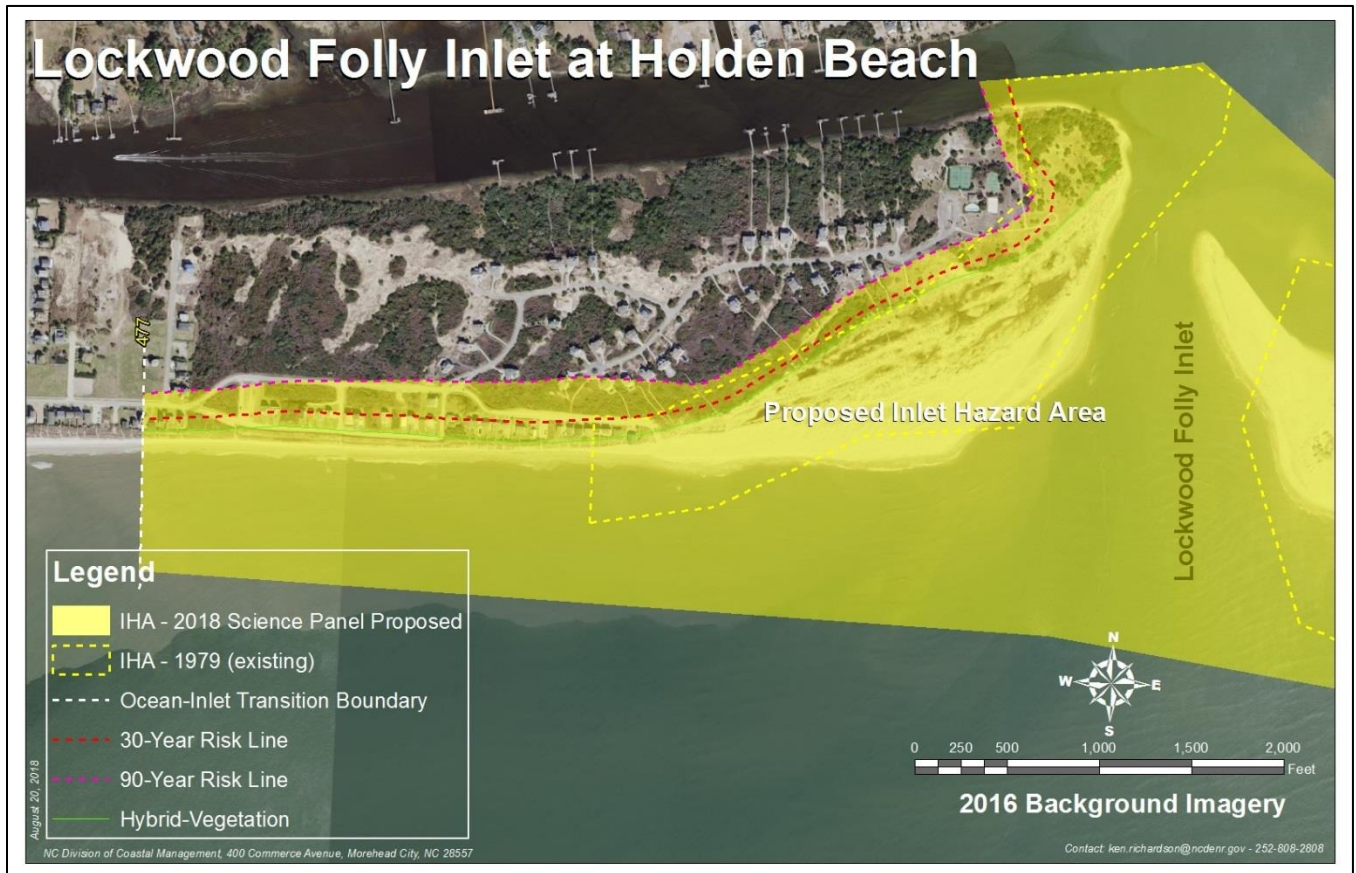


Figure 25. Based on the standard deviation of shoreline position and linear regression rate of shoreline change at Lockwood Folly Inlet-Holden Beach, transect-477 is recommended as the inlet-ocean transition boundary along the shoreline. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis)³.



³ Updated on 04/27/2021 to add clarity for selection of transect-477.

Figure 26. Lockwood Folly Inlet at Holden Beach Hybrid Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.3b Oak Island side of Lockwood Folly Inlet

Oak Island experienced severe erosion between 1974 to 1984 (Cleary and Marden, 1999) causing building failures and relocations; partial loss of the loop road; and the construction of various erosion control structures. Analysis of longer-term data (1971-2016) demonstrate the shoreline's recovery resulting in extensive long-term accretion. Some of the lots that previously lost buildings were redeveloped after 2000. Several of the new houses that were threatened by a local shift in the ebb channel in 2014-6 were armored with sandbags. Vegetation and shoreline data for the Oak Island side of Lockwood Folly Inlet are shown in Figures 27 and 28.

Using the IHAM, the standard deviation suggests that inlet influence extends to at least transect-85. However, the shoreline change, or LRR, appears to be influenced and remains high to transect-70 (Figure 29). An accretionary dune feature exists centered around transect-63 and the visible landward dip in the HVL ending at transect-70. Transect-70 is recommended as the IHA boundary to include the accretionary dunes influenced by the inlet. The recommended landward IHA boundary is the 90-Year Risk Line (Figure 30).

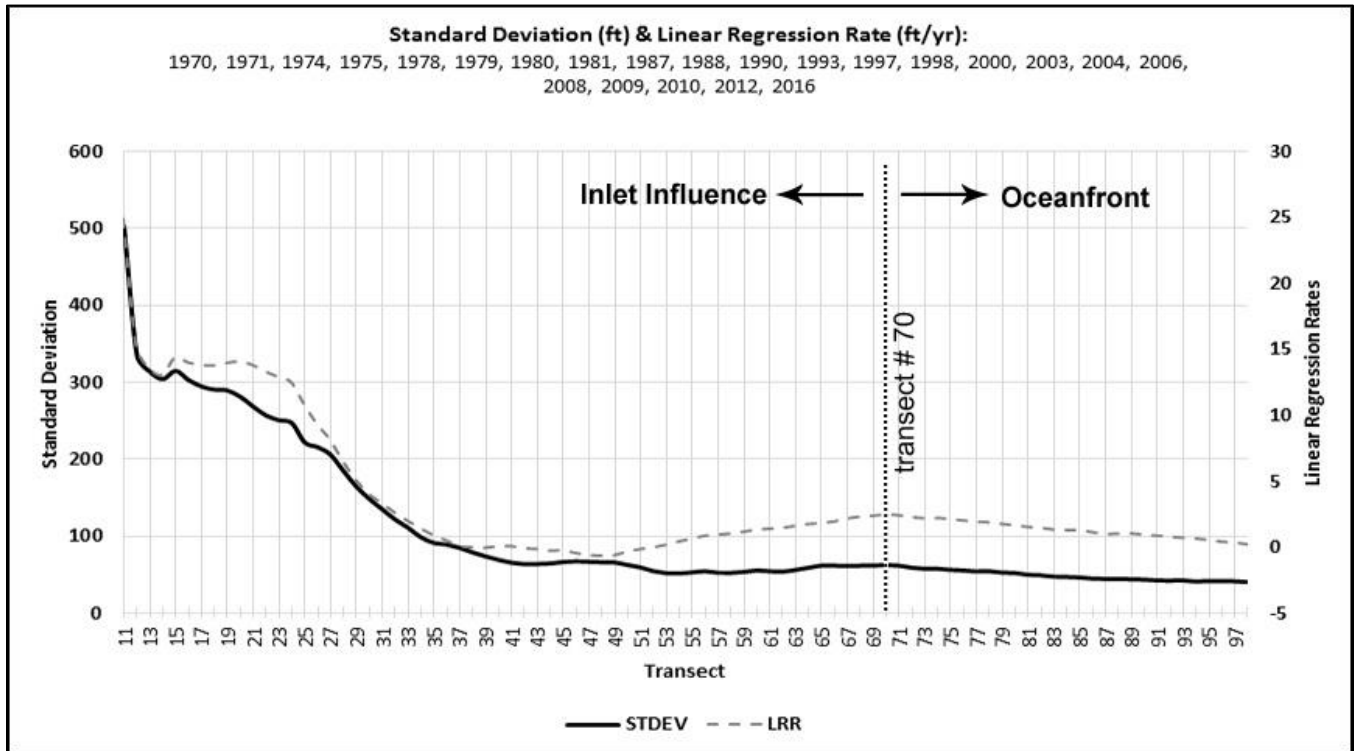
Figure 27. Lockwood Folly Inlet at Oak Island. Vegetation Lines mapped: 1971, 1974, 1975, 1978, 1979, 1980, 1987, 1988, 1990, 1993, 1998, 2000, 2003, 2004, 2008, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 1971, 1987, 1988, 1990, 1993, 2016.



Figure 28. Lockwood Folly Inlet at Oak Island. Shorelines included: 1970, 1971, 1974, 1975, 1978, 1979, 1980, 1981, 1987, 1988, 1990, 1993, 1997, 1998, 2000, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016.



Figure 29. Based on the standard deviation of shoreline position and linear regression rate of shoreline change at Lockwood Folly Inlet-Oak Island, transect-70 is recommended as the inlet-ocean transition boundary along the shoreline. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis)⁴.



⁴ Updated on 04/27/2021 to include clarity for selection of transect-70

Figure 30. Lockwood Folly Inlet at Oak Island Hybrid Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.4 Carolina Beach Inlet

Carolina Beach Inlet is an oscillatory inlet that was opened by private interests in 1952, at a location approximately 7,500 feet northeast of the Town of Carolina Beach. The inlet was opened along the closure zone of former Sugarloaf Inlet, a short-lived inlet of the late 19th Century. Carolina Beach inlet is an authorized Federal shallow-draft navigation project that connects the open ocean and the AIWW through a short, narrow and relatively deep navigation channel. The inlet also provides a connection to the Cape Fear River across the mainland via Snows Cut. Since the 1970s a designated borrow area has been regularly used as a borrow source for a US Army Corps of Engineers beach nourishment project along sections of Carolina Beach. During the past 50 years the inner and outer segments of the main channel have shifted toward Masonboro Island as much as 475 feet. After the opening of the inlet, the adjacent oceanfront shorelines along both Carolina Beach and Masonboro Island began to erode at rapid rates that ultimately led to a significant landward offset of Carolina Beach. As part of the US Army Corps of Engineers project a rock revetment was constructed to protect the northern 1,800 feet of development. The chronic erosion was related to the reduced rate of sand bypassing at the inlet as the ebb-tidal delta continued to impound sand. The reduced rate of bypassing also severely impacted

updrift Masonboro Island, where the oceanfront has retreated approximately 500 feet since 1962.

3.4a Carolina Beach side of Carolina Beach Inlet

Vegetation and shoreline data for the Carolina Beach side of Carolina Beach Inlet are shown in Figures 31 and 32. Using the IHAM, transect-1267 is the boundary of inlet influence along the oceanfront shoreline (Figure 33). The 90-Year Risk Line is recommended as the landward boundary until it intersects with the 1979 IHA boundary closer to the inlet to include the sand spit along the inlet channel (Figure 34).

Figure 31. Carolina Beach Inlet at Carolina Beach. Vegetation Lines mapped: 1971, 1974, 1977, 1984, 1992, 1998, 2002, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 1971, 1974, 1977, 1984, 1992, 1998, 2002, 2006, 2008, 2009, 2012.

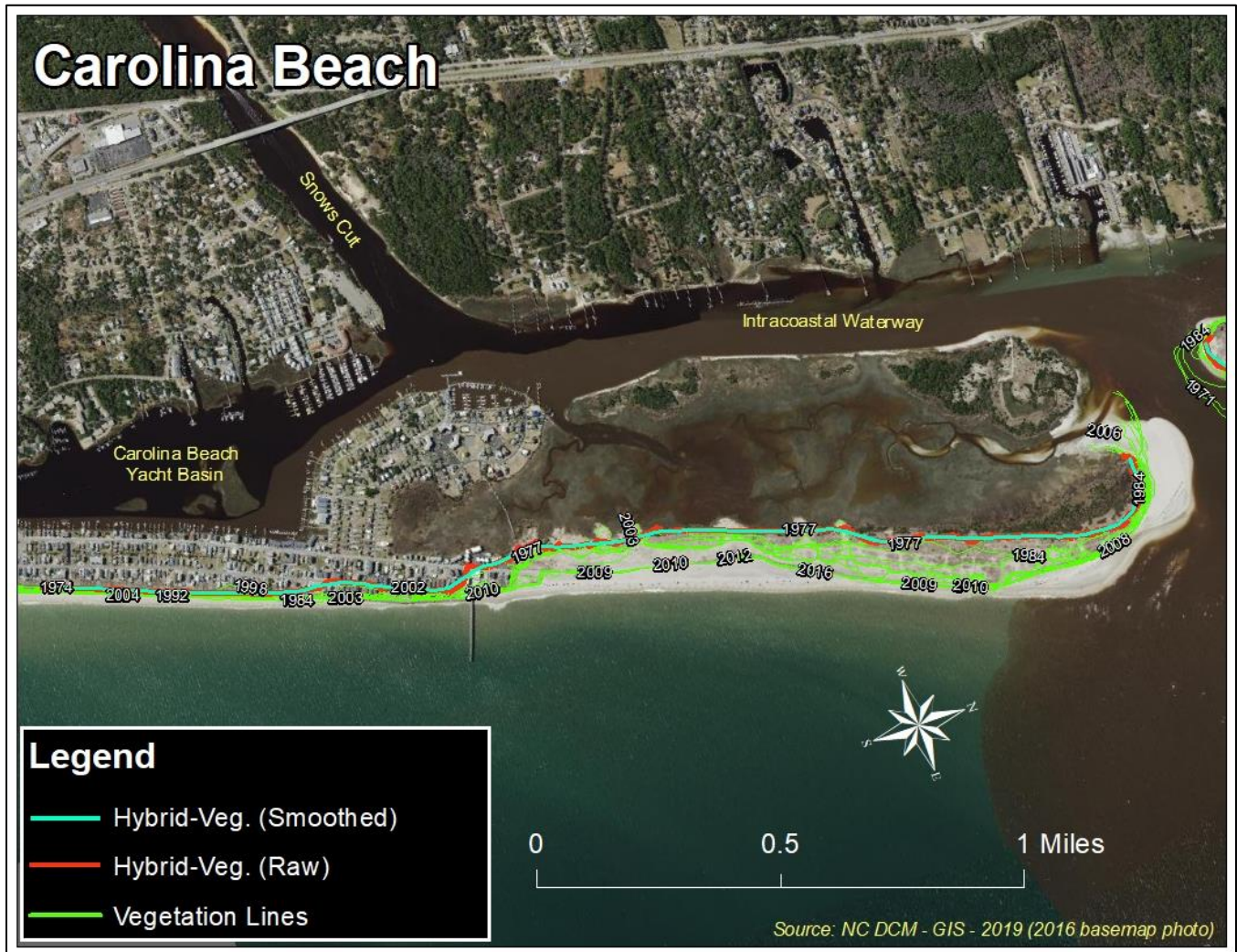


Figure 32. Carolina Beach Inlet at Carolina Beach. Shorelines included in the analysis: 1971, 1973, 1974, 1977, 1984, 1992, 1997, 1998, 2002, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016.

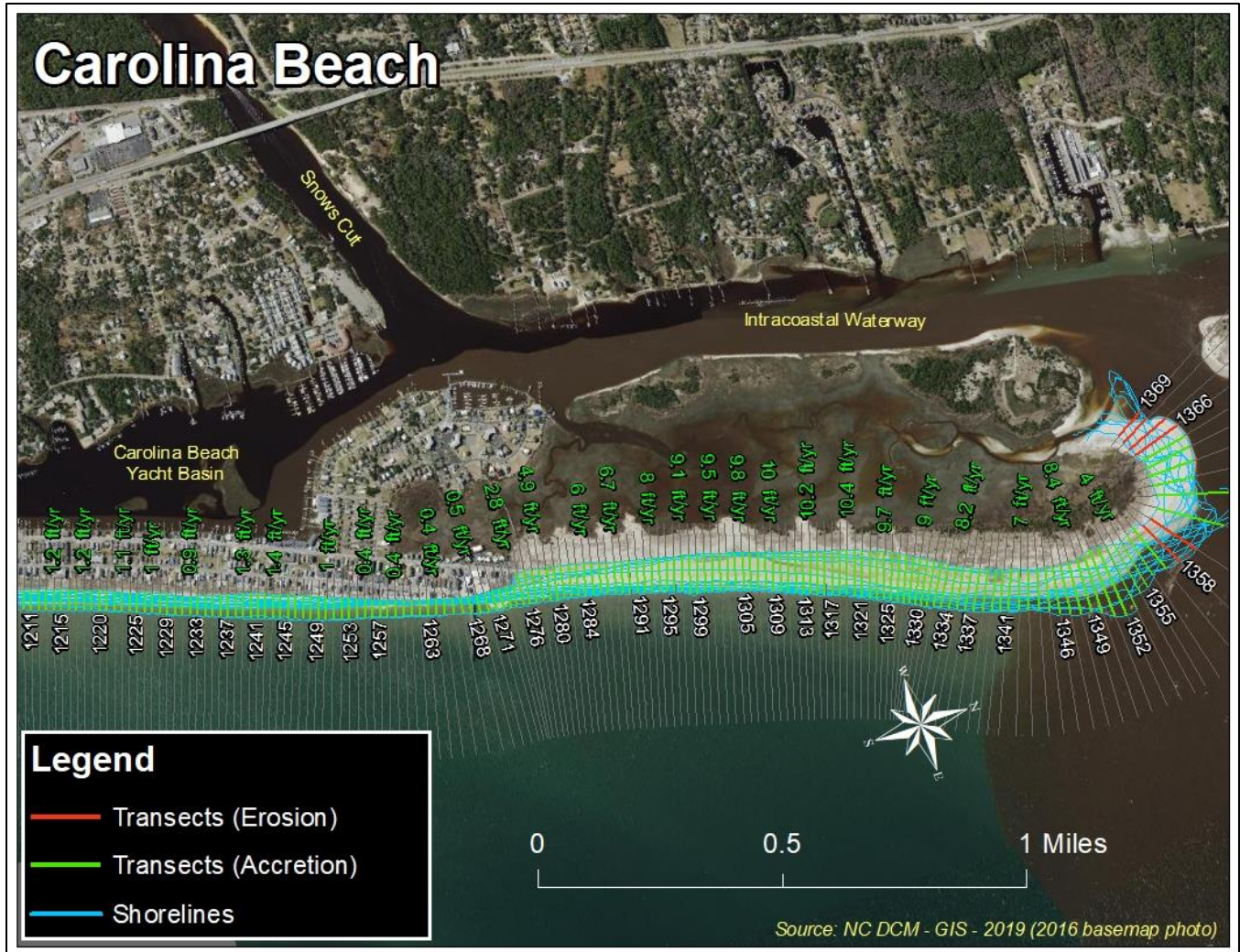


Figure 33. Based on the standard deviation of shoreline position at Carolina Beach Inlet-Carolina Beach, transect-1267 is recommended as the inlet-ocean transition boundary along the shoreline. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

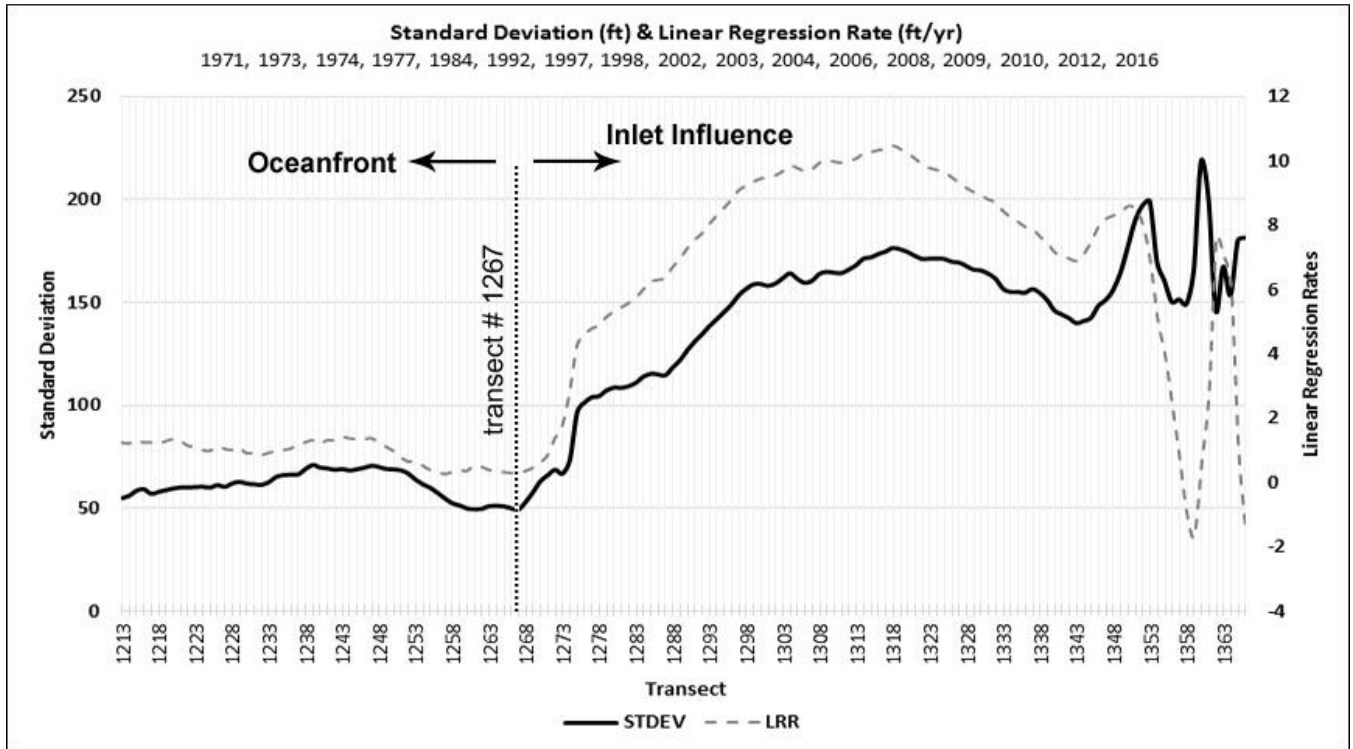
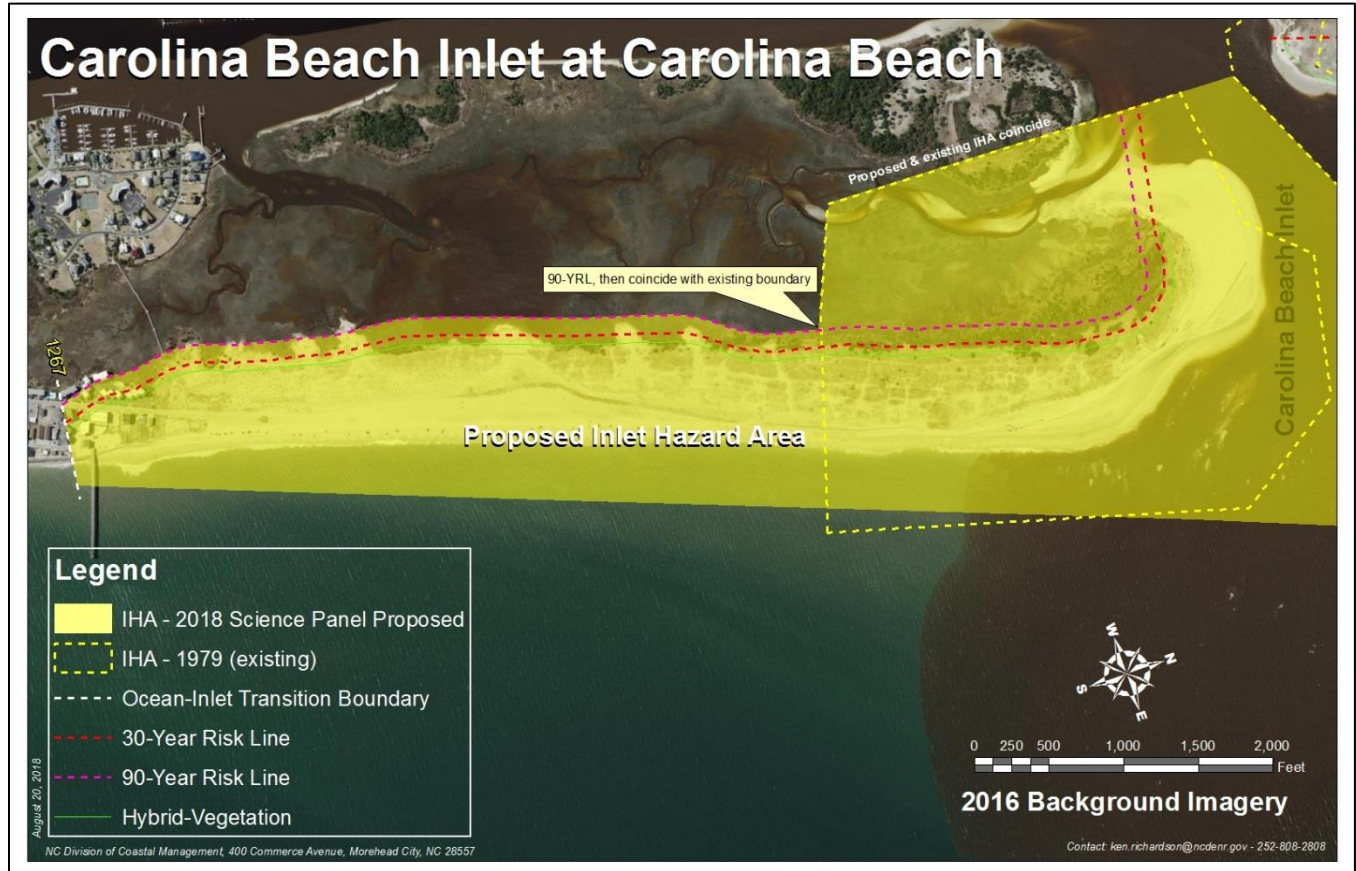


Figure 34. Carolina Beach Inlet at Carolina Beach Hybrid Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.4b Masonboro Island side of Carolina Beach Inlet

Carolina Beach Inlet is bordered on the north by uninhabited Masonboro Island, a narrow, low-lying and dynamic barrier island characterized by extensive overwash, a 1954 breach during Hurricane Hazel, and a wide back-barrier marsh. The entire island is affected by both Carolina Beach Inlet and Masonboro Inlet to the north. This can be seen in the vegetation and shoreline data shown in Figures 35 and 36, which illustrate the high rates of erosion occurring within Carolina Beach Inlet and along most of the oceanfront. The erosion is a consequence of sediments not bypassing the Masonboro Inlet jetties from the north. Accretion is occurring at the north end of the island in an area that is within the depositional fillet of and protected by the Masonboro Inlet south jetty.

Using the IHAM, the standard deviation in shoreline position was examined along the Masonboro Island oceanfront and it is high everywhere, being lowest at transect-376 and increasing toward each inlet (Figure 37). Based on that finding and considering that the 90-Year Risk Line falls into the back-barrier marsh, the recommended IHA extends along the entire length of Masonboro Island (Figure 38).

Figure 35. Carolina Beach and Masonboro Inlets at Masonboro Island. Vegetation Lines mapped: 1971, 1974, 1977, 1984, 1992, 1998, 2000, 2002, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 1974, 1977, 1984, 1998, 2000, 2002, 2003, 2004, 2006, 2008, 2010, 2012, 2016.

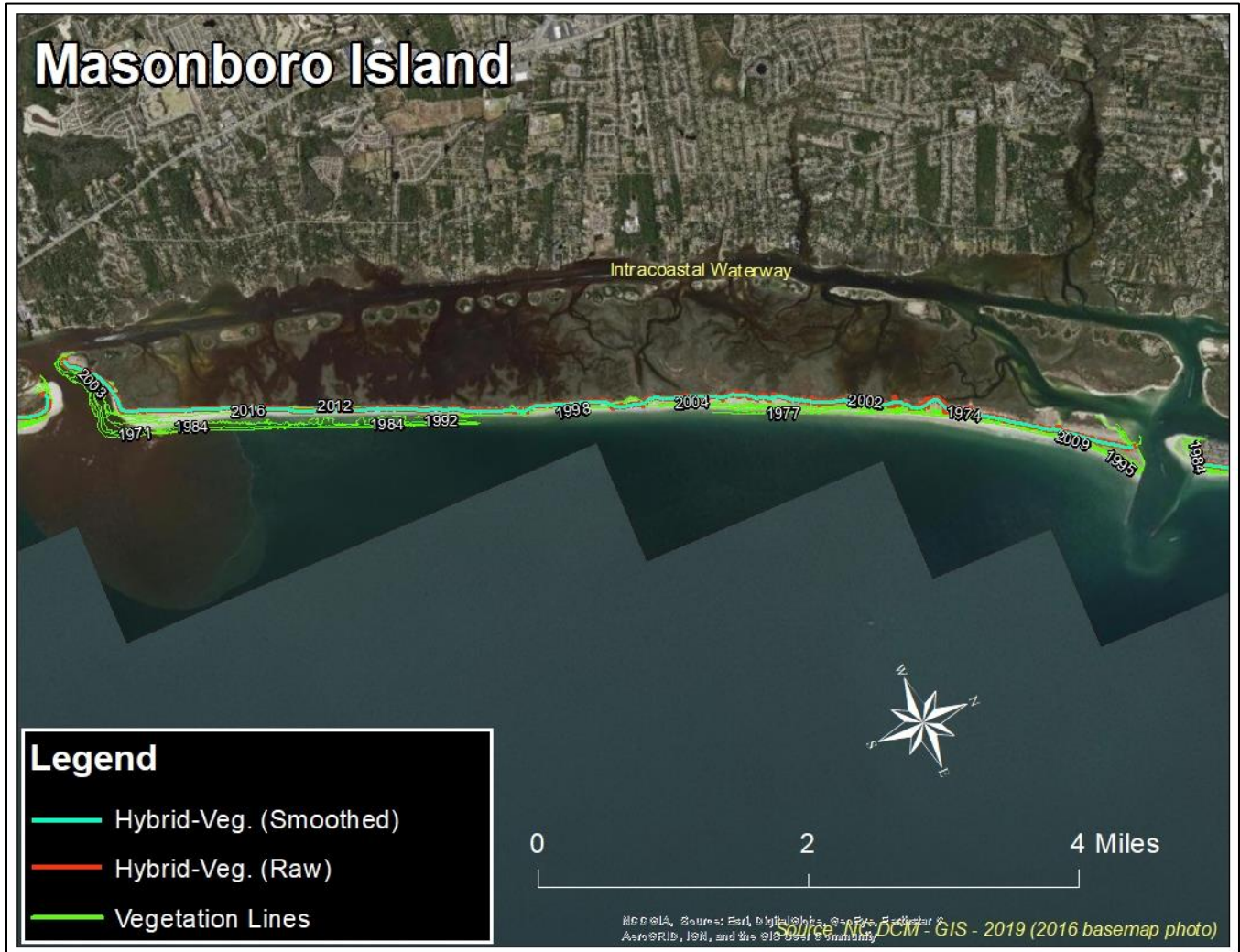


Figure 36. Carolina Beach and Masonboro Inlets at Masonboro Island. Shorelines included in the analysis: 1971, 1974, 1977, 1984, 1992, 1997, 1998, 2000, 2002, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016.

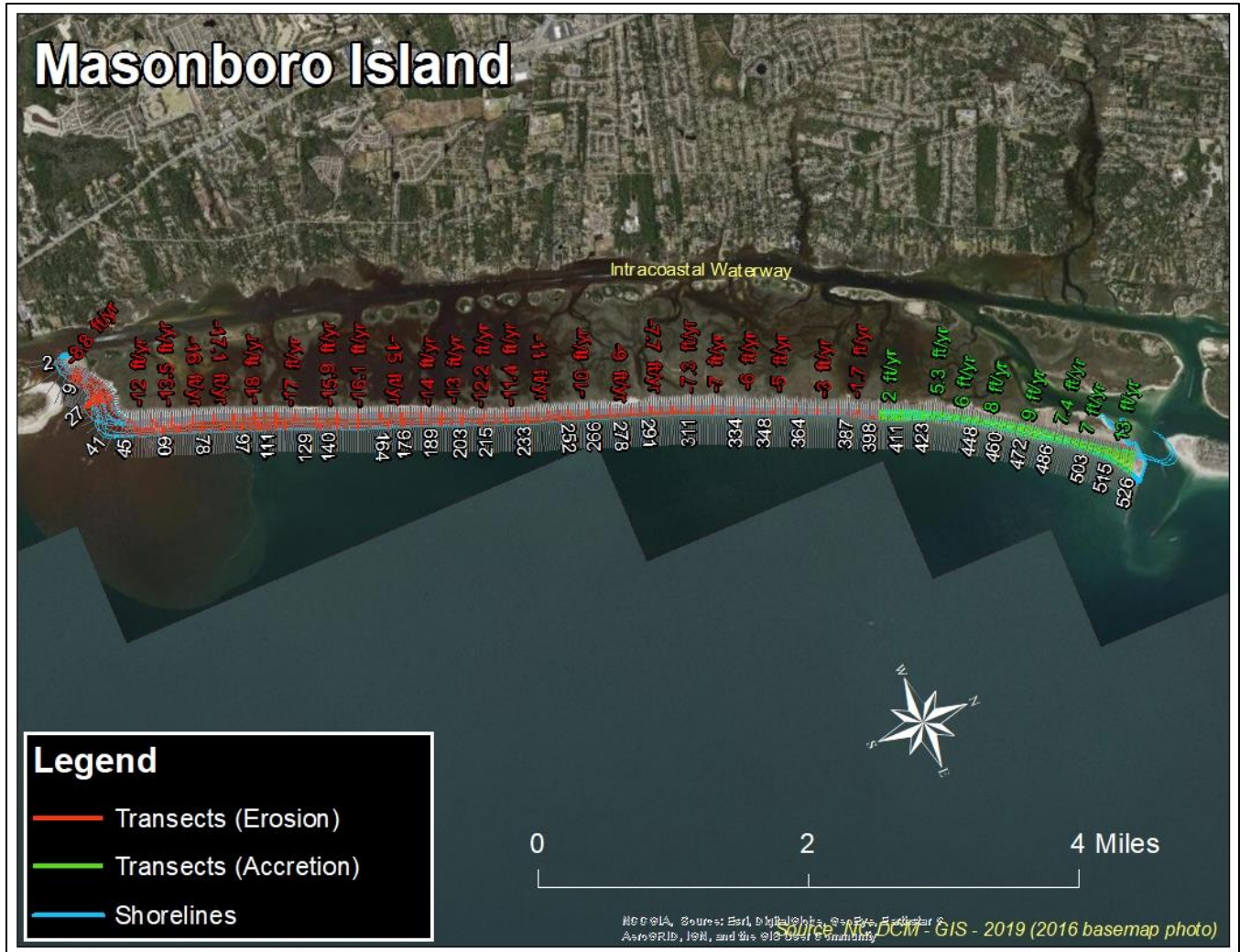


Figure 37. Masonboro Island Standard Deviation of Shoreline Change and Linear Regression Rates. Because both Carolina Beach Inlet (left) and Masonboro Inlet (right) influence Masonboro Island's entire shoreline, the recommended IHA includes Masonboro Island in its entirety. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

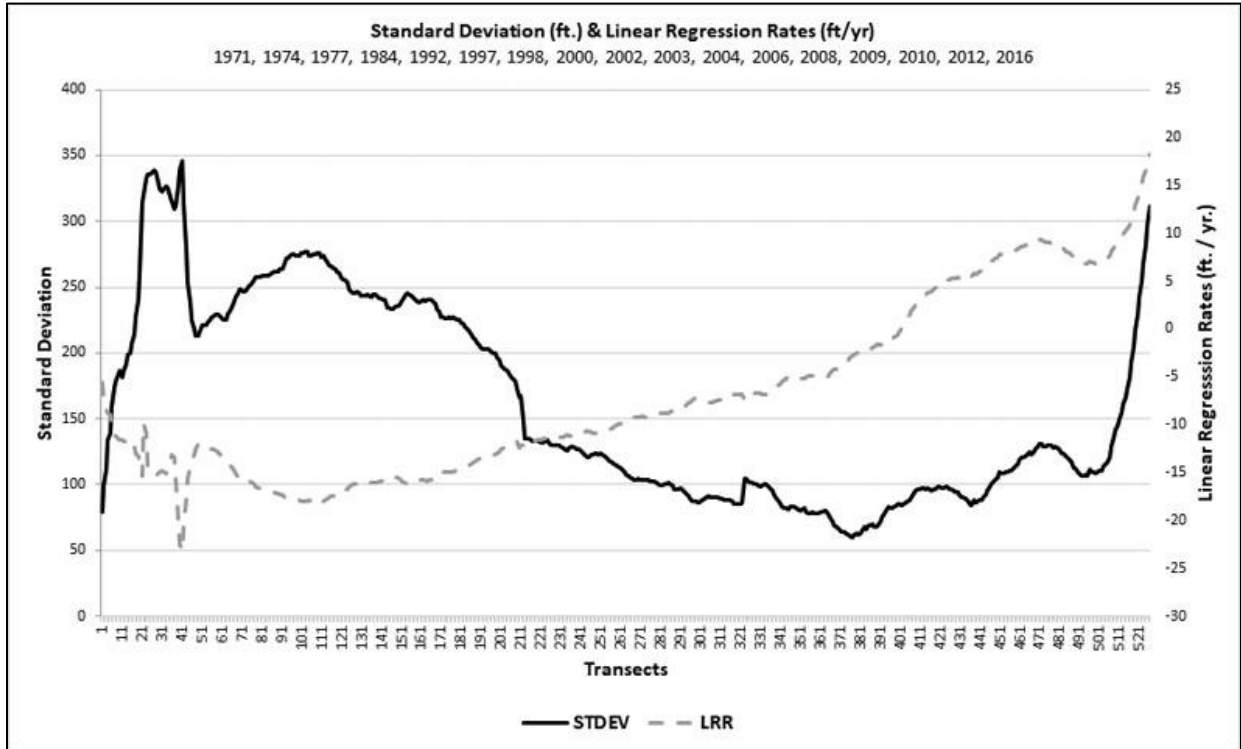


Figure 38. Carolina Beach and Masonboro Inlets at Masonboro Island Hybrid Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.5 Masonboro Inlet

Masonboro Inlet is a migrating inlet that is now stabilized. It was documented on historic charts from 1733 and likely opened in a storm in the early 1700s approximately 7,650 feet northeast of its current location. Since completion of the AIWW (ca. 1930) the inlet and the tidal basin have been modified by a variety of projects on Wrightsville Beach designed to mitigate the oceanfront erosion, dredge and landfill along the sound and improve navigation. In May 1950, a navigation project was authorized by Congress that proposed the construction of a 14-foot deep by 400-foot wide channel across the ebb-tidal delta flanked by twin jetties and a series of access channels to the AIWW. A single northern weir-jetty was completed in 1966. The south jetty was constructed in 1981.

In the first decade after construction, the north jetty trapped sand extending at least a mile north of the jetty with up to 400 feet of accretion near the jetty. Since then, the low weir has stabilized the ocean shoreline changes by allowing excess sand from the north to be transported inside the jetty, preventing additional entrapment north of the jetty.

The Wrightsville Beach Storm Damage Reduction Project (dune and beach nourishment), completed in 1965, initially involved the placement of approximately 3.0 million cubic yards of material along the oceanfront, extending from the weir-jetty northward to the closure zone of Moore's Inlet, approximately 2.5 miles north. Since that time an additional 13 million cubic yards of beach fill has been used to renourish the oceanfront beach north of the accretion caused by the jetty. Sand accumulating in the inlet area and adjacent navigation channels is periodically dredged for nourishment to the north, backpassed onto Wrightsville Beach and less frequently bypassed to the south onto Masonboro Island as mitigation for the jetty system.

Following construction of the north jetty, the north end of Masonboro Island experienced rapid oceanfront erosion as the sheltered inlet shoreline rapidly migrated north, narrowing the inlet and eventually eroding the inlet shoreline on Wrightsville Beach. By the initiation of construction of the south jetty, erosion threatened the street at the south end of Wrightsville Beach. The shifting navigation channel threatened to undermine sections of the new north jetty. Those changes initiated plans to complete the other half of the originally designed twin jetties.

Construction of the south jetty in 1980 trapped sand on the northern oceanfront of Masonboro Island, reversing the rapid erosion that followed construction of the north jetty. Within the next decade, the fillet created south of the new jetty accreted over 420 feet and eventually stabilized. The fillet has stabilized at least 3000 feet of Masonboro Island shoreline immediately south of the jetty.

Construction of the south jetty simultaneously blocked the sand transport driving the migration of the northern tip of the island and navigation channel. After sand transport from the south was terminated, the remaining primary sand transport into the inlet was over the weir in the north jetty. That reversed the prior erosion on the Wrightsville Beach inlet shoreline inside the jetties. Over the decade following construction of the south jetty, the tip of the island accreted more than 1300 feet into the inlet. The spit eventually interfered with the navigation channel alignment and threatened to undermine the south jetty. In 1996 the US Army Corps of Engineers began removing the southern 400 feet of spit. The material is now regularly removed for beachfill in Wrightsville Beach or jetty mitigation on Masonboro Island.

Since construction of the second jetty, the ebb-tidal delta has enlarged, extended seaward and steepened. The emplacement of the jetties and the consequent increase in the tidal prism has increased sediment entrapment within the ebb-tidal delta and along the fillets. The twin jetties have cut off all natural bypassing across the inlet. The only bypassing is by the irregular dredging to Masonboro Island. Although several thousand feet of ocean shoreline on the north end of Masonboro Island has accreted or stabilized due to the fillet of the south jetty, the end of natural bypassing and the limited volume of dredged mitigation bypassing has accelerated erosion on much of the rest of the island.

3.5a Masonboro Island side of Masonboro Inlet

As discussed in Section 3.4b, the Masonboro Island side of Masonboro Inlet is included in the island-wide recommended IHA for Masonboro Island. The northern tip of Masonboro Island was removed by dredging after the construction of the south jetty in 1980. The jetty now armors the entire inlet shoreline.

3.5b Wrightsville Beach side of Masonboro Inlet

Vegetation and shoreline data for Wrightsville Beach at Masonboro Inlet are shown in Figures 39 and 40. After the north jetty construction caused an initial accretion, the ocean shoreline has been relatively stable since the 1970s for more than a mile north of the structure. Prior to construction of the north jetty and beach nourishment in 1965, the NC General Assembly declared the oceanfront dunes and beach, including all sand trapped by the jetty, were state-owned. Construction of the south jetty in 1980 reversed the previous northward migration of the inlet. Because of this, only shorelines since 1992 were used for analysis.

Using the IHAM, transect-16 was first identified as separating inlet from oceanfront influence. However, transect-12 is the terminus point of the north inlet jetty, and its standard deviation is only slightly higher. The recommended IHA boundary is the jetty (Figure 41). The 30- and 90-Year Risk Lines and IHA boundary are within the north jetty inlet shoreline (Figure 42).

Figure 39. Masonboro Inlet at Wrightsville Beach. Vegetation Lines mapped: 1992, 1995, 1998, 2000, 2002, 2003, 2004, 2006, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 1992, 1998, 2000, 2002, 2003, 2004, 2009, 2010.



Figure 40. Masonboro Inlet at Wrightsville Beach. Shorelines included: 1973, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2002, 2003, 2004, 2006, 2009, 2010, 2012, 2016.



Figure 41. At Masonboro Inlet-Wrightsville Beach, the standard deviation of shoreline position has a break in slope around transect-16. Transect-12 is the anchor point of the north inlet jetty, and since its standard deviation is only slightly higher it is recommended as the IHA boundary between inlet and oceanfront influence. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

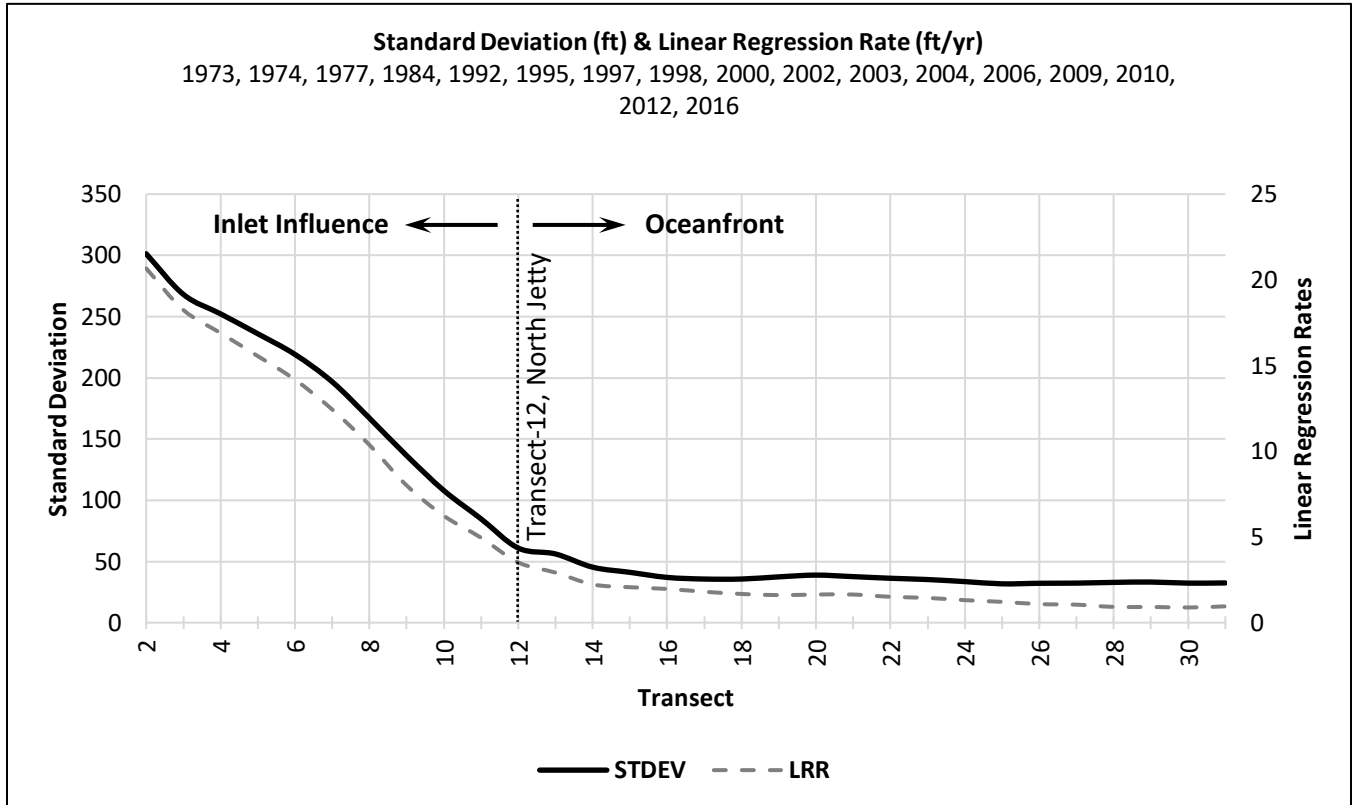
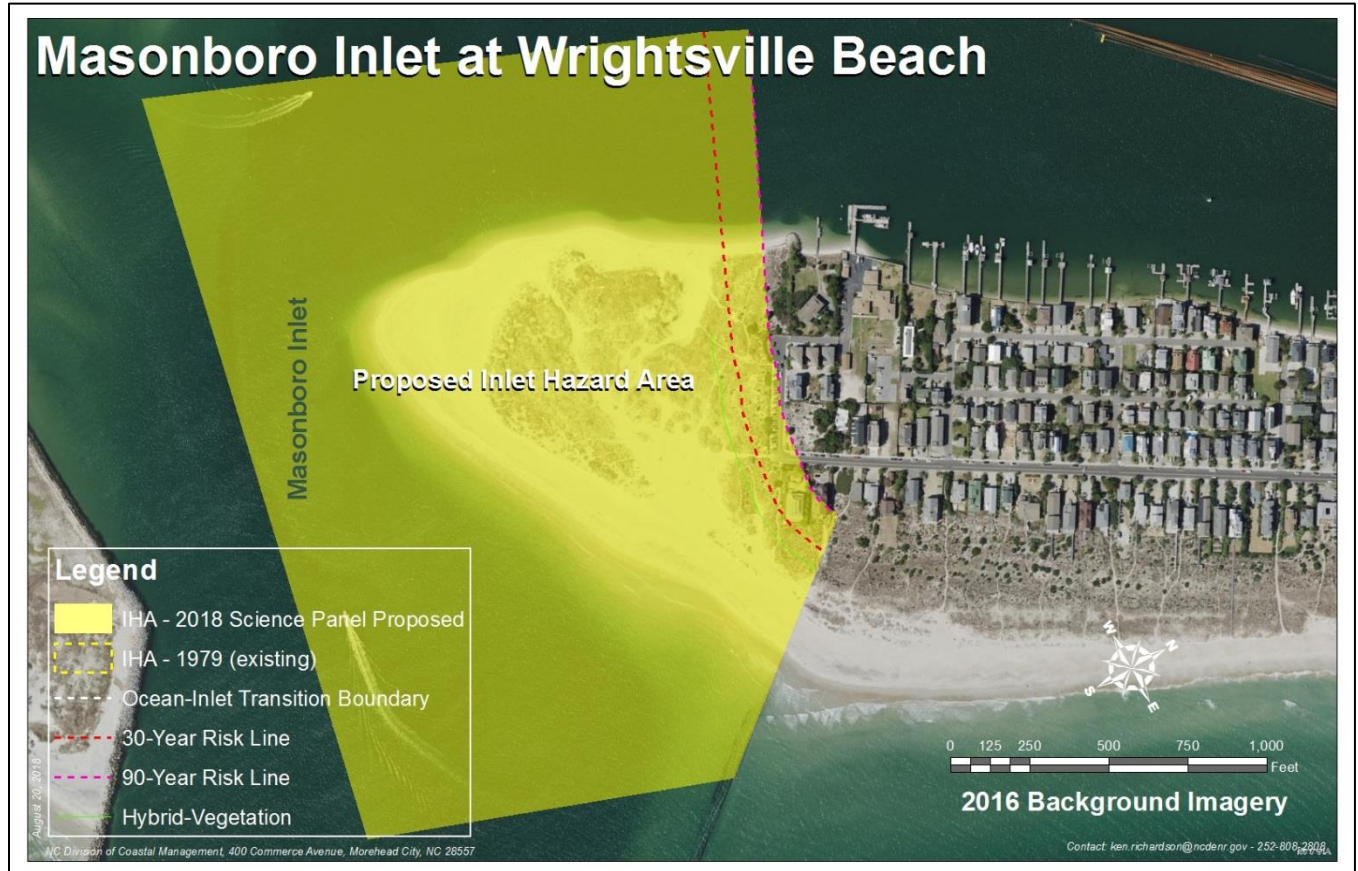


Figure 42. Masonboro Inlet at Wrightsville Beach Hybrid-Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.6 Mason Inlet

Mason Inlet is a small migrating system that opened in the early 1880s 1.8 miles northeast of its current location. The rate of inlet migration varied over decadal scales and there have been short-term reversals in the migration direction. During the period between 1974 and 1997 the inlet migrated southward 3,600 feet, at an average rate of 160 feet per year. Actual rates have ranged from 6 and 310 feet per year with the highest rates coinciding with significant shoaling of both the channel and within the back-barrier area. In 1997 the inlet threatened buildings on the north end of Wrightsville Beach and the southern inlet shoreline was hardened with a large geotextile tube revetment, which remains in place. Infilling of sound-side channels stemmed from the migration of the inlet and the associated juxtaposition of the flood-tidal delta and Mason Creek. The near closure of Mason Creek, the primary channel connection to the AIWW, led to a dramatic reduction of the tidal prism and accelerated the migration rate. Both oceanfront shorelines near the inlet are also oscillating.

In 2002, the inlet was relocated approximately 2,800 feet to the northeast on Figure Eight Island. Since that time the inlet location and feeder channels have been maintained by periodic dredging, which has maintained the increased tidal prism and slowed the natural migration rate.

During the period from the mid-1960s to the early 1980s, the planform of the updrift oceanfront shoreline along Figure Eight Island was concave seaward. The bulbous nature of the shoreline near the inlet reflected the positive influence of the relatively large ebb-tidal delta whose wave-sheltering effect extended approximately 5,000 feet updrift on Figure Eight Island. The overlapping ebb platform protected and frequently nourished the shoreline with the attachment of large swash bars. During the 1970s, progradation extended and widened the beach by 300 feet. As migration continued, the zone of bar attachment also shifted southward. The former shoreline reaches that had accreted began to rapidly erode as the barrier lengthened and the planform changed accordingly. The erosion hot-spot is currently located approximately 3,500 feet northeast of the inlet where beach nourishment and sand bag revetments have been placed.

3.6a Wrightsville Beach side of Mason Inlet

The vegetation and shoreline data for the Wrightsville Beach side of Mason Inlet are shown in Figures 43 and 44. Using the IHAM, transect-258 is the southern boundary of inlet influence along the oceanfront shoreline, near the current IHA boundary (Figure 45). The 90-Year Risk Line is recommended as the landward IHA boundary (Figure 46).

Figure 43. Mason Inlet at Wrightsville Beach. Vegetation Lines mapped: 1971, 1977, 1984, 1987, 1992, 1995, 1998, 2000, 2002, 2003, 2004, 2006, 2009, 2010, 2012, 2016. Vegetation line segments making up the hybrid-vegetation line: 1971, 1977, 1984, 1987, 1998, 2000, 2002, 2003, 2006, 2009, 2010.



Figure 44. Mason Inlet at Wrightsville Beach. Shorelines included: 1971, 1973, 1974, 1977, 1984, 1987, 1992, 1995, 1997, 1998, 2000, 2002, 2003, 2004, 2006, 2009, 2010, 2012, 2016.



Figure 45. Based on the standard deviation of shoreline position at Mason Inlet-Wrightsville Beach, transect-258 is recommended as the inlet-ocean transition boundary along the shoreline. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

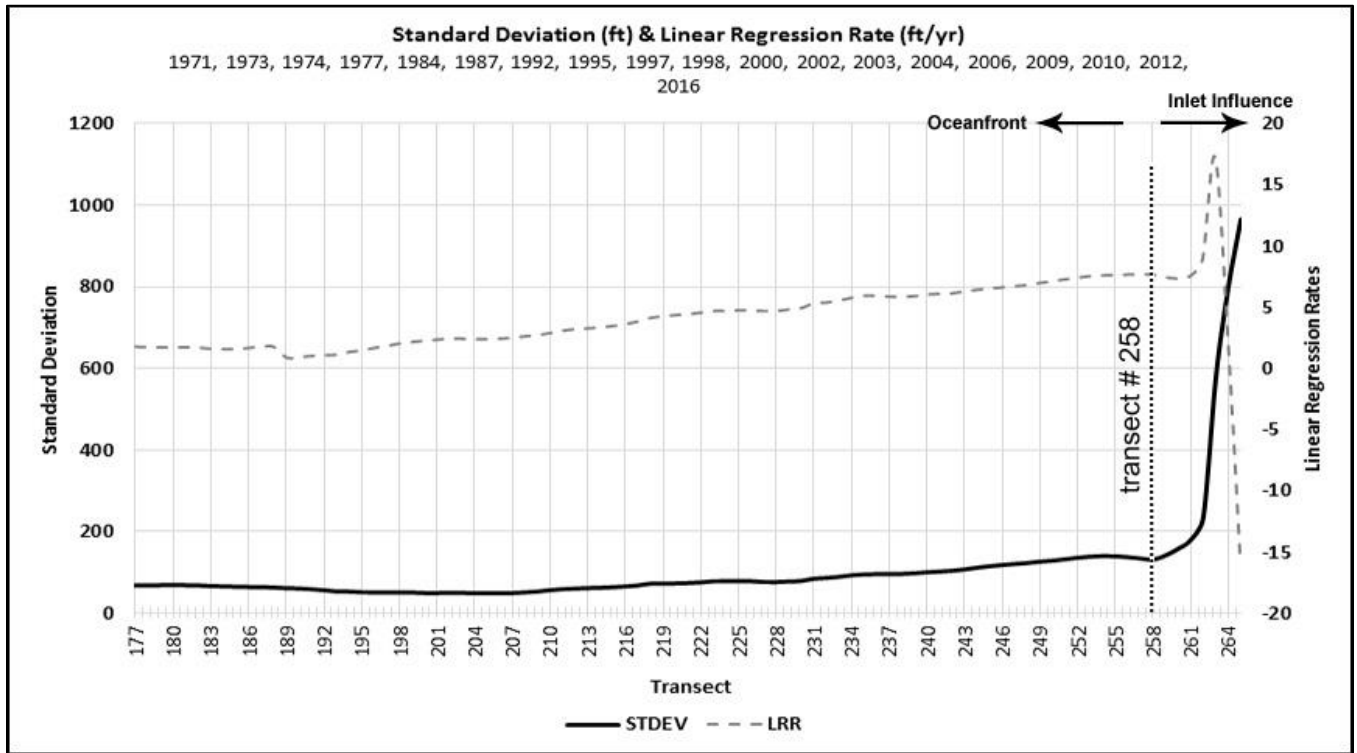
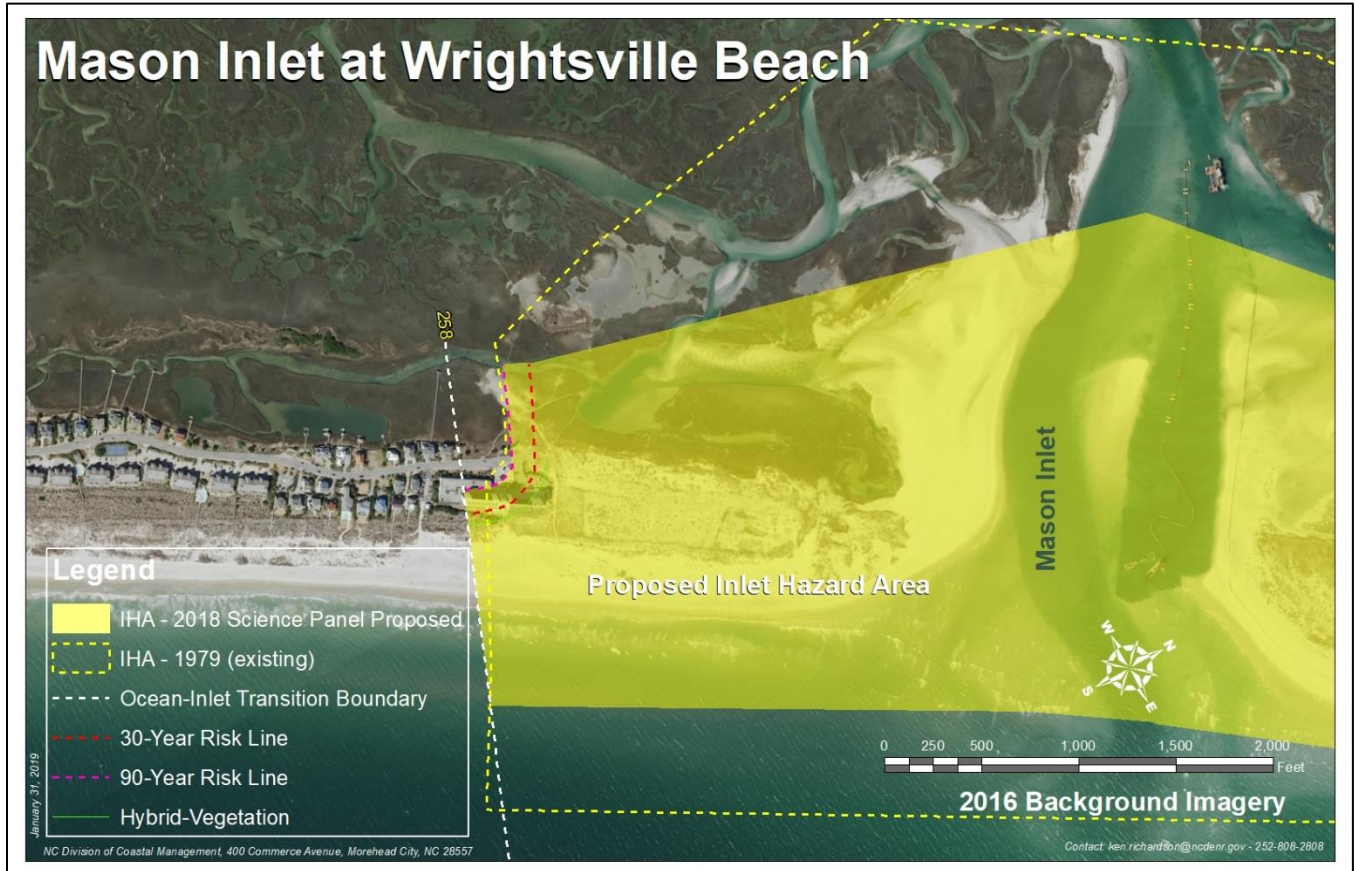


Figure 46. Mason Inlet at Wrightsville Beach Hybrid-Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.6b Figure Eight Island side of Mason Inlet

The vegetation and shoreline data for the Figure Eight Island side of Mason Inlet are shown in Figures 47 and 48. Although the IHAM identified transect-31 as the inlet-ocean boundary (Figure 49), the Panel agreed that the risk related to the inlet actually extended further north. It is expected that without regular management, the inlet related erosional risk would encompass the area up to transect-45, which is approximately the start of truncated dunes, indicating relative stability of the oceanfront shoreline’s position over time with continued nourishment. This stability can also be seen in the shoreline change rate (LRR), which stabilizes after transect-45 (Figure 49). The recommended landward boundary is the 90-Year Risk Line (Figure 50).

Figure 47. Mason Inlet at Figure Eight Island. Vegetation Lines mapped: 1971, 1973, 1977, 1987, 1992, 1998, 2002, 2003, 2004, 2006, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 1971, 1977, 1998, 2002, 2004, 2012.



Figure 48. Mason Inlet at Figure Eight Island. Shorelines included in the analysis: 1971, 1973, 1977, 1987, 1992, 1998, 2002, 2003, 2004, 2006, 2009, 2010, 2012, 2016.



Figure 49. Based on the increased potential for erosion at Mason Inlet-Figure Eight Island, transect-45 is recommended as the inlet-ocean transition boundary along the shoreline. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

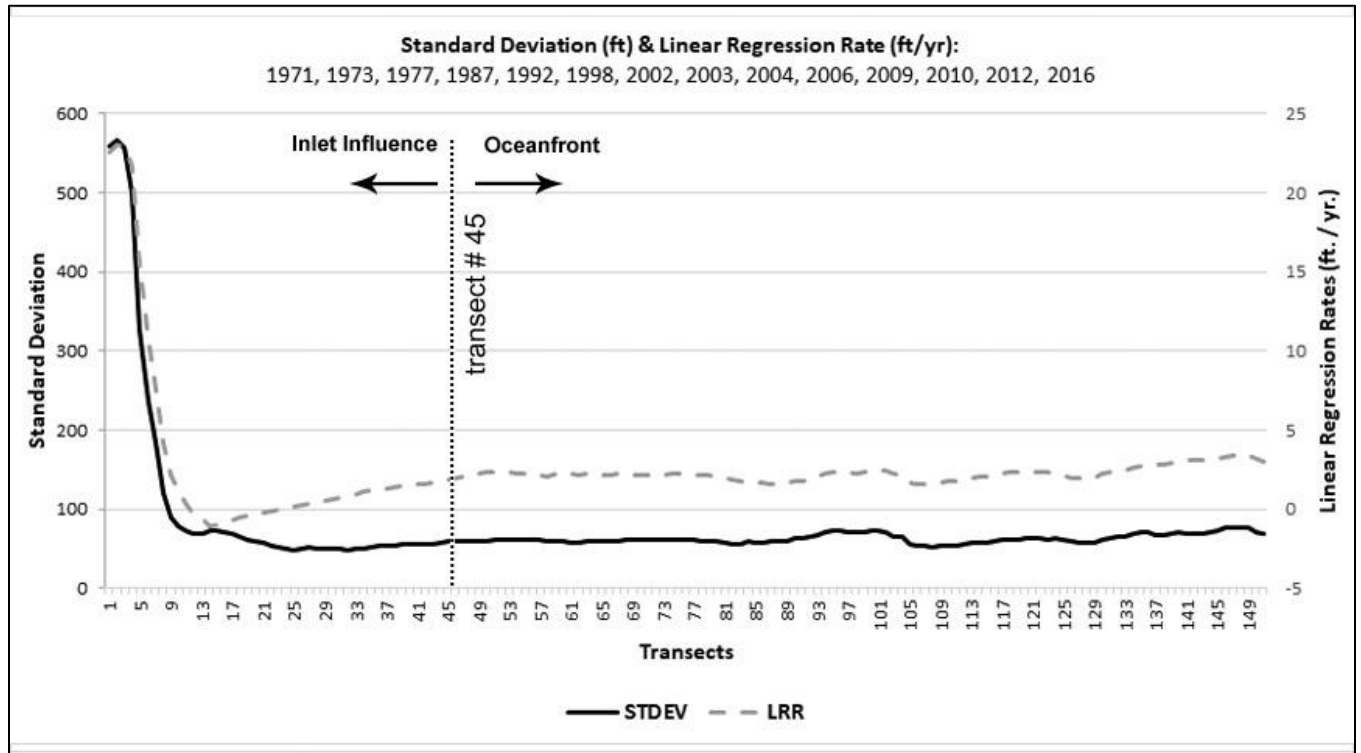
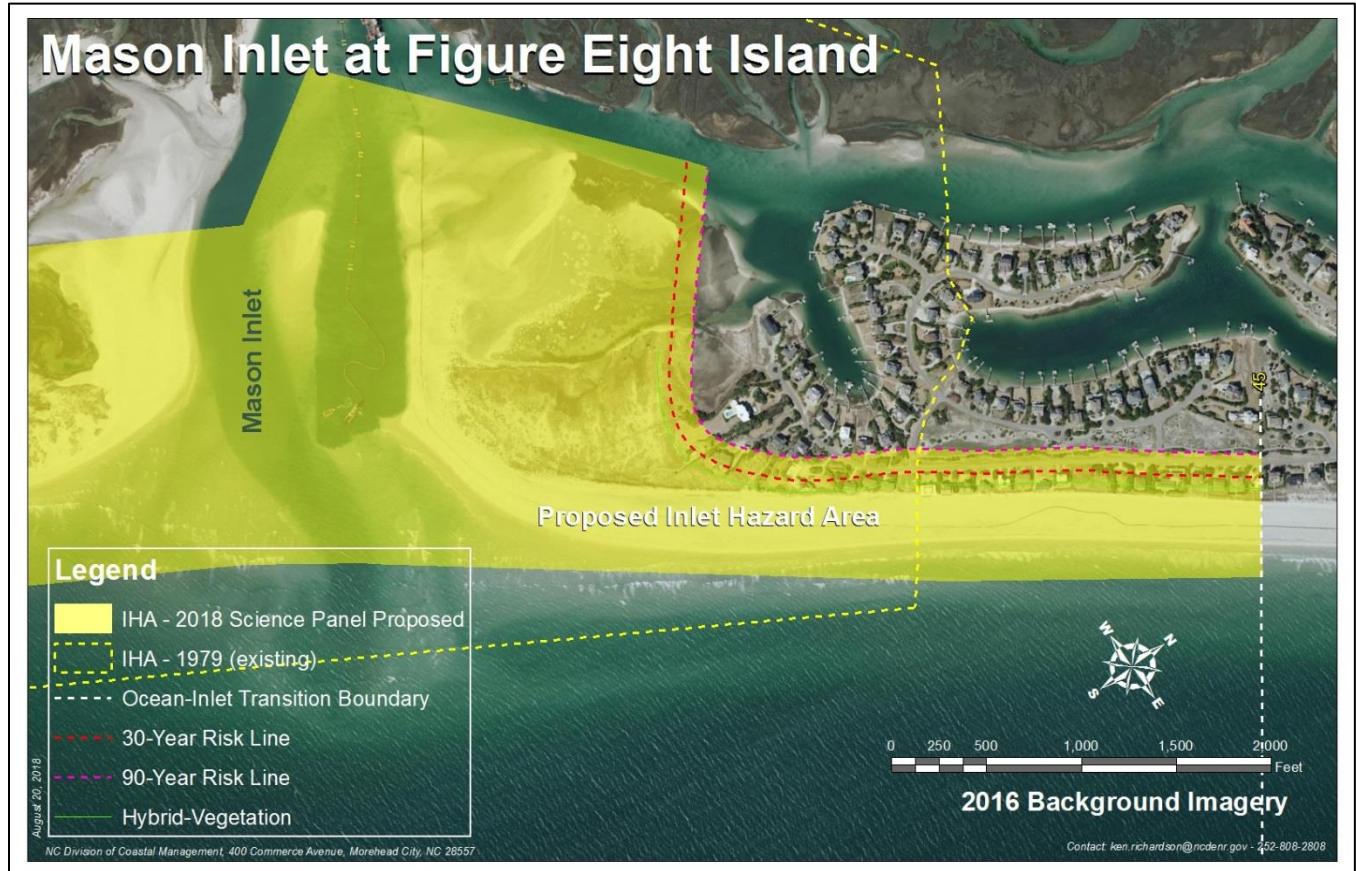


Figure 50. Map of Mason Inlet at Figure Eight Island Hybrid-Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.7 Rich Inlet

Rich Inlet is an oscillatory inlet that drains a bar-built estuary and adjacent Futch Creek. Both oceanfront shorelines near the inlet are also widely oscillating. The inlet has been identified on charts dating from the 1700s. Its origin is related to an incised paleo-channel. The inlet has been relatively stable during the past 80 years as determined by the length of its migration pathway (1,500 feet) when compared to the inlet’s width (1,800-4,000 feet). Migration rates and direction have been highly variable. The inlet’s variability is directly related to the continual and often rapid (NE or SW) reorientation and repositioning of the offshore ebb channel. As the ebb channel deflects across the offshore shoal, the ebb-tidal delta’s position, shape and areal extent are continually changing. Channel deflection episodes have caused the adjacent barrier shorelines to erode or prograde, as the wave-sheltering effect of the ebb-tidal delta has decreased or increased with the size and shape of the ebb-tidal delta.

In late 1994 a major ebb-tidal breaching event occurred that led to a 1,200 feet northeasterly repositioning of the inlet and a 3,800 feet northeasterly movement of the bar channel. The dramatic shift altered the “breakwater effect” along Figure Eight Island that was previously

afforded by the ebb-tidal delta during the previous 50 years. Additionally, the zone of swash bar attachment shifted to the northeast.

The chronic oceanfront erosion that ensued (1997-2012) along the northern 3,000 feet of the Figure Eight Island shoreline ranged from 100 to 580 feet and averaged approximately 280 feet. Due to the poor performance of the nourishment efforts used to mitigate the erosion, an 1,800 feet-long reach was eventually armored with sandbags. In October 2004, both the throat and bar channel segments shifted to the southwest and by June 2012, the throat segment migrated 950 feet at an average rate of 120 feet per year. By contrast, the outer bar channel segment shifted southwest 2,700 feet at a rate of 330 feet per year between 2011 and 2012; the highly asymmetric ebb-tidal delta provided a significant wave-sheltering effect that promoted shoreline progradation that averaged 90 feet.

Additionally, the 2012 breaching event that repositioned the ebb channel 2,530 feet to the northeast provided the downdrift bypassing of a large volume of sand. This bypassing caused large swash bars to attach to Figure Eight Island by 2015, which in turn caused the ocean shoreline to prograde an average of 190 feet. Since 2012, the ebb channel has deflected 940 feet to the northeast and reconfigured the ebb-tidal delta. By 2016, the ebb channel within the throat migrated 820 feet back to the southwest, which led to the erosion of 280 feet of shoreline along the Figure Eight Island spit's inlet.

3.7a Figure Eight Island at Rich Inlet

The vegetation and shoreline data for Figure Eight Island at Rich Inlet are shown in Figures 51 and 52. Because it is an outlier, the 1958 post-hurricane vegetation line was not included in the analysis. To better reflect the shoreline oscillations, shorelines beginning in 1934 were considered. Using the IHAM, the standard deviation suggests that inlet influence extends to at least transect-163. However, transect-181, closer to the inlet, is located near the start of a primary dune line that has remained unchanged for the time period. It also falls within a peak in shoreline accretion (LRR). Based on their knowledge of the inlet, the Panel recommends transect-181 as the boundary of inlet influence along the oceanfront shoreline (Figure 53). The 90-Year Risk line is recommended as the landward limit of the IHA. (Figure 54).

Figure 51. Rich Inlet at Figure Eight Island. Vegetation Lines mapped: 1938, 1949, 1958, 1971, 1977, 1980, 1984, 1992, 1998, 2002, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 1984, 1998, 2002, 2006, 2009, 2010, 2012, 2016.



Figure 52. Rich Inlet at Figure Eight Island. Shorelines included: 1934, 1938, 1944, 1949, 1958, 1971, 1973, 1977, 1980, 1984, 1992, 1998, 2002, 2003, 2004, 2006, 2008, 2009, 2010, 2012, 2016.



Figure 53. Based on the shoreline change rate and stable primary dune line, transect-181 at Rich Inlet-Figure Eight Island is recommended as the inlet-ocean transition boundary. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

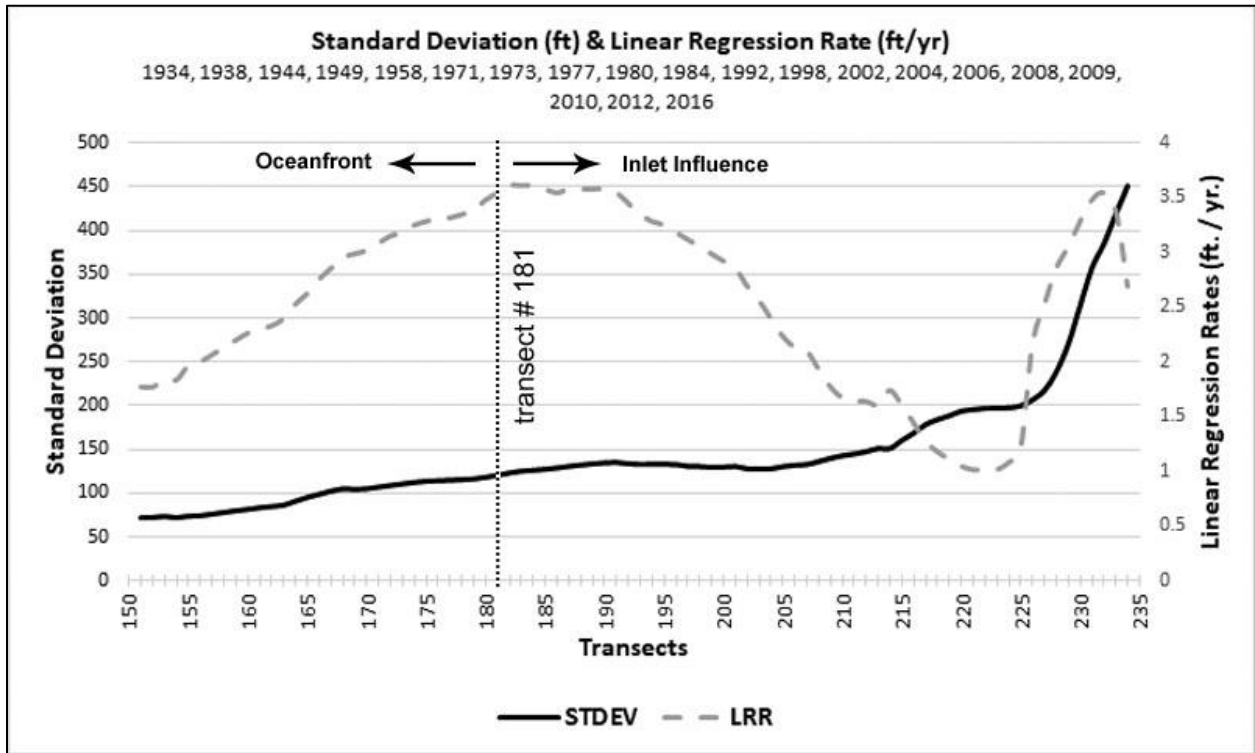
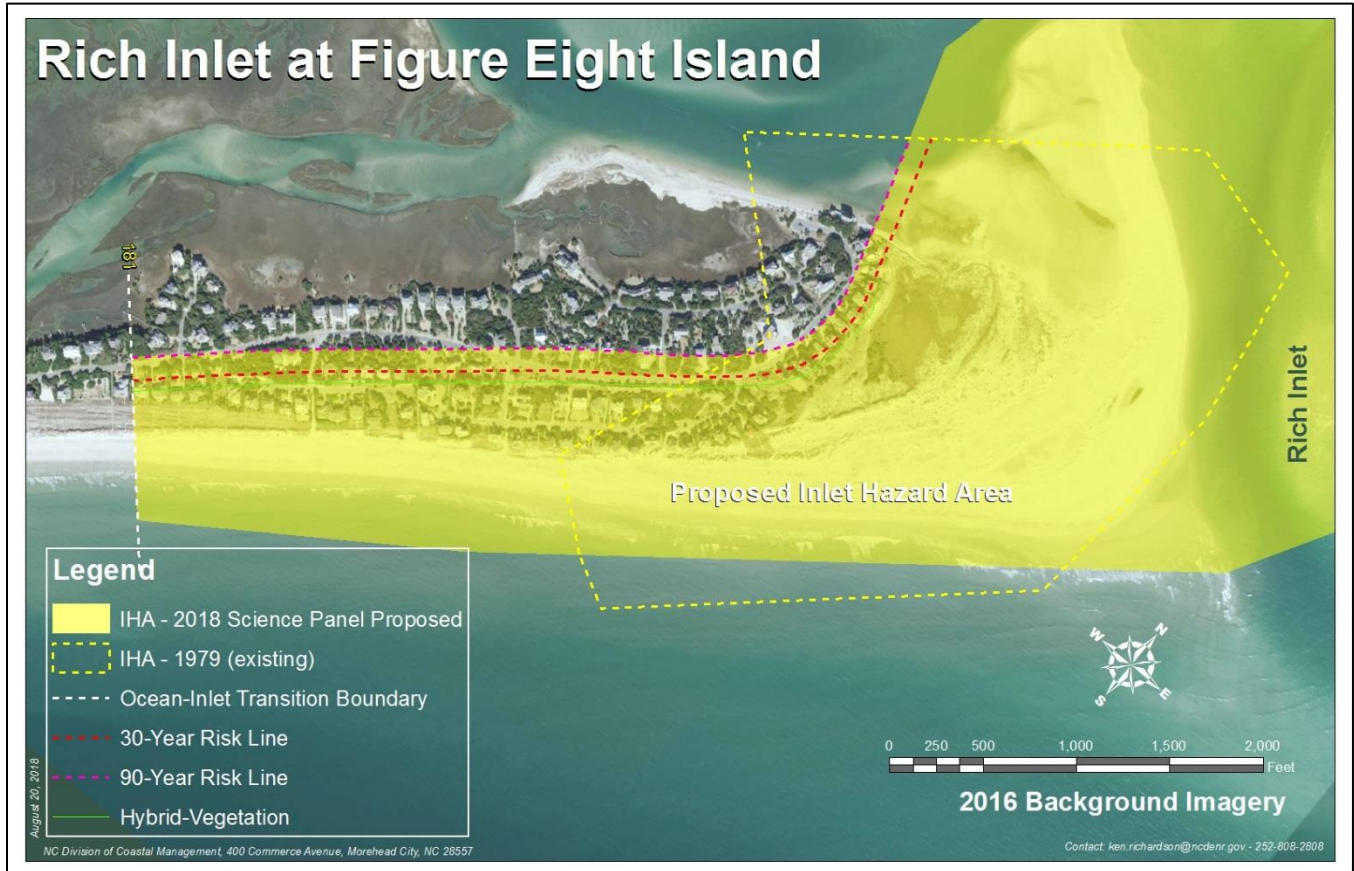


Figure 54. Rich Inlet at Figure Eight Island Hybrid-Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.7b Lea-Hutaff Island side of Rich Inlet

The Lea and Hutaff Islands (also referred to as Coke and No-Name islands) were joined in 1997 by the closure of Old Topsail Inlet. The resulting Lea-Hutaff Island is strongly influenced by the adjacent Rich and New Topsail Inlets. Because of the closure, pre-1997 shorelines were excluded from the analyses. The vegetation and shoreline data are shown in Figures 55 and 56. The standard deviation of shoreline change and linear shoreline regression rate is shown in Figure 57. Based on their narrow and low-lying topography, lack of dune ridges and regular and extensive overwash, the Panel recommends that the boundary of the IHA include the entire island (Figure 58).

Figure 55. Rich and New Topsail Inlets at Lea-Hutaff Island. Vegetation Lines mapped: 1997, 1998, 2000, 2004, 2006, 2008, 2009, 2010, 2012, 2016. Vegetation line segments making up the Hybrid-Vegetation Line: 2016.

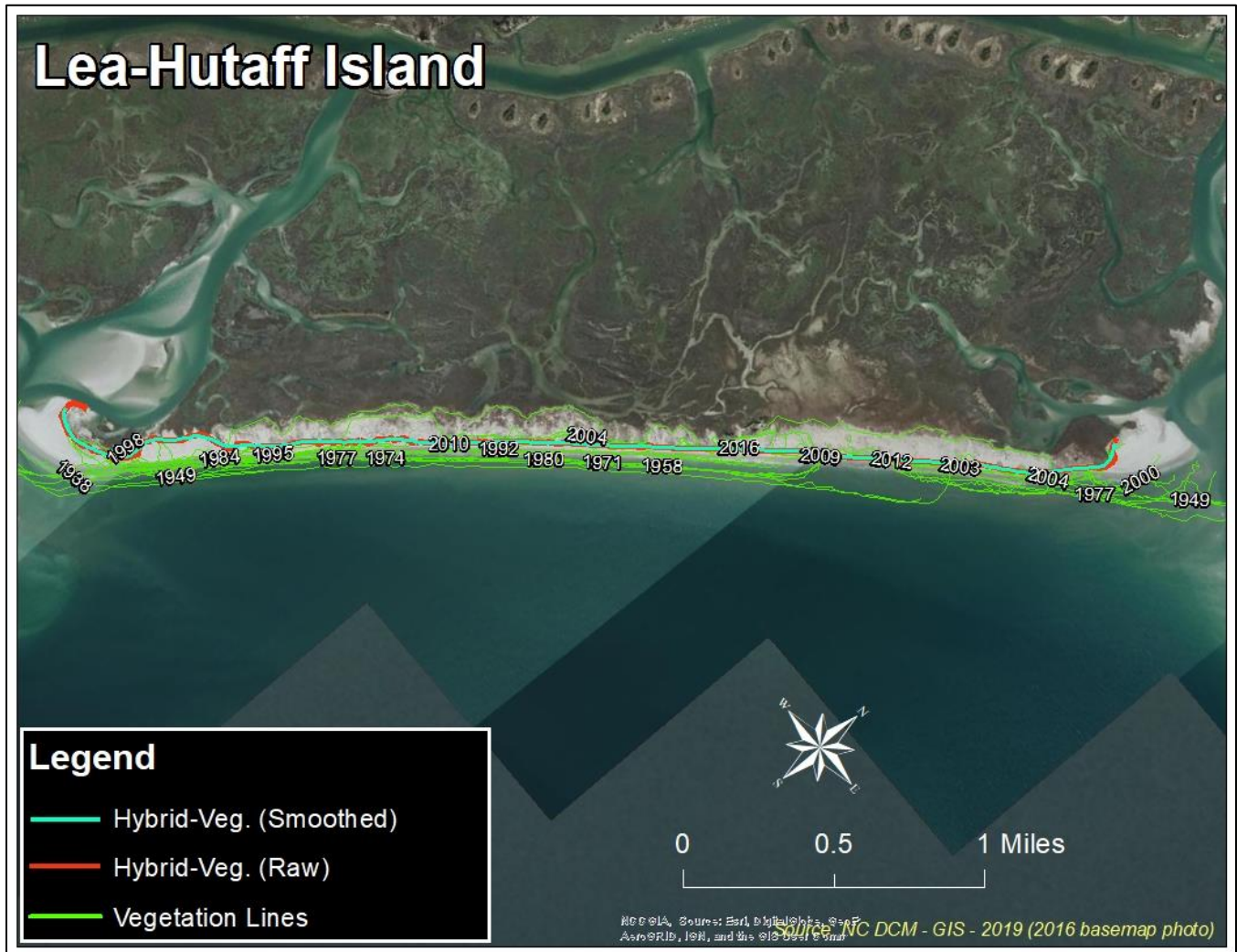


Figure 56. Shorelines included in the analysis: 1997, 1998, 2000, 2004, 2006, 2008, 2009, 2010, 2012, 2016.

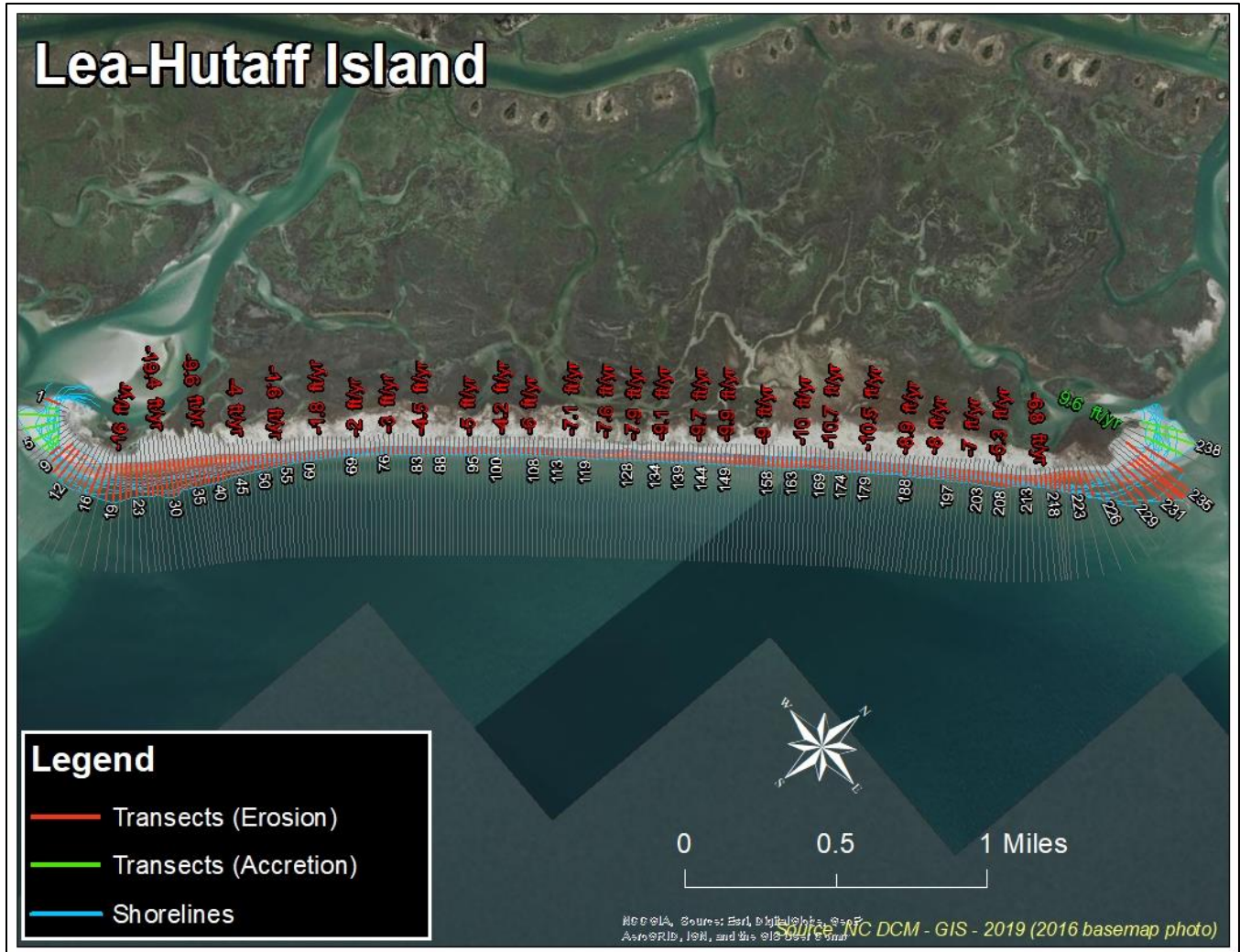


Figure 57. Because Lea and Hutaff Island welded together in 1997, have low topography and are heavily influenced by both Rich and New Topsail Inlets, the Panel recommends including all Lea-Hutaff Island in the IHA. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

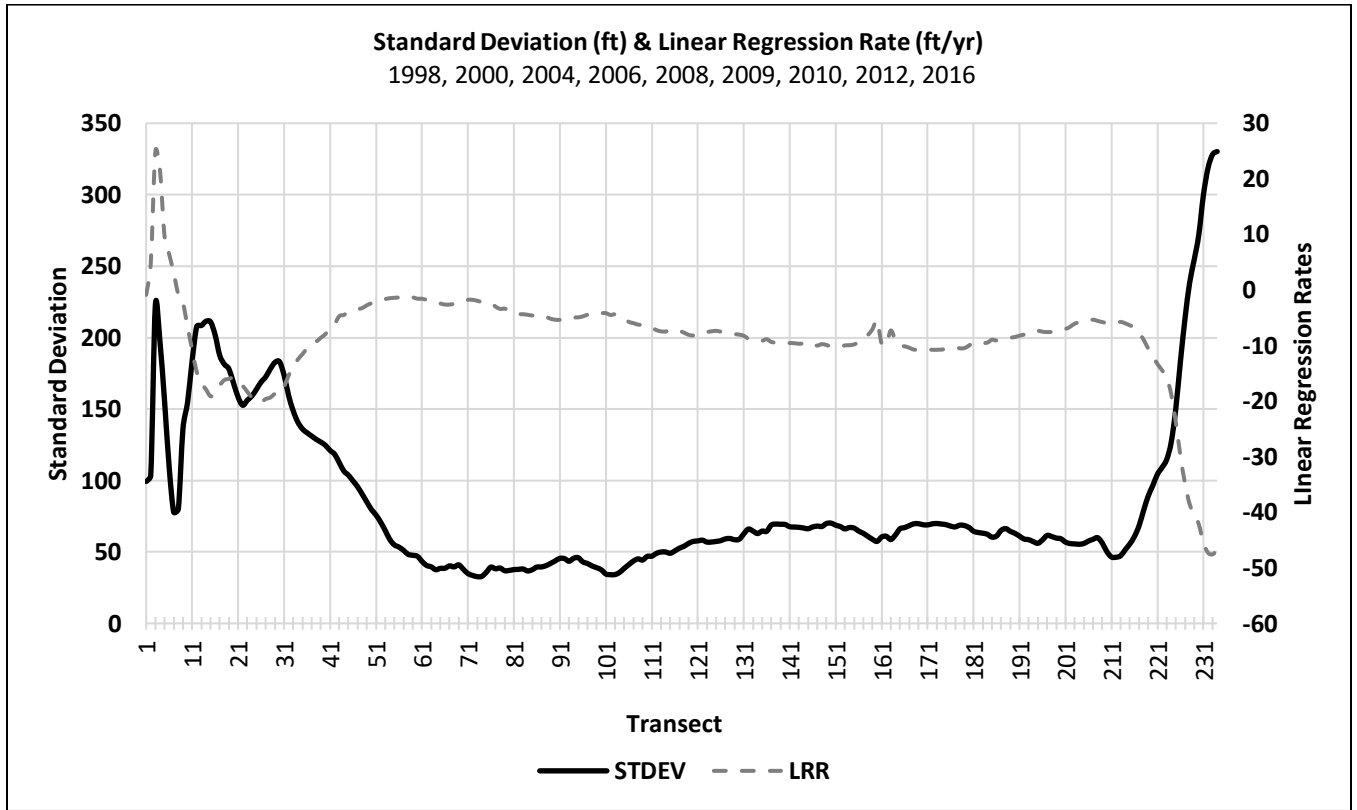
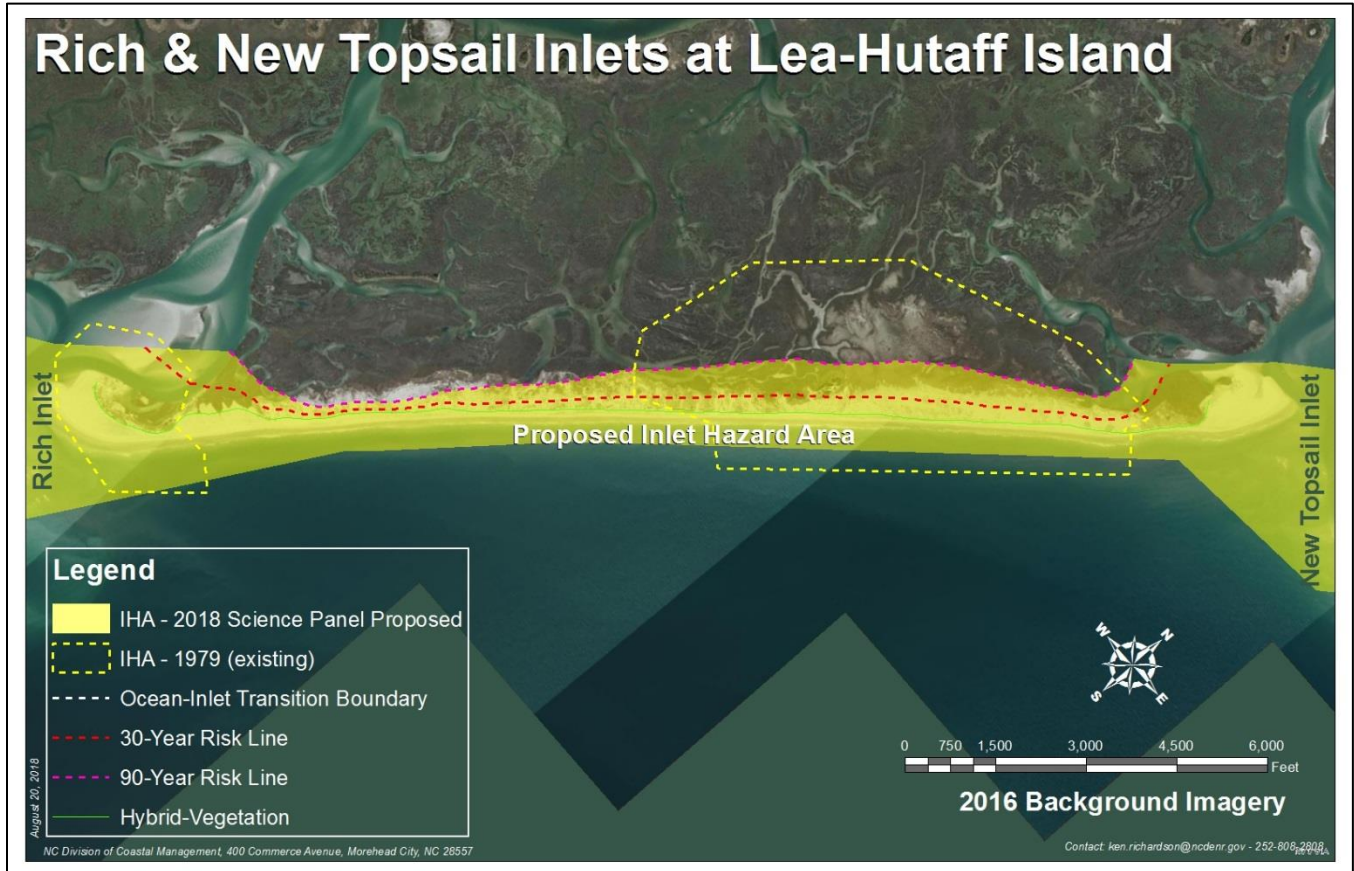


Figure 58. Rich and New Topsail Inlets at Lea-Hutaff Island Hybrid-Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.8 New Topsail Inlet

New Topsail Inlet is historically the most persistent migrating inlet in North Carolina, having migrated 6.2 miles to the southwest. The earliest land grants record the existence of New Topsail Inlet as early as 1726. Between 1938 and 2009, the ebb channel within the throat migrated 6,300 feet to the southwest at an average rate of 90 feet per year. Migration direction and rates were highly variable. More recently, between 2010 and 2014 the channel reversed its migration direction and shifted 590 feet toward Topsail Beach at an average rate of 150 feet per year. By August 2016, the ebb channel had been repositioned an additional 1,000 feet to the northeast during a breaching event in the offshore channel.

The inlet's minimum width has fluctuated considerably from 1,000 feet (1984) to 2,300 feet (1995). The mean inlet minimum width for the past 70 years was 1,600 feet. It typically narrows due to spit growth on both shoulders, which often marks a shift in the migration direction. Cyclical deflection and reorientation of the offshore ebb channel has occurred numerous times since 1938. Reorientation of the channel is due to storm-related ebb delta breaching events, which result in sand bypassing to Topsail Beach.

The inlet-related variables that control shoreline change patterns are the migration direction and rate, the channel alignment across the offshore ebb platform and the attendant shape of the ebb tidal delta. The planform of Topsail Beach curves seaward near the inlet, due to the attachment of swash bars that perpetuate this maximum accretion zone as the inlet migrates to the southwest. During the period between 1949 and 1962, the inlet migrated southward 180 feet, at a rate of 14 feet per year. As a result, the zone of maximum accretion (swash bar attachments) incrementally shifted toward the inlet approximately 3,500 feet. As migration occurred, the planform of the trailing shoreline was altered as erosion commenced along the former zone of maximum progradation.

3.8a Lea-Hutaff Island side of New Topsail Inlet

The 1979 IHA shoreline boundary for Lea Island is now located near the inlet shoreline of Topsail Beach; no longer on Lea Island. As discussed in Section 3.7b above, this area is included in the island-wide proposed IHA for Lea-Hutaff Island.

3.8b Topsail Beach side of New Topsail Inlet

New Topsail Inlet's rapid migration results in a reduction of risk on the north side as the inlet moves south. Since a migration reversal is unlikely, in such cases it is recommended to limit the inlet analysis to the most recent 30 years. For the Topsail Beach side of New Topsail Inlet, the computation of the Hybrid-Vegetation Line used the full record (1971-2016) on the oceanfront but was limited to an approximate 30-year data record (1984-2016) within the inlet. Because of the rapid migration, the inlet Hybrid-Vegetation Line is defined by one date, the 1984 vegetation line (Figure 59). It is recommended that this 30-year adjustment should be reevaluated during each IHA update. If the inlet continues to migrate, the IHA should move south with the inlet.

Shoreline data for Topsail Beach are shown in Figure 60. Using the IHAM, the standard deviation suggests that inlet influence extends to transect-27 (Figure 61). However, in order to include the area most prone to erosion hazards associated with storm-enhanced inlet processes, transect-42 is recommended as the IHA boundary. From transect-42, the boundary extends landward, north of the canal at Trout Avenue to Topsail Sound connecting with the back boundary of the current IHA (Figure 62).

Figure 59. New Topsail Inlet at Topsail Beach. Vegetation Lines mapped: 1971, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004, 2008, 2009, 2010, 2011, 2012, 2016. To account for the inlet's rapid migration, the Hybrid-Vegetation Line within the inlet was based on a ~30-year period (1984-2016); all vegetation lines were considered on the oceanfront.

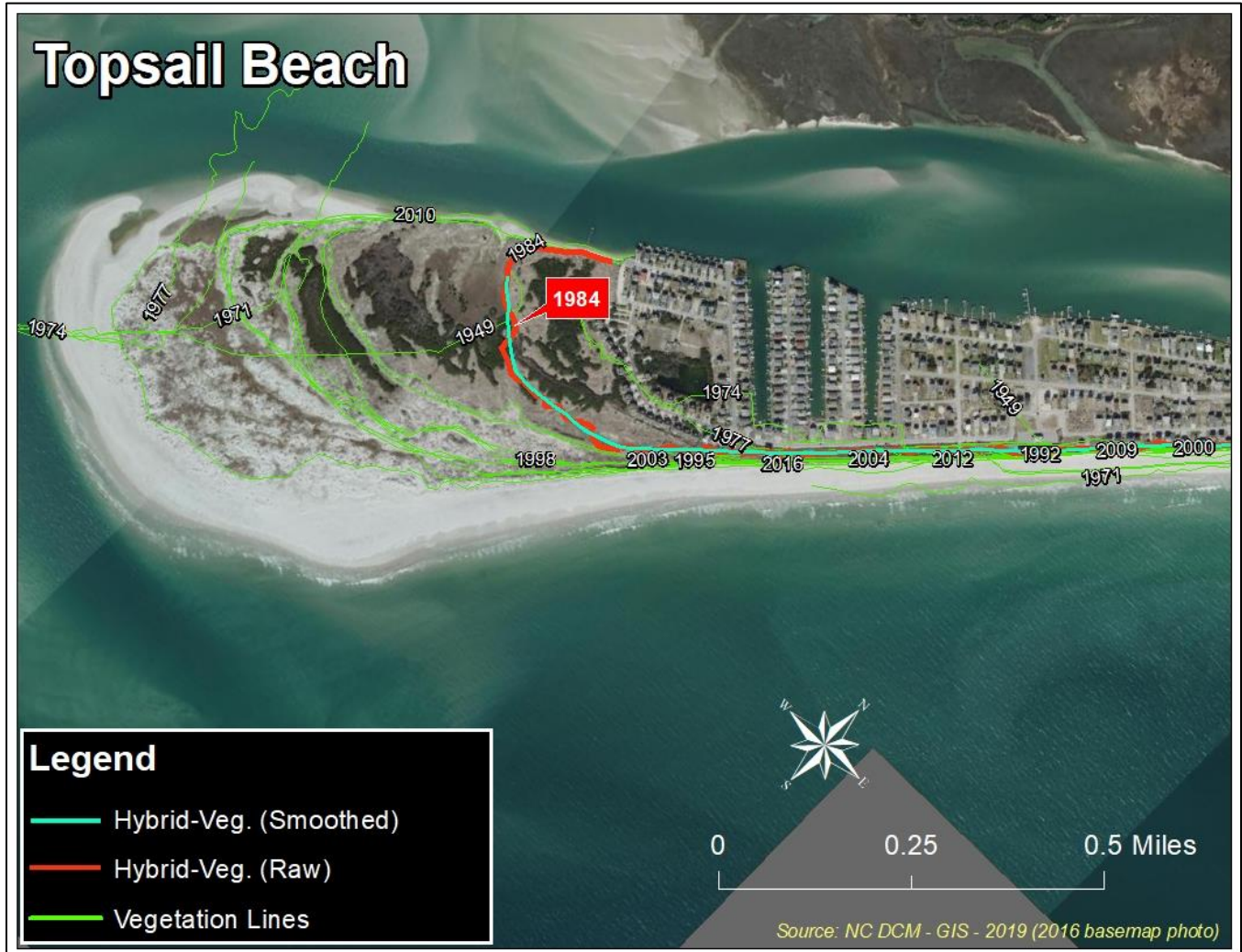


Figure 60. New Topsail Inlet at Topsail Beach Shorelines included: 1971, 1973, 1974, 1976, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004, 2006, 2008, 2009, 2010, 2011, 2012, 2016.



Figure 61. At New Topsail Inlet-Topsail Island, transect-42 is recommended as the inlet-ocean transition boundary in order to include the area most prone to erosion hazards associated with storm-enhanced inlet processes. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

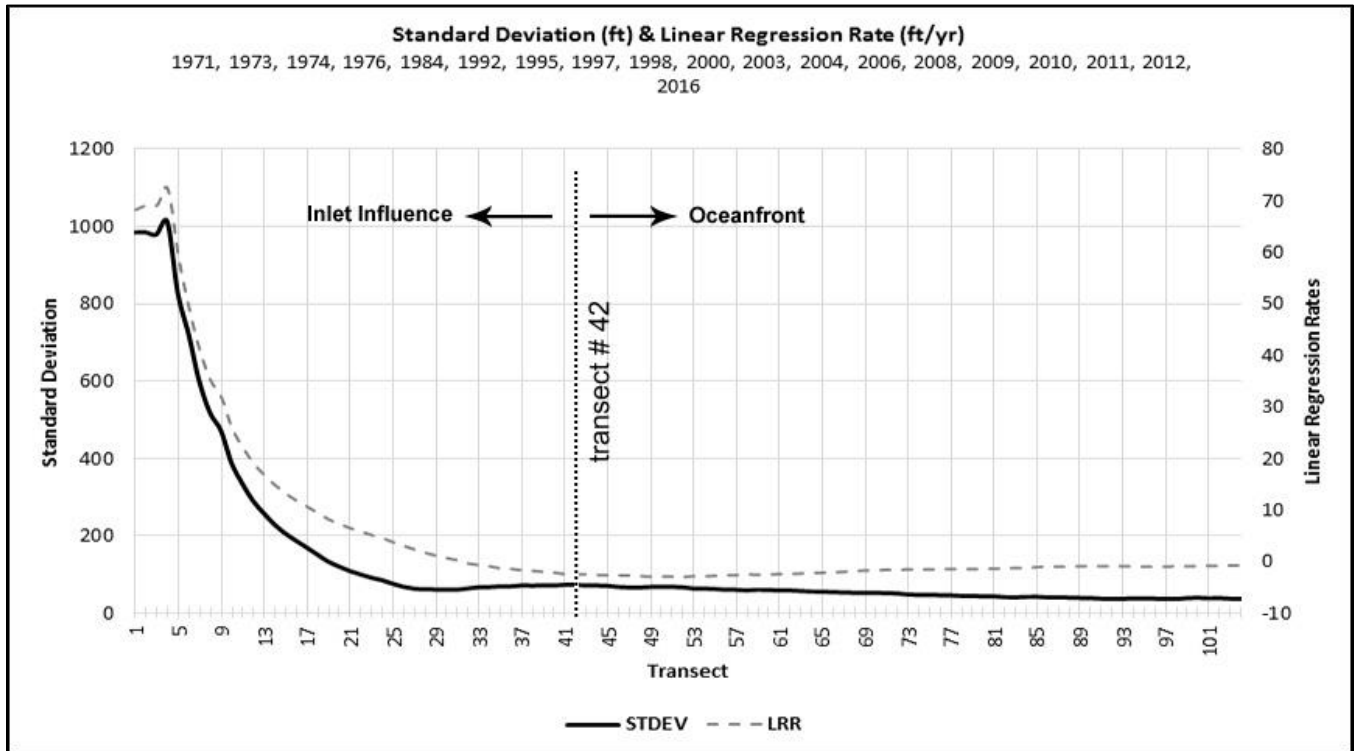
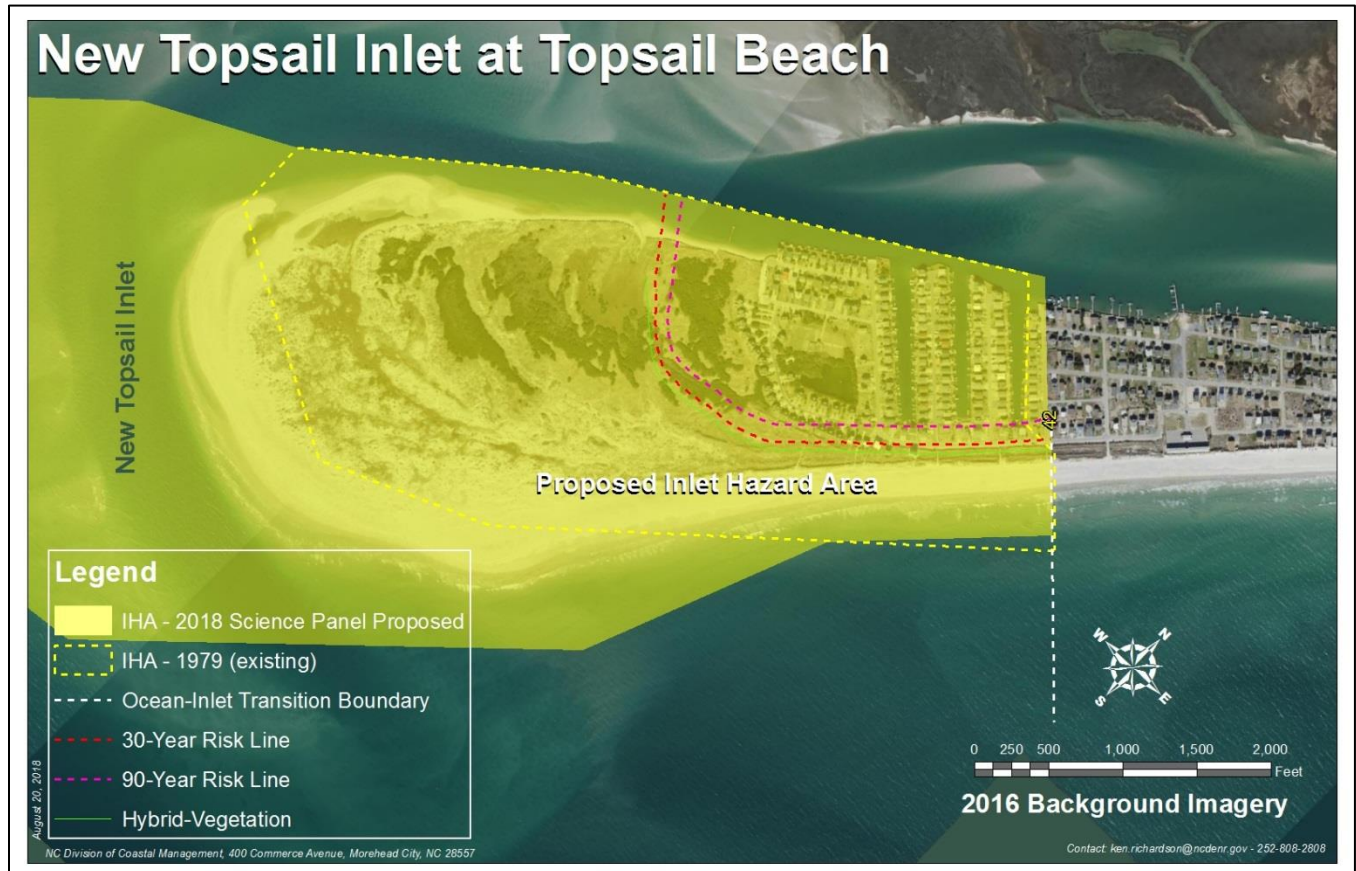


Figure 62. New Topsail Inlet at Topsail Beach Hybrid-Vegetation Line and the recommended IHA boundary at inlet transect-42 to define the boundary of inlet influence along the oceanfront shoreline. It is recommended that the IHA boundary cross the island by extending transect-42 landward following Trout Avenue, beside the northernmost canal, to Topsail Sound.



3.9 New River Inlet

New River Inlet is a migrating inlet that drains New River and the adjacent estuaries. Its origin is related to the location of the incised paleo-channel of New River. Although navigation channel improvements within the marsh occurred between 1885-1940, the inlet was basically unmodified when major system-wide modifications began in 1940. The US Army Corps of Engineers excavated a channel, 6-foot depth by 90 feet wide extending 2.3 miles from the AIWW to the inlet gorge. Concurrently the ebb channel was relocated approximately 1,700 feet to the northeast of its 1938 position. The new hydraulic connections substantially increased the tidal prism and the retention capacity of the ebb-tidal delta. The inlet is an authorized Federal shallow-draft navigation channel which, along with the access channel, has been periodically maintained since 1963. Side-cast dredging of the bar channel began in 1964.

Between 1945 and 1962, the inlet migrated 490 feet to the southwest at an average rate of 29 feet per year. From 1962 to 1974, the inlet shifted 530 feet southwest at an average rate of approximately 41 feet per year. During the following period (1974-1990) the inlet migrated 120 feet southward at approximately 7 feet per year. During this period, the orientation of the outer bar channel caused the ebb-tidal delta to be offset to the southwest. During this period the North Topsail Beach (NTB) oceanfront prograded an average of 180 feet. However, the inlet configuration changed as the outer bar channel shifted to an ESE-SE alignment. As a result, the ebb-tidal delta shifted toward Onslow Beach and the former accretion zone began to erode at rapid rates. During the past 25 years, chronic erosion has been the norm along the North Topsail Beach shoreline while the inlet has migrated southward 140 feet, at a rate of approximately 9 feet per year. Sandbag revetments now armor more than 3,000 feet of the developed shoreline near and on the inlet.

In an effort to mitigate the erosion along the oceanfront shoreline, the ebb channel was realigned by dredging in 2013 to a near shore-normal alignment in order to cause a reconfiguration of the ebb-tidal delta and to restore the breakwater effect it once afforded end of North Topsail Beach in the 1980's. Beach nourishment was placed on the shoreline at that time but was eroded rapidly near the inlet.

Only the North Topsail Beach side of New River Inlet is considered here as the Onslow Beach side of the inlet is owned and operated by the US Marine Corps Base, Camp Lejeune.

3.9a North Topsail Beach side of New River Inlet

The vegetation and shoreline data for the North Topsail Beach side of the New River Inlet are shown in Figures 63 and 64. Using the IHAM, inlet transect-1345 is defined as the boundary of inlet influence along the oceanfront shoreline (Figure 65). The recommended landward boundary is the 90-Year Risk Line (Figure 66).

Figure 63. New River Inlet at North Topsail Beach. Vegetation Lines mapped: 1971, 1974, 1977, 1984, 1992, 1995, 1998, 2000, 2003, 2004, 2006, 2009, 2010, 2012, 2016, and; vegetation line composite segments making up the Hybrid-Vegetation Line: 1971, 1974, 1998, 2000, 2016.

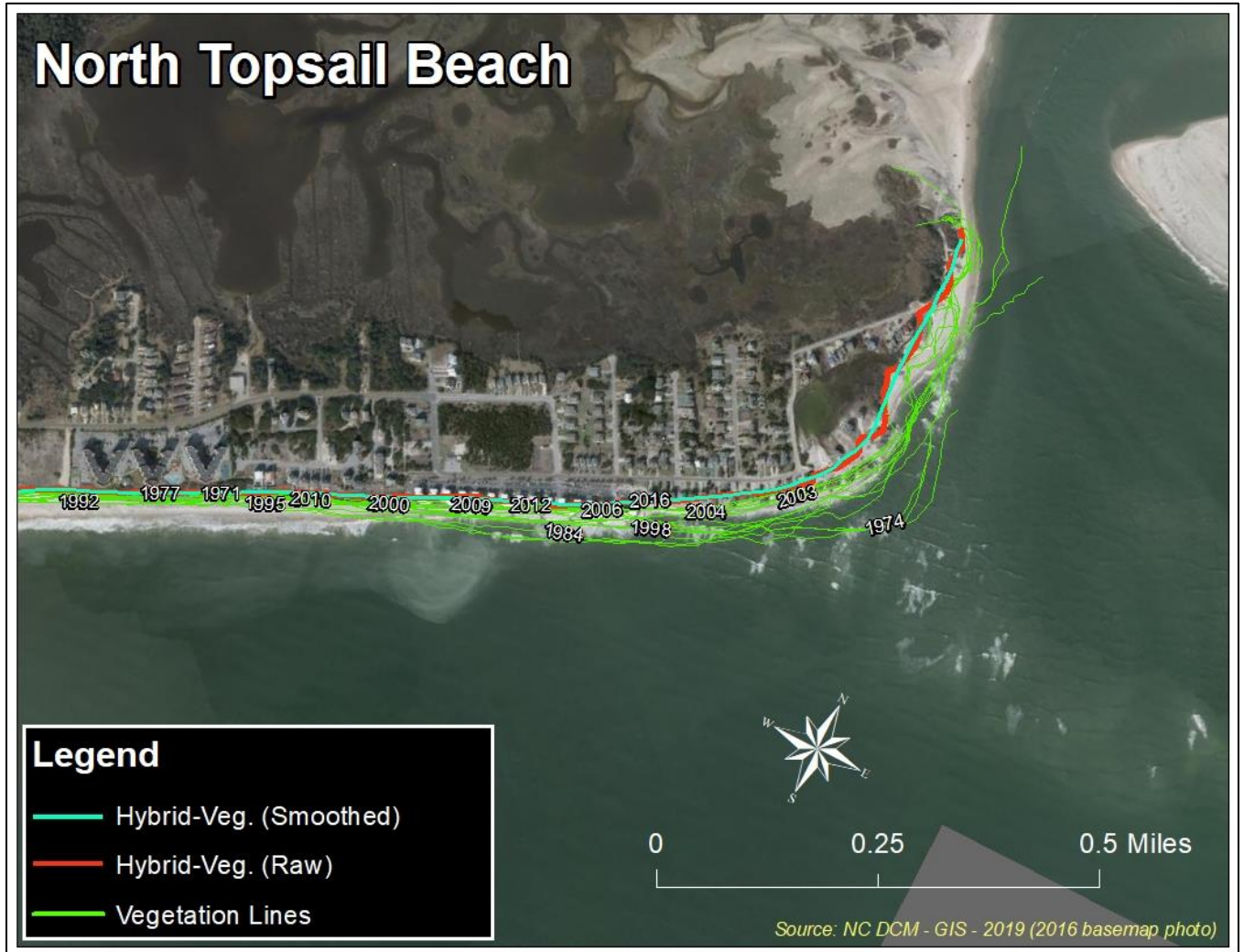


Figure 64. New River Inlet at North Topsail Beach. Shorelines included: 1971, 1973, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004, 2006, 2009, 2010, 2012, 2016.

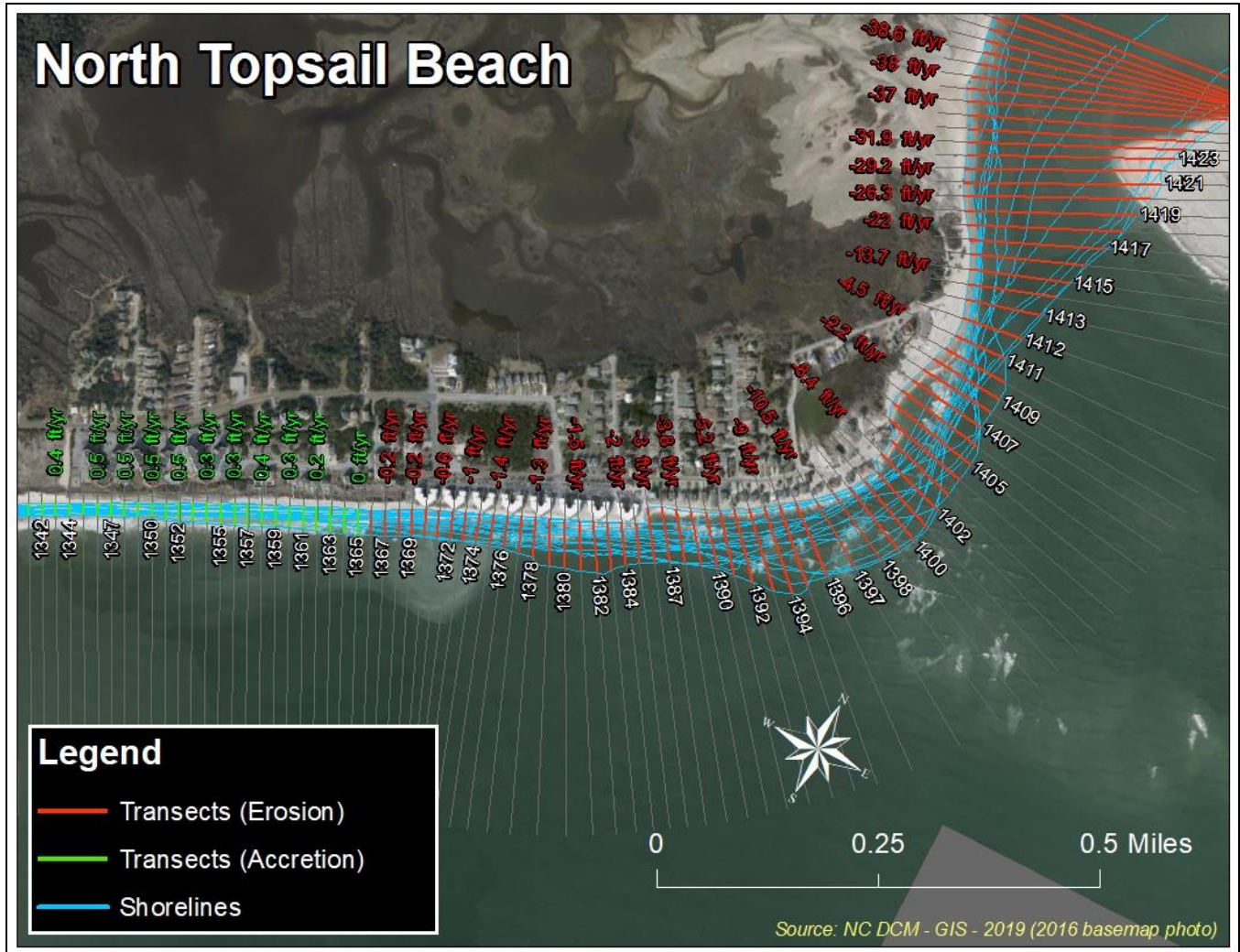


Figure 65. Based on the standard deviation of shoreline position at New River Inlet at North Topsail Beach, transect-1345 is recommended as the inlet-ocean transition boundary along the shoreline. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

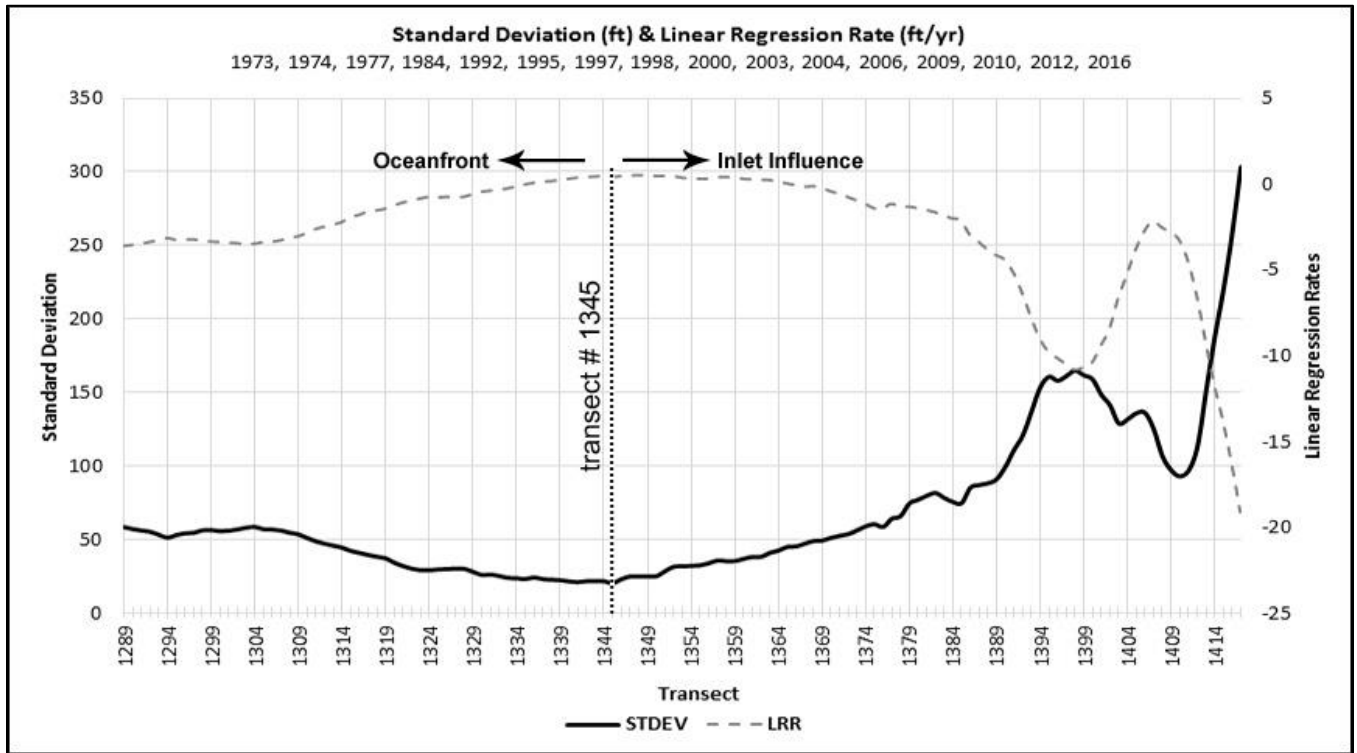
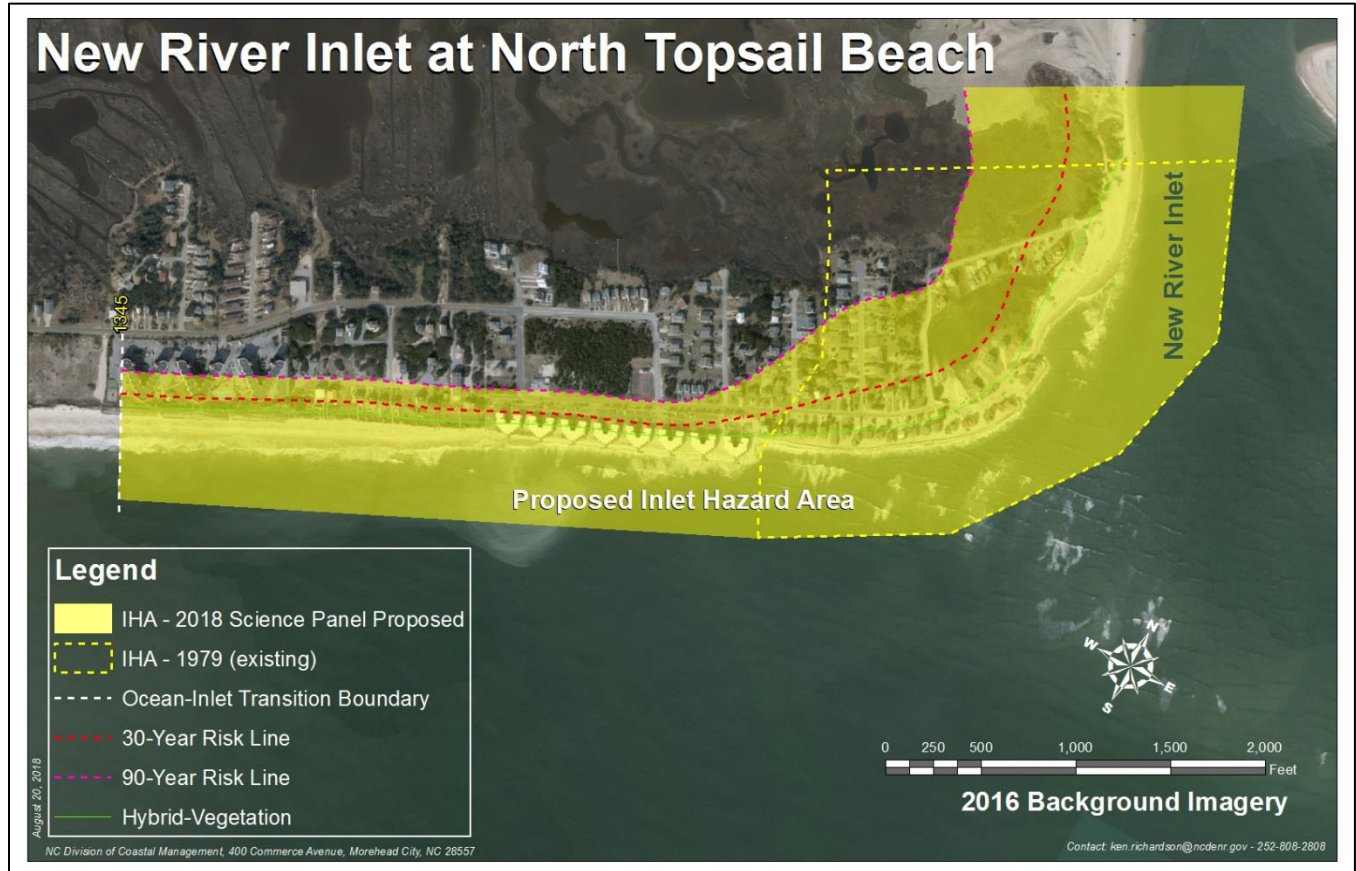


Figure 66. New River Inlet-North Topsail Beach Hybrid-Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



3.10 Bogue Inlet

Bogue Inlet is an oscillatory inlet that has been open continuously and in the same general location since the first map of coastal North Carolina was produced in 1585. Bogue Inlet is one of the larger inlets in southeastern North Carolina and drains an expansive estuary as well as the White Oak River Basin. The general inlet floodway is stable, and its position is controlled by the ancestral location of White Oak River. The inlet width and both ocean shorelines near the inlet have oscillated widely during the study period.

During the past 70 years the inlet’s width ranged from 3,800 to 8,300 feet and averaged 6,200 feet; depths in the ebb channel have fluctuated between 16 and 30 feet. The main offshore ebb channel is highly unstable and has a history of rapid migration along its 10,200-foot-long pathway. The migration rate and direction have varied considerably.

The orientation and position of the ebb platform channel have changed repeatedly. During the past 50 years, the outer bar channel has generally been aligned in a southeast-to-south-southwest orientation. The channel movement and orientation, coupled with the migration of

the landward segments of the channel, have dictated much of the change along both the inlet and oceanfront shorelines. Breaching of the ebb-tidal delta has led to rapid repositioning of the ebb channel. The most dramatic natural realignment event occurred between October 1938 and July 1949 when the ebb channel was repositioned approximately 3,000 feet east of its 1938 position. A similar but smaller-scale event occurred in the mid-1970s. Between 2000 and 2010 approximately 1,500 feet of the Emerald Isle inlet shoreline was armored with sandbag revetments.

In March 2005, the ebb channel was artificially relocated approximately 3,200 feet westward to mitigate the chronic erosion along the Bogue Banks inlet shoreline. Between October 2006 and April 2014, the ebb channel migrated toward Bogue Banks a net distance of 1,400 feet, and subsequently shifted westward 380 feet. The average eastward migration rate was 150 feet per year.

The inlet variables that control the behavior of the oceanfront shorelines are the position and alignment of the ebb channel, which ultimately dictate the shape of the ebb-tidal delta. The symmetry of the outer bar in turn controls its breakwater and natural nourishment effects along the adjacent oceanfront shorelines. The natural coastwise progradation that has occurred along Bogue Banks during various periods is directly attributable to the easterly migration of the ebb channel and the changing shape of the ebb-tidal delta. By contrast, the historic recession along Bear Island has reflected the negative influence of the ebb channel as it tracked eastward toward Bogue Banks. Since 1946, the US Army Corps of Engineers has maintained a 3.1-mile-long, 6.5-foot-deep channel connecting the inlet to the AIWW.

3.10a Emerald Isle side of Bogue Inlet

The vegetation and shoreline data for the Emerald Isle side of Bogue Inlet are shown in Figures 67 and 68. Using the IHAM, inlet transect-81 defines the boundary of inlet influence along the oceanfront shoreline (Figure 69). The 90-Year Risk Line is recommended as the landward boundary of the IHA (Figure 70).

Figure 67. Bogue Inlet at Emerald Isle. Vegetation Lines mapped: 1971, 1976, 1987, 1992, 1998, 2003, 2004, 2006, 2009, 2010, 2012, 2016, and; vegetation line composite segments making up the Hybrid-Vegetation Line: 1971, 1976, 1987, 1992, 1998, 2004, 2006, 2009, 2010, 2012.



Figure 68. Shorelines included in the analysis: 1949, 1956, 1958, 1960, 1971, 1973, 1976, 1987, 1992, 1997, 1998, 2003, 2004, 2006, 2009, 2010, 2012, 2016.



Figure 69. Based on standard deviation of relative shoreline position at Bogue Inlet-Emerald Isle, transect-81 is recommended as the inlet-ocean transition boundary along the shoreline. Negative Linear Regression rates indicate erosion, while positive values represent accretion (right axis).

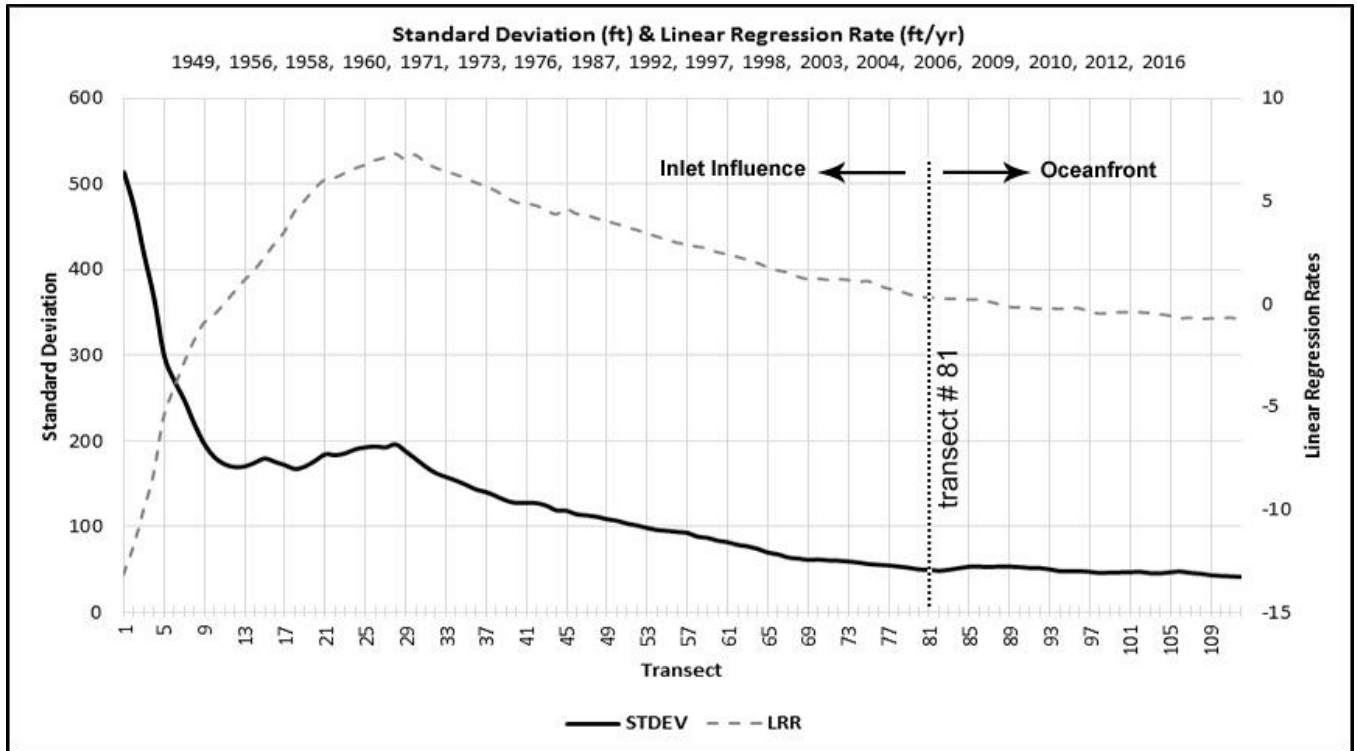
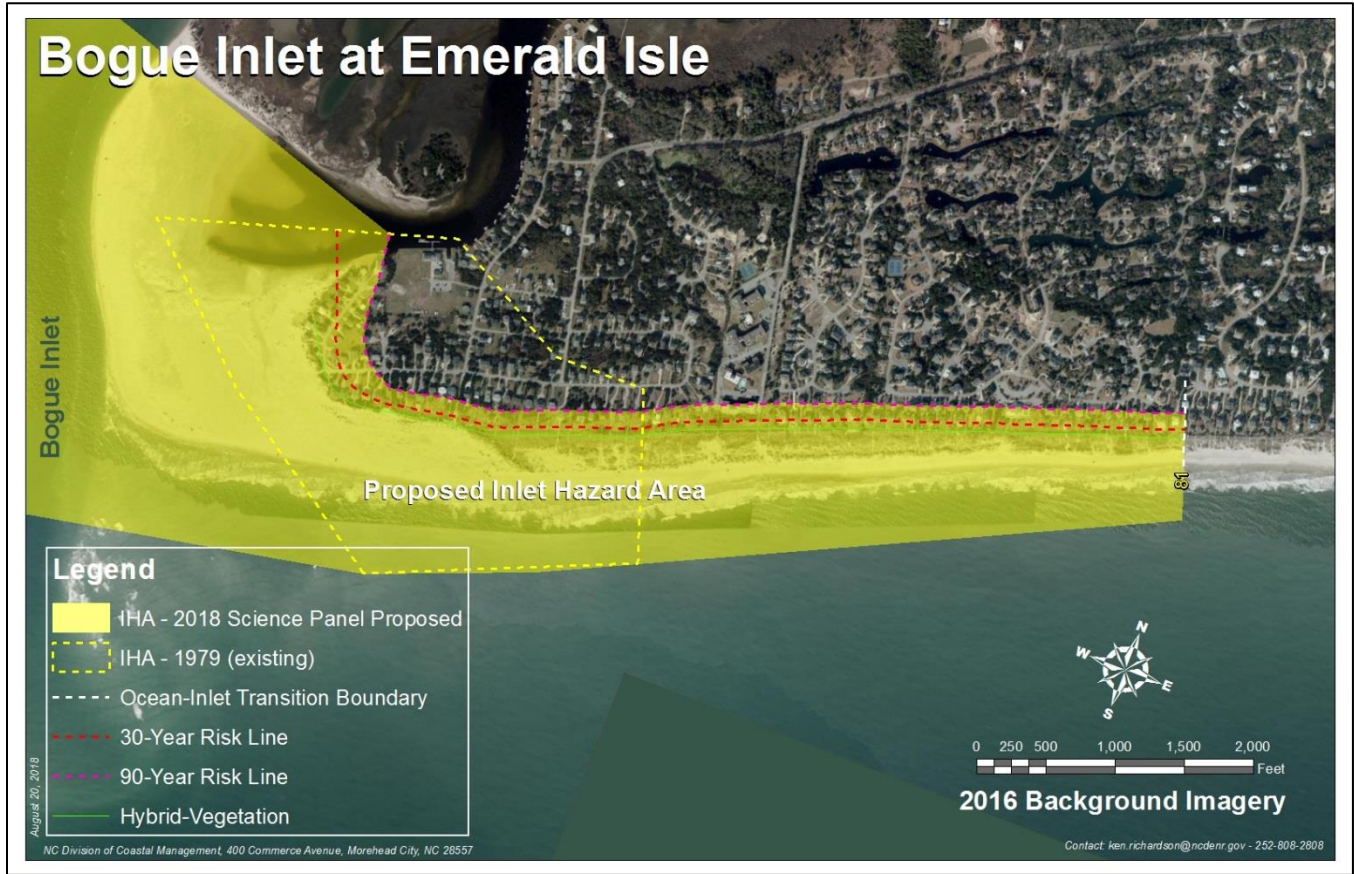


Figure 70. Bogue Inlet at Emerald Isle Hybrid-Vegetation Line and the recommended IHA boundary with the 30- and 90-Year Risk Lines.



4.0 Recommendations

The Inlet Hazard Area Method (IHAM) outlined and applied here is an objective methodology for calculating inlet shoreline change rates and for delineating the Inlet Hazard Areas (IHA) and areas within the IHA at greatest risk of experiencing inlet related erosion. Given the uniqueness of each inlet, it is important that the IHAM combines both accurate shoreline change data with variability statistics with detailed, professional knowledge of the underlying inlet geology and hydrodynamics. IHA boundaries have been proposed for the 10 developed North Carolina Inlets.

Given the potential for conditions at inlets to rapidly fluctuate over both the short- and long-term, the Science Panel on Coastal Hazards also recommends that the CRC consider updating the IHA every five years, coinciding with the oceanfront erosion rate and Ocean Eroding Area updates. Recommended issues to evaluate in the next update include:

- a more detailed analysis of the effect of including dates after construction of the AIWW but prior to 1970;
- the effect of various running averages in smoothing transect points alongshore;
- evaluate more effective ways to establish inlet transects;
- continue to evaluate the effectiveness of the IHA in managing near-inlet development.

Other issues may arise to consider in future updates as the Inlet Hazard Areas are implemented.

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Appendix A: List of Acronyms

AEC	Area of Environmental Concern
AIWW	Atlantic Intracoastal Waterway
CAMA	NC Coastal Area Management Act of 1974
CRC	NC Coastal Resources Commission
CSC	NOAA Coastal Services Center
DCM	NC Division of Coastal Management
DOT	Department of Transportation
EP	End-Point (Shoreline Change Rate Methodology)
GIS	Geographic Information System
GS	General Statute
HVL	Hybrid-Vegetation Line
IHA	Inlet Hazard Area
IHAM	Inlet Hazard Area Method
lidar	Light Detection and Ranging
LRR	Linear Regression (Shoreline Change Rate Methodology)
MLW	Mean Low Water
MHW	Mean High Water
NC	North Carolina
NCAC	NC Administrative Code
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
OEA	Ocean Erodible Area
T-sheet	Topographic Sheet
US	United States
USGS	US Geological Survey
30-YRL	30-Year Risk Line
90-YRL	90-Year Risk Line

Appendix B: Definition of Key Terms

Vegetation Lines (Veglines): Vegetation lines were interpreted as the First Line of Stable and Natural Vegetation (*FLSNV*). Although a few were mapped in the field using a mapping grade GPS, most vegetation lines were digitized using Geographic Information Systems (GIS) and orthorectified imagery.

Hybrid-Vegetation Line (HVL, Hybrid-Veg): This line represents the landward-most position of all vegetation lines at each inlet. The Hybrid-Vegetation Line is most often a composite containing landward-most segments from multiple vegetation lines, or at some locations, may represent only a single date.

Smoothed Hybrid-Vegetation Line: This line was digitized using the smoothed point locations where the Hybrid-Vegetation Line intersects transects. Point coordinates for each intersection were smoothed using a 5-point running average to minimize landward-oceanward cusping, or “jagged” segments along the Hybrid-Vegetation Line. This line served as the starting point, or baseline, from which landward measurements were cast along each transect.

Transects: These measurements are spaced 25 meters (82.03 feet) apart and cast perpendicular to the trending direction of all shorelines. Transects are used when calculating shoreline change rates at specific locations. Transects were cast using GIS and the US Geological Survey’s Digital Shoreline Analysis System (DSAS).

Linear Regression Shoreline Change Rates: Shoreline change rates are calculated using multiple shorelines. A linear regression rate-of-change statistic is determined by fitting a least-squares regression line to all shoreline points for a transect. The regression line is placed so that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized. The linear regression rate is the slope of the line. The method of linear regression includes these features: (1) All the data are used, regardless of changes in trend or accuracy; (2) the method is purely computational; (3) the calculation is based on accepted statistical concepts; and (4) the method is easy to employ (Dolan et al., 1991). However, the linear regression method is susceptible to outlier effects and tends to underestimate the rate of change relative to other statistics, such as EPR (Dolan et al., 1991; Genz et al., 2007). In conjunction with the linear regression rate, the standard error of the estimate (LSE), the standard error of the slope with user-selected confidence interval (LCI), and the R-squared value (LR2) are reported. Linear Regression was used to calculate inlet shoreline change rates.

End-Point Shoreline Change Rates: This shoreline change rate is calculated by measuring the distance between two shorelines (early and current) and dividing by the time period. This method has been used on the oceanfront since 1979.

Ocean Erodible Area (OEA): The OEA is an Area of Environmental Concern (AEC) defined in NC’s Coastal Resource Commission’s Rules (15A NCAC 07H. 0300). This is the area where there exists a substantial possibility of excessive erosion and significant shoreline fluctuation. The oceanward

boundary of this area is the mean low water line. The landward extent of this area is the distance landward from the first line of stable and natural vegetation to the recession line established by multiplying the long-term annual erosion rate times 90; provided that, where there has been no long-term erosion or the rate is less than two feet per year, this distance shall be set at 120 feet landward from the first line of stable and natural vegetation (15A NCAC 07H. 0304 (1)).

Inlet Hazard Area (IHA): Is an Area of Environmental Concern (AEC) defined in NC's Coastal Resource Commission's Rules (15A NCAC 07H. 0300). These are natural-hazard areas that are especially vulnerable to erosion, flooding, and other adverse effects of sand, wind, and water because of their proximity to dynamic ocean inlets. This area extends landward from the mean low water line a distance sufficient to encompass that area within which the inlet migrates, based on statistical analysis, and shall consider such factors as previous inlet territory, structurally weak areas near the inlet, and external influences such as jetties and channelization (15A NCAC 07H. 0304 (2)). Current rule language also states: *"In all cases, the IHA shall not be an extension of the adjacent OEAs and in no case shall the width of the IHA be less than the width of the adjacent OEA."* The reason for referencing current rule language is because at the June 29, 2018 Science Panel meeting, panel members agreed that this is an important consideration and that the IHA should match the OEA at a minimum, but not less than.

Appendix C: Proposed Inlet Hazard Area Maps

Tubbs Inlet at Sunset Beach



Figure C1. Proposed Inlet Hazard Area at Tubbs Inlet (Sunset Beach).

Tubbs Inlet at Ocean Isle

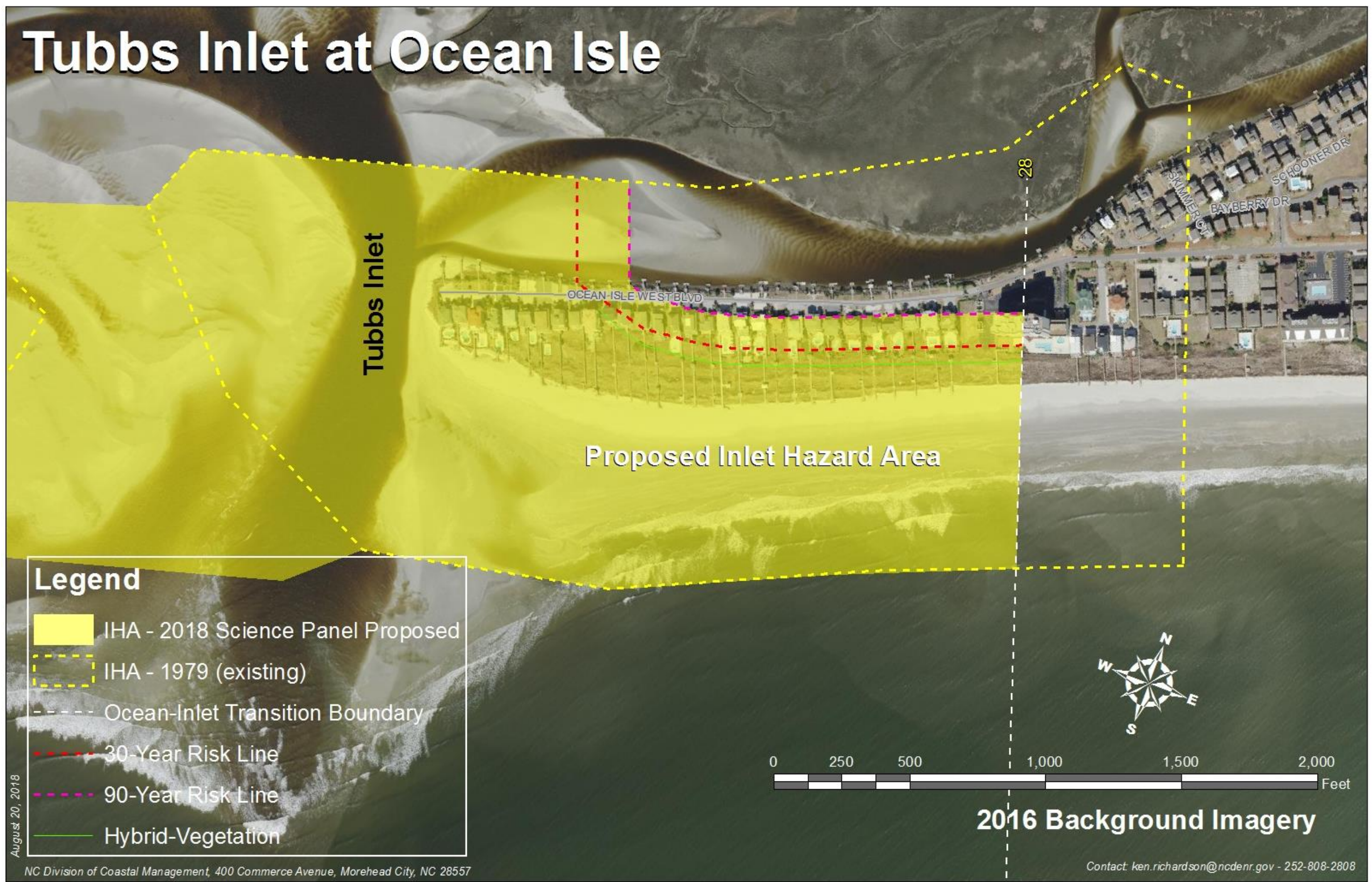


Figure C2. Proposed Inlet Hazard Area at Tubbs Inlet (Ocean Isle Beach).

Shallotte Inlet at Ocean Isle

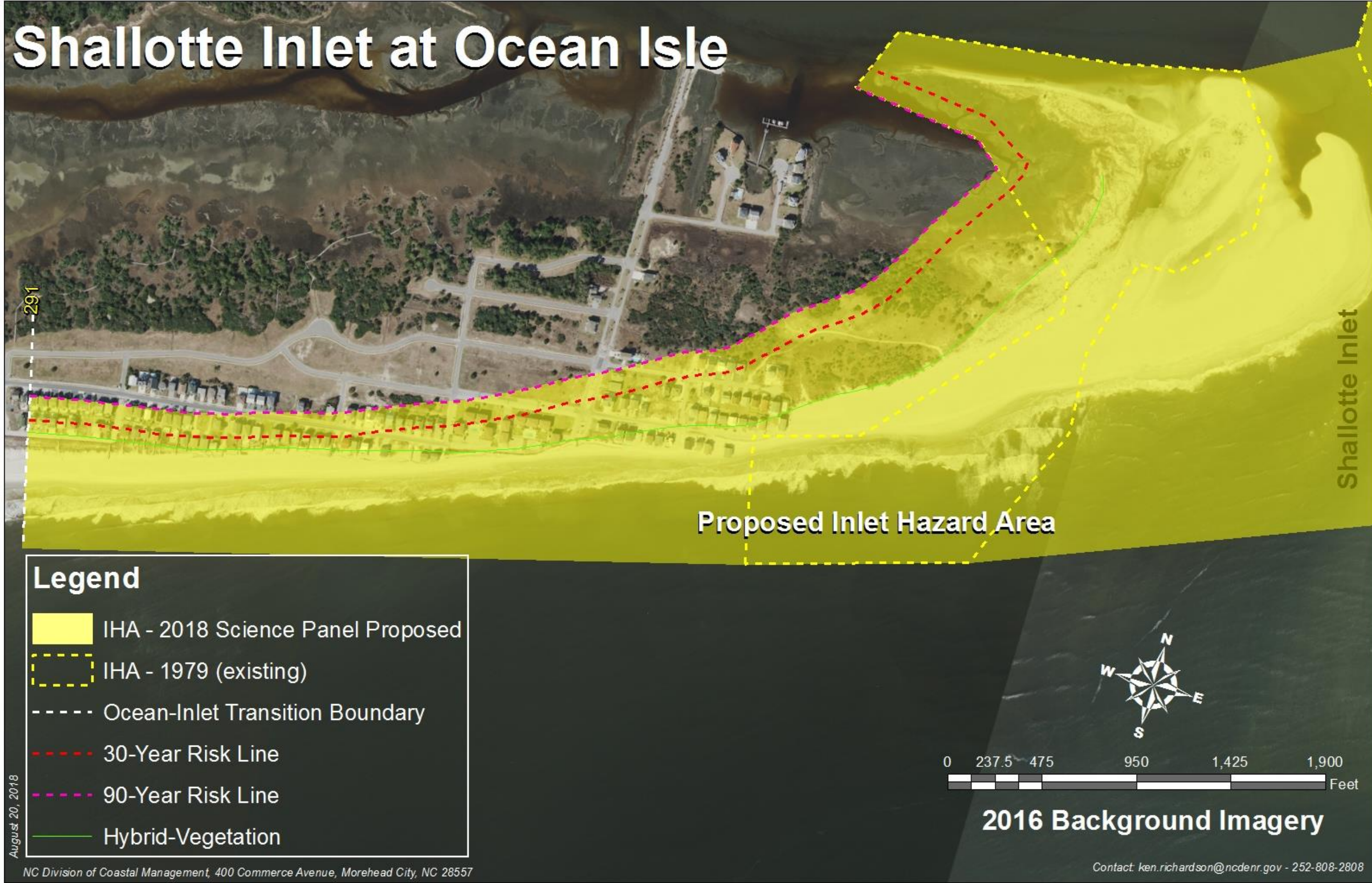


Figure C3. Proposed Inlet Hazard Area at Shallotte Inlet (Ocean Isle).

Shalotte Inlet at Holden Beach

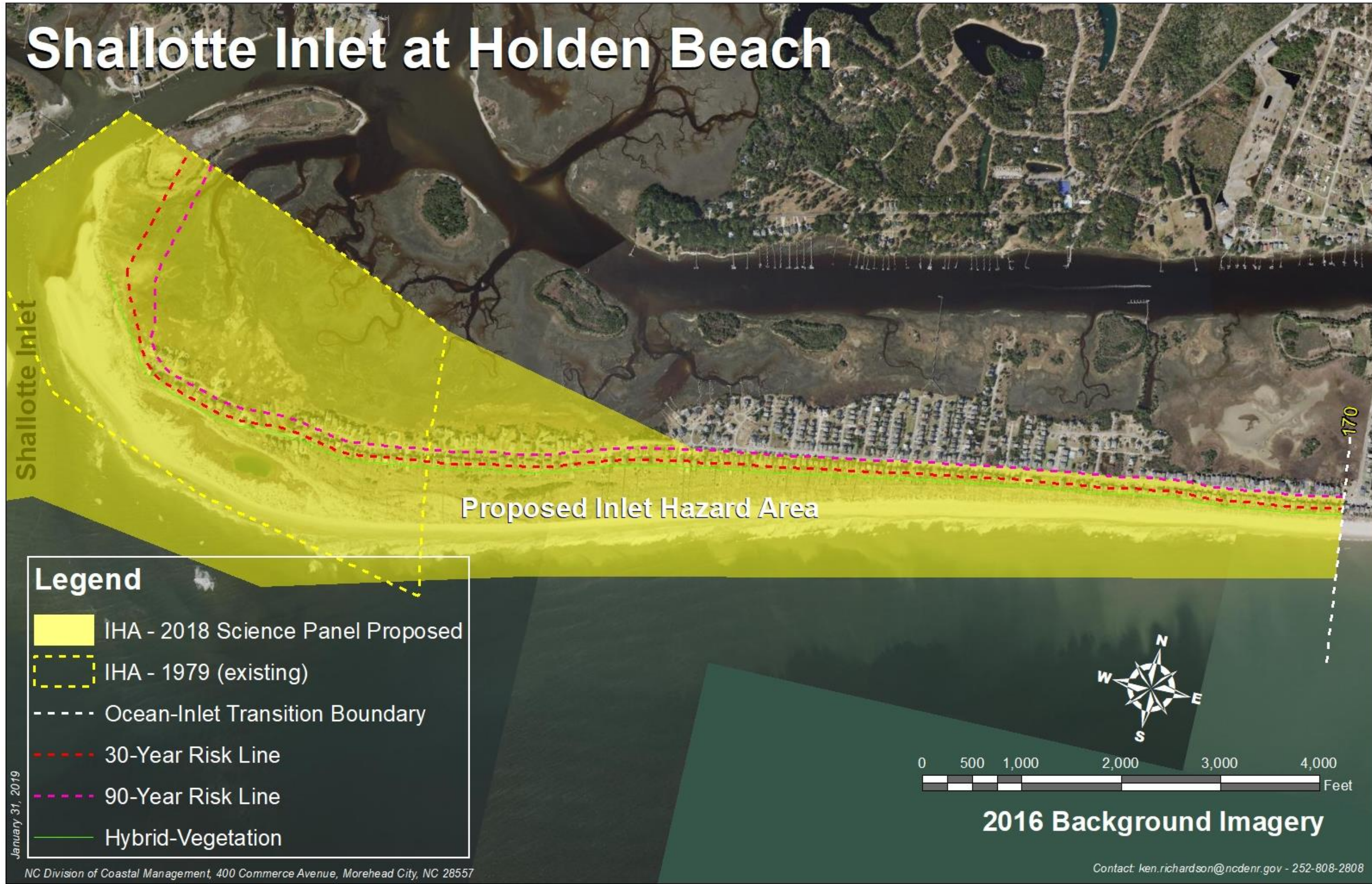


Figure C4. Proposed Inlet Hazard Area at Shallotte Inlet (Holden Beach).

Lockwood Folly Inlet at Holden Beach

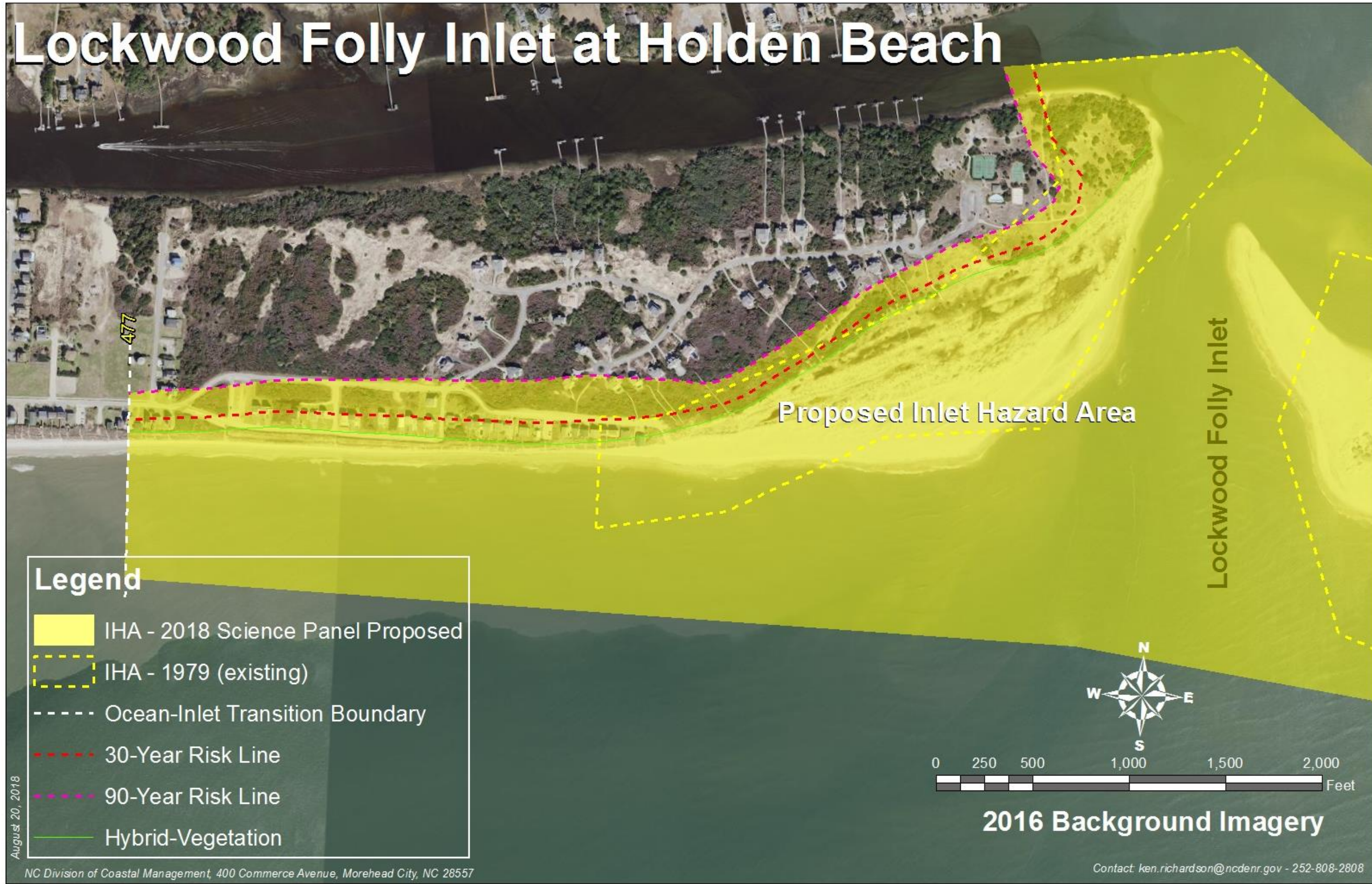


Figure C5. Proposed Inlet Hazard Area at Lockwood Folly Inlet (Holden Beach).

Lockwood Folly Inlet at Oak Island

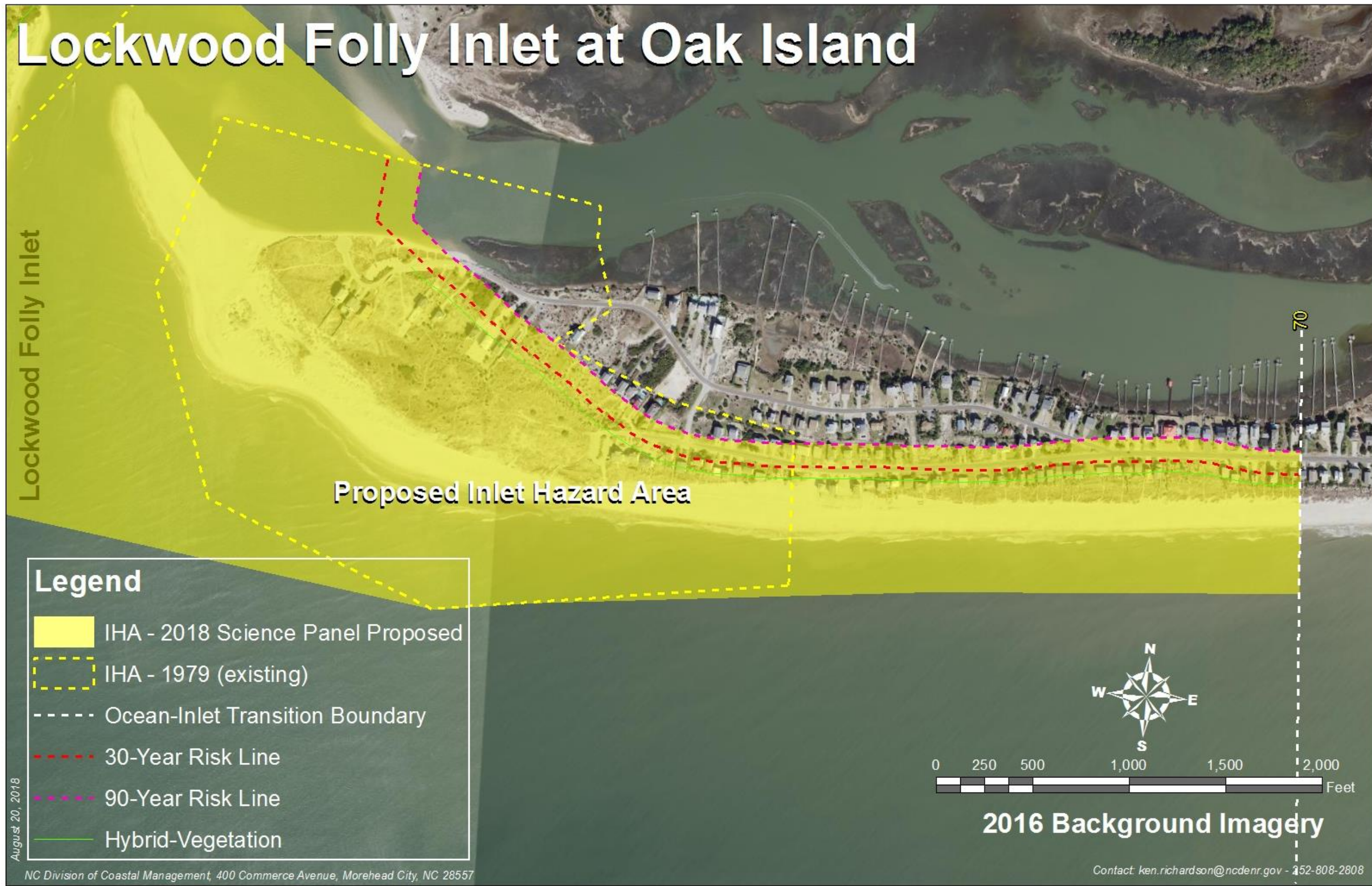
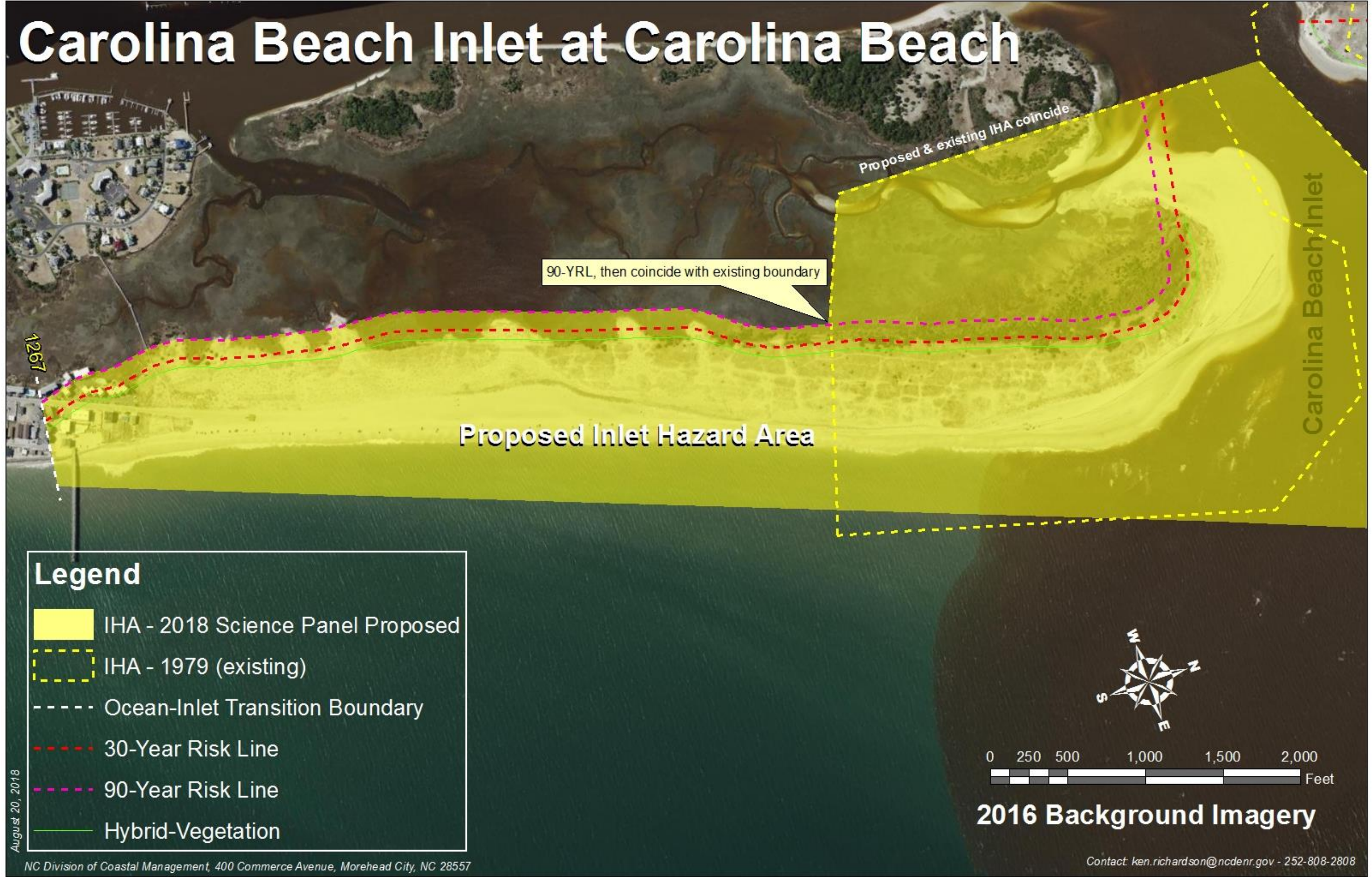


Figure C6. Proposed Inlet Hazard Area at Lockwood Folly Inlet (Oak Island).

Carolina Beach Inlet at Carolina Beach



Legend

- IHA - 2018 Science Panel Proposed
- IHA - 1979 (existing)
- Ocean-Inlet Transition Boundary
- 30-Year Risk Line
- 90-Year Risk Line
- Hybrid-Vegetation

August 20, 2018

NC Division of Coastal Management, 400 Commerce Avenue, Morehead City, NC 28557

0 250 500 1,000 1,500 2,000 Feet

2016 Background Imagery

Contact: ken.richardson@ncdenr.gov - 252-808-2808

Figure C7. Proposed Inlet Hazard Area at Carolina Beach Inlet (Carolina Beach).

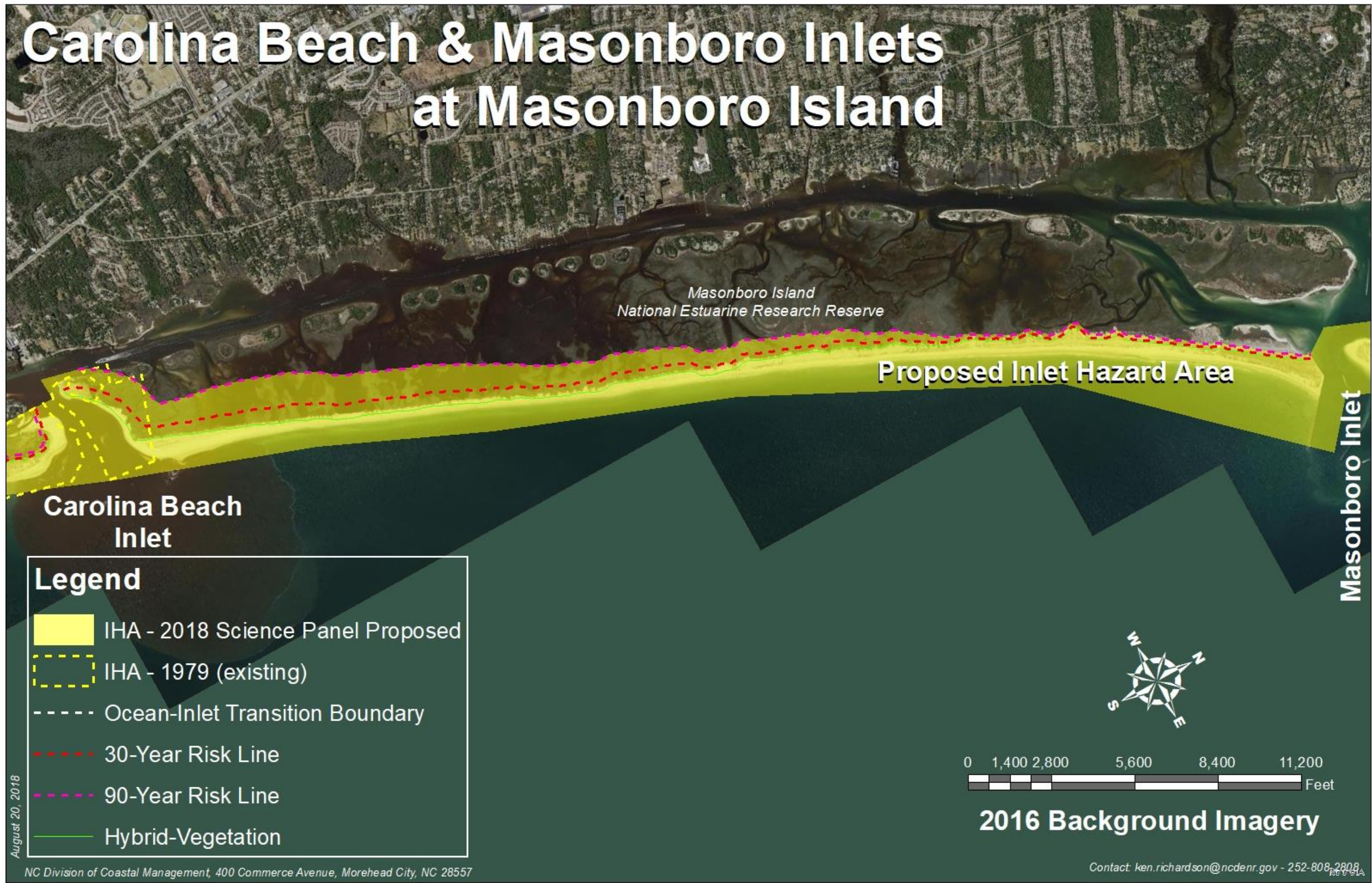


Figure C8. Proposed Inlet Hazard Area for Masonboro Island.

Masonboro Inlet at Wrightsville Beach

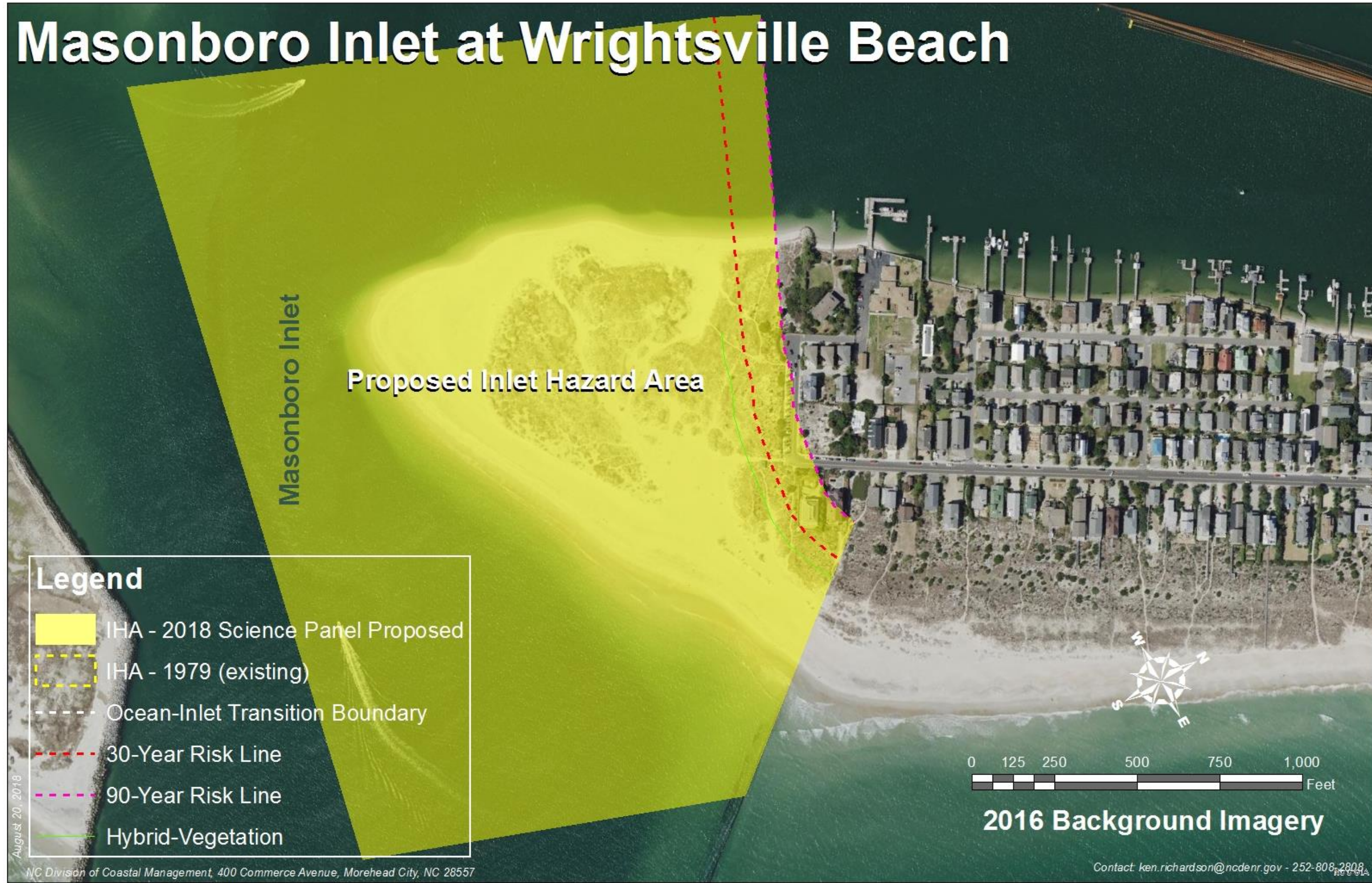


Figure C9. Proposed Inlet Hazard Area at Masonboro Inlet (Wrightsville Beach).

Mason Inlet at Wrightsville Beach

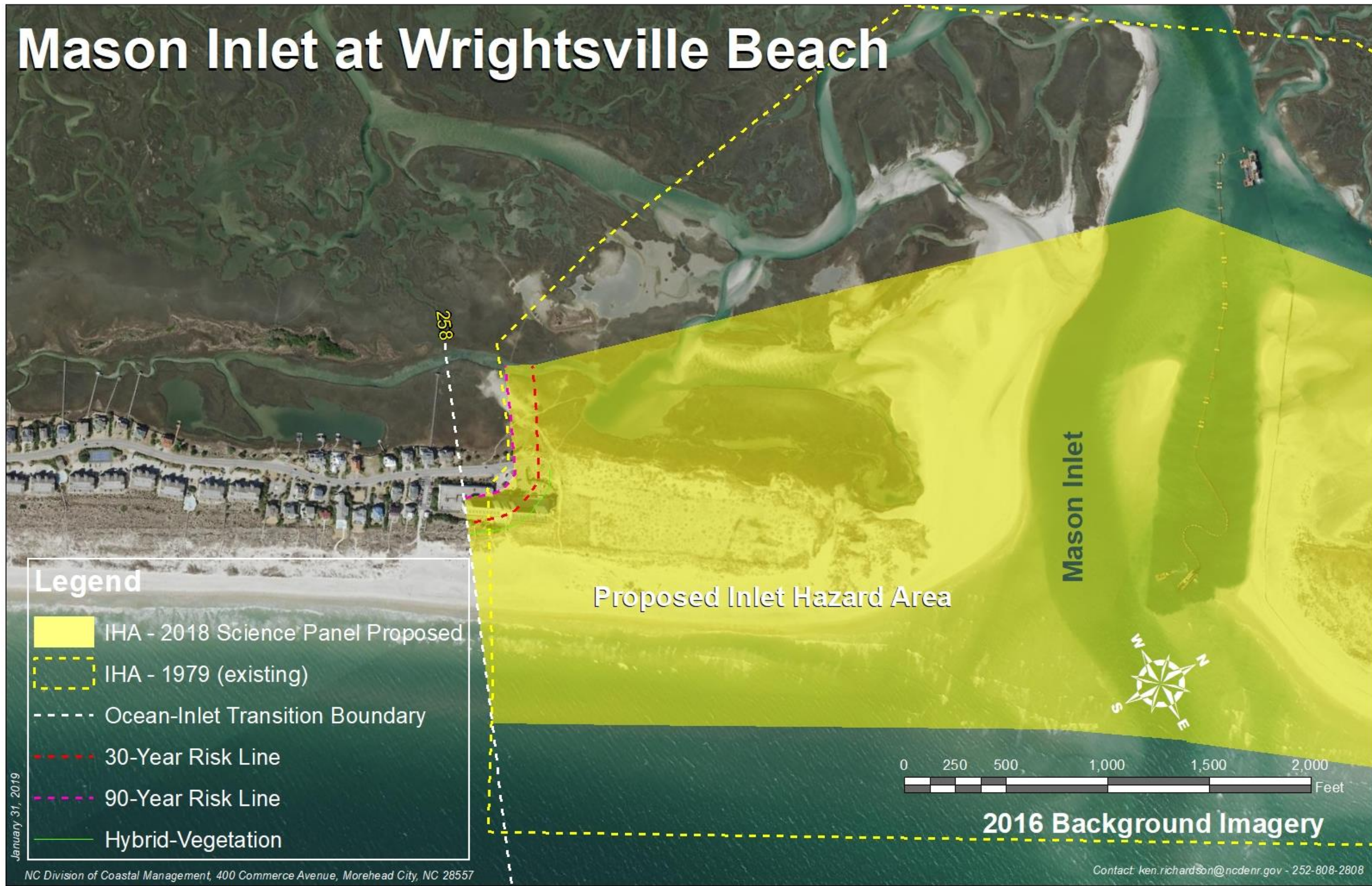


Figure C10. Proposed Inlet Hazard Area at Mason Inlet (Wrightsville Beach).

Mason Inlet at Figure Eight Island

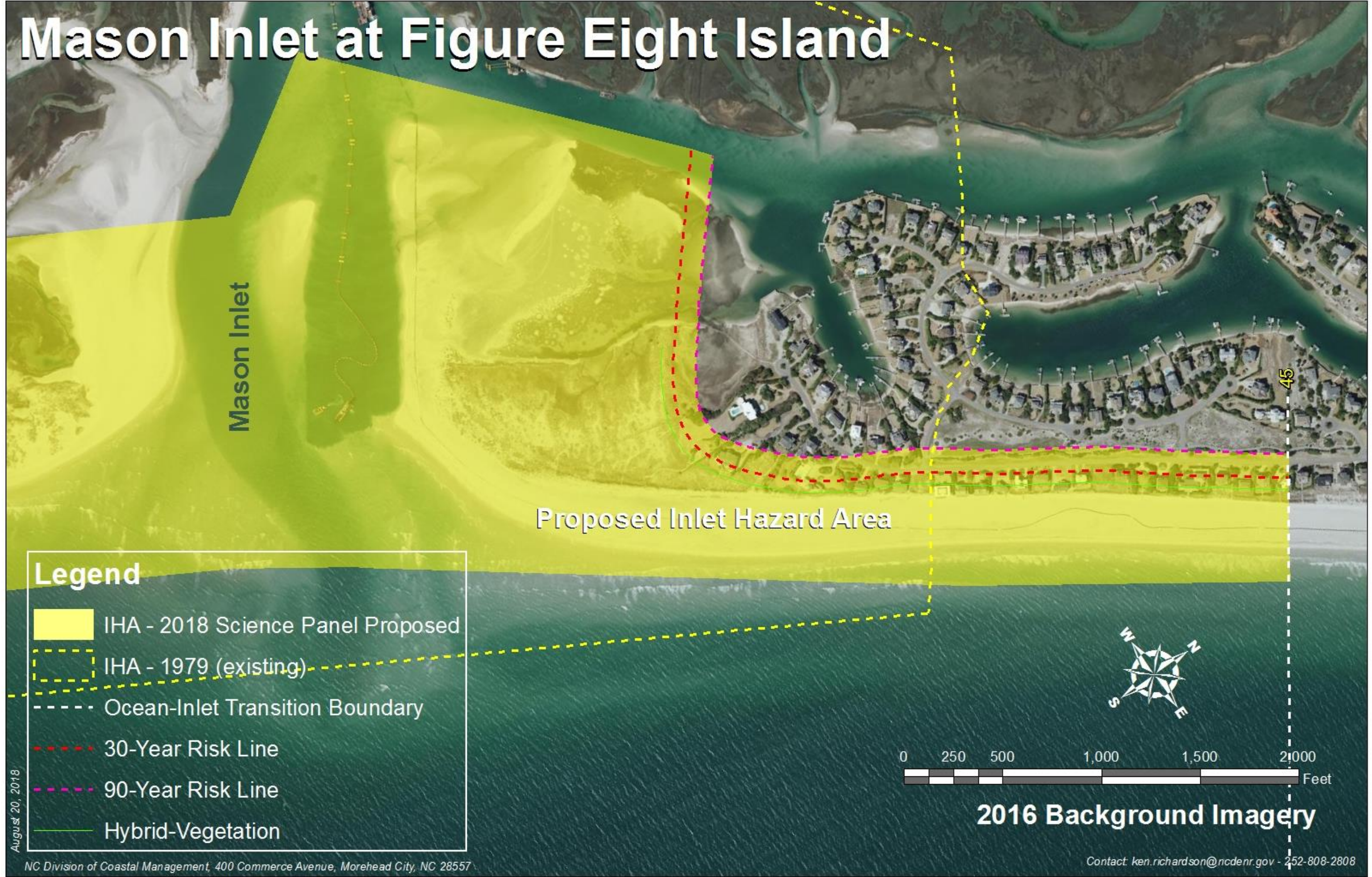


Figure C11. Proposed Inlet Hazard Area at Mason Inlet (Figure Eight Island).

Rich Inlet at Figure Eight Island

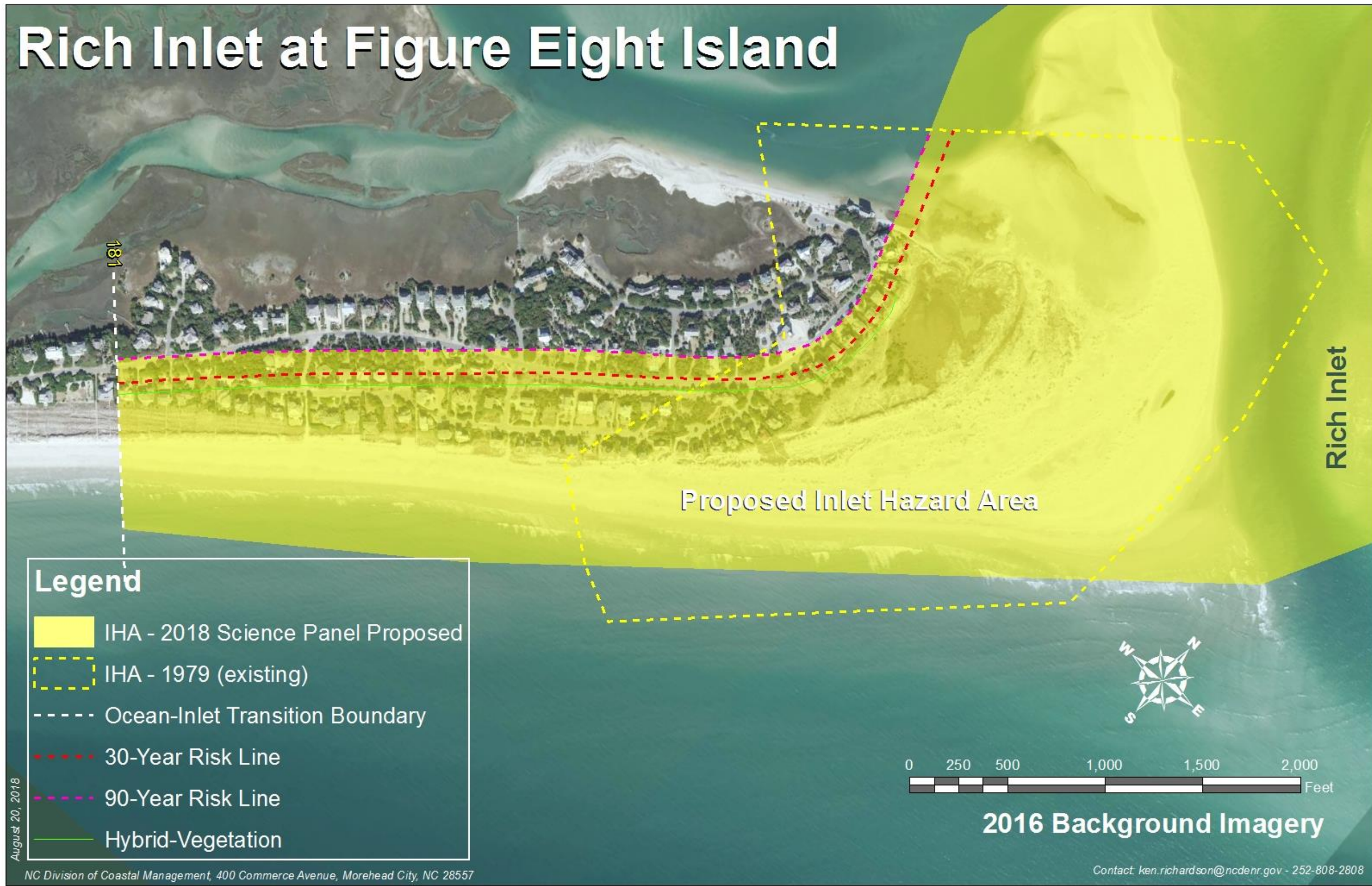


Figure C12. Proposed Inlet Hazard Area at Rich Inlet (Figure Eight Island).

Rich & New Topsail Inlets at Lea-Hutaff Island

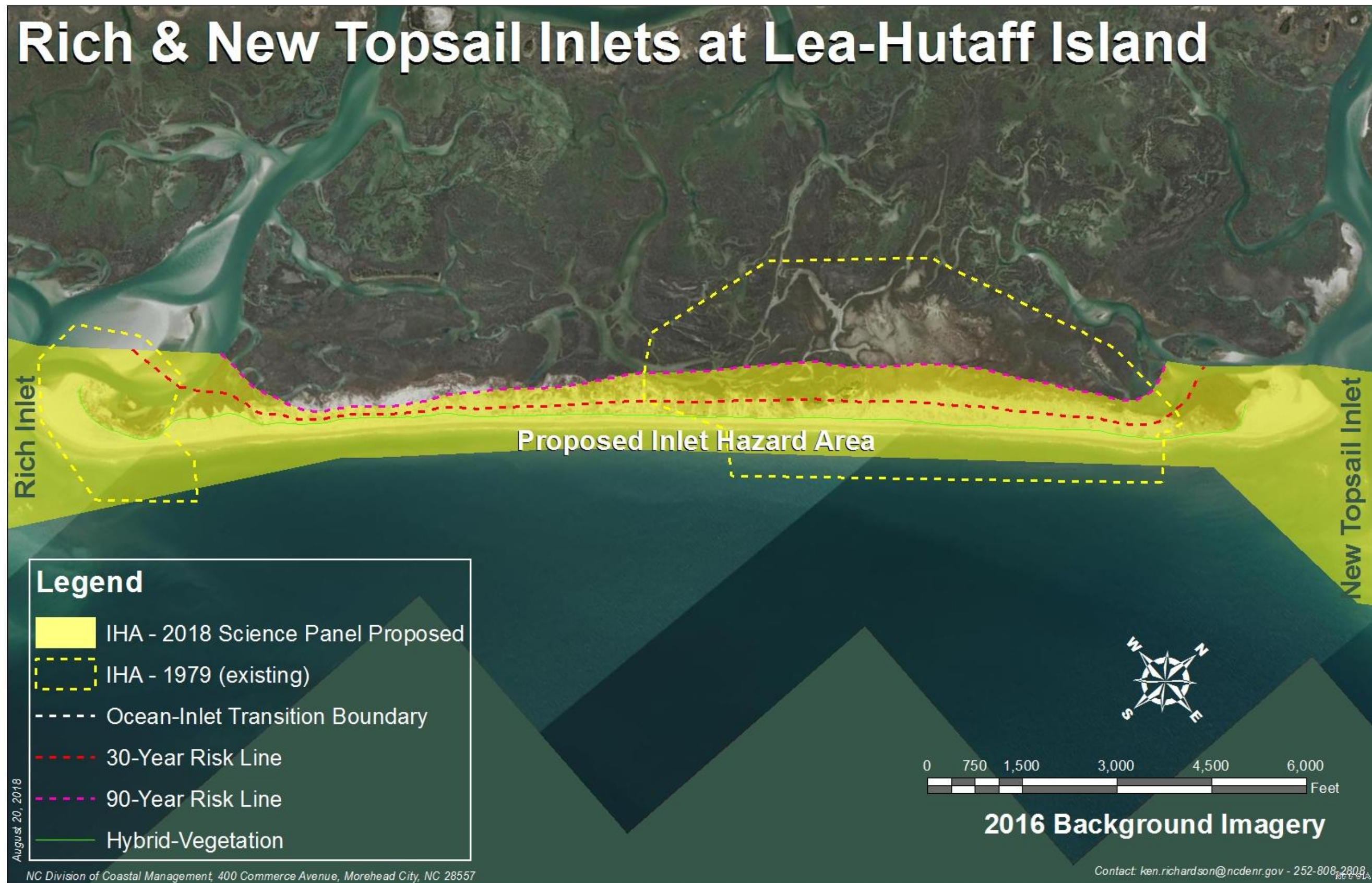


Figure C13. Proposed Inlet Hazard Area at Rich & New Topsail Inlets (Lea-Hutaff Island).

New Topsail Inlet at Topsail Beach

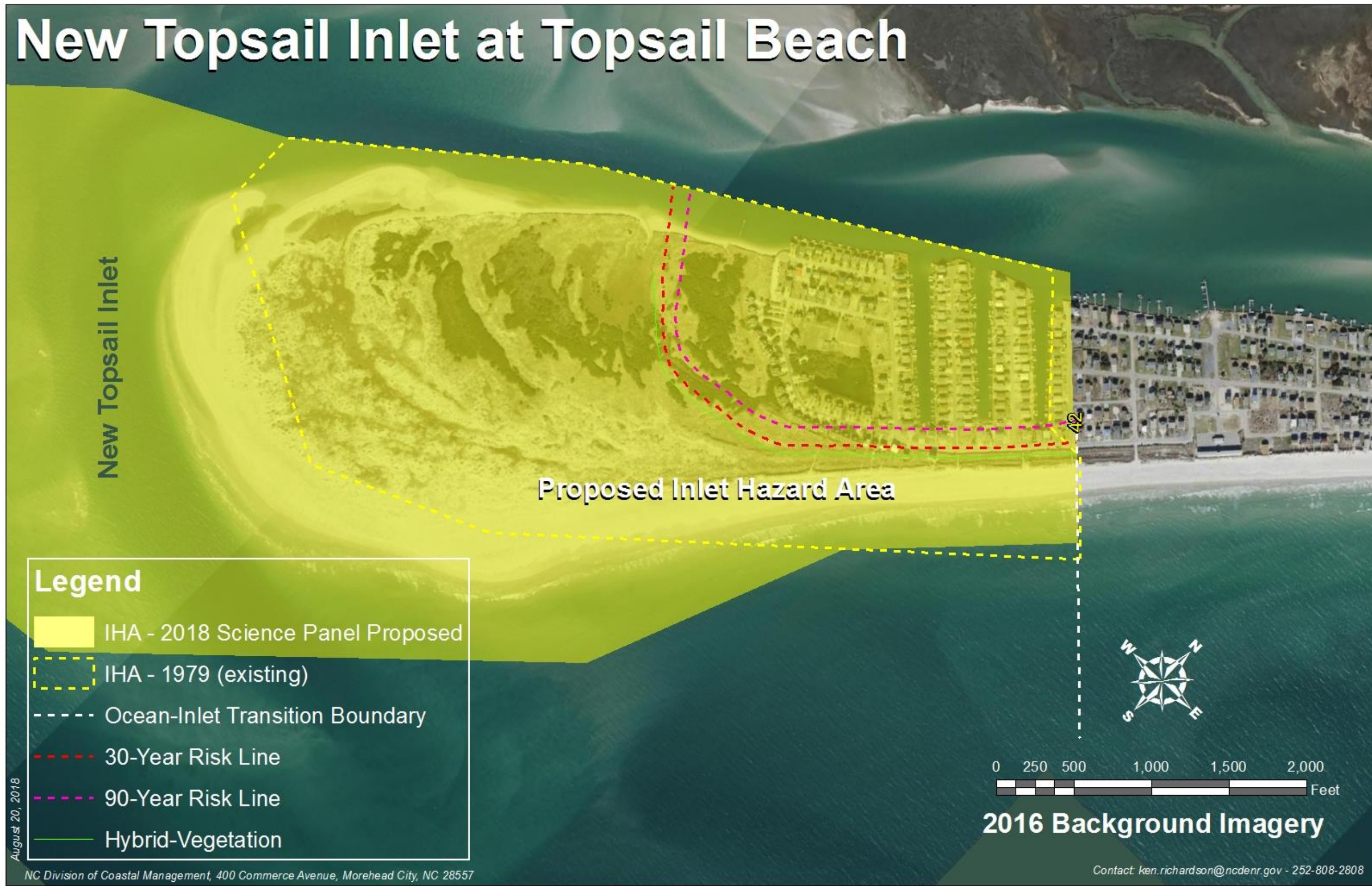


Figure C14. Proposed Inlet Hazard Area at New Topsail Inlet (Topsail Beach).

New River Inlet at North Topsail Beach

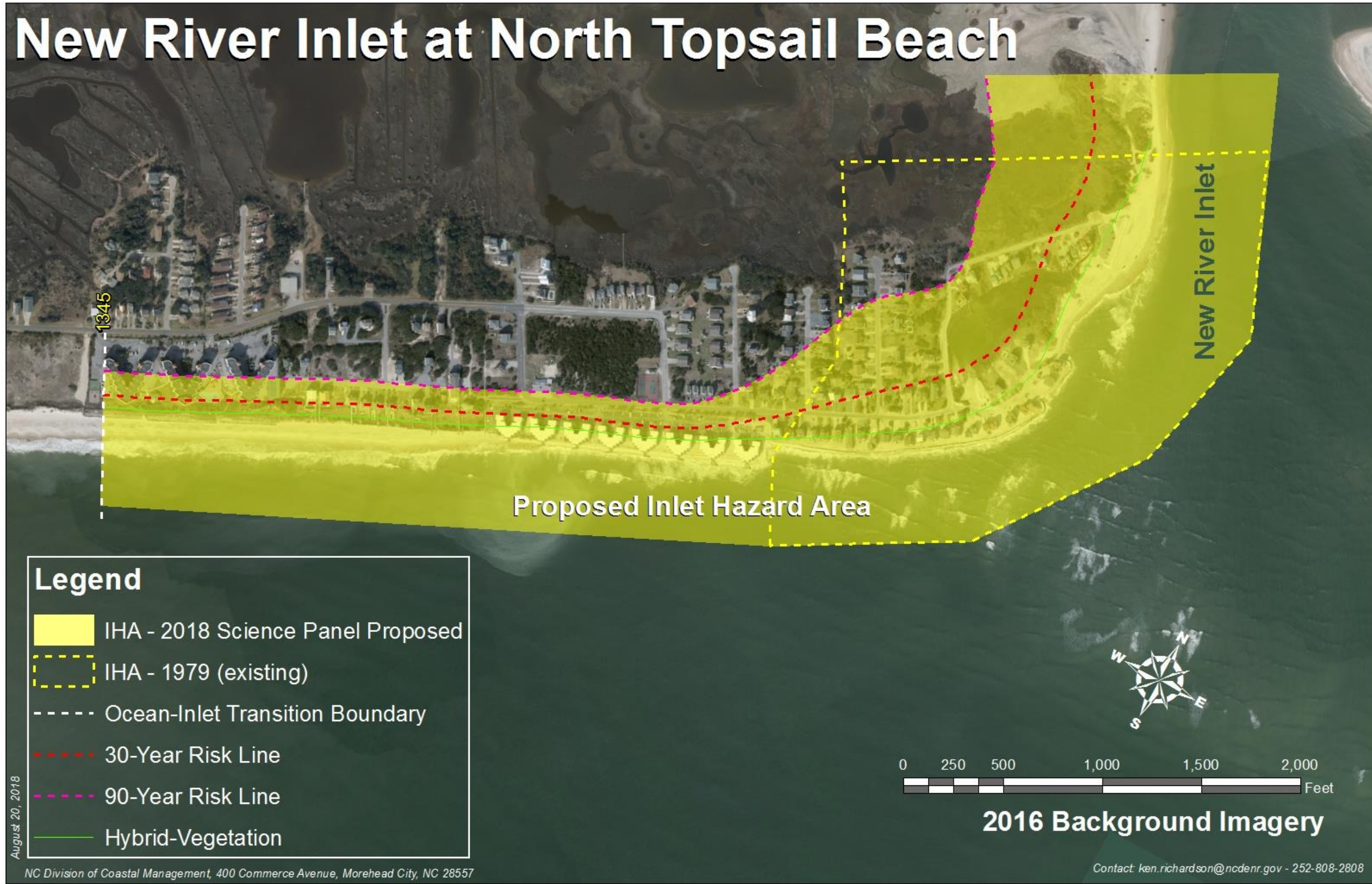


Figure C15. Proposed Inlet Hazard Area at New River Inlet (North Topsail Beach).

Bogue Inlet at Emerald Isle

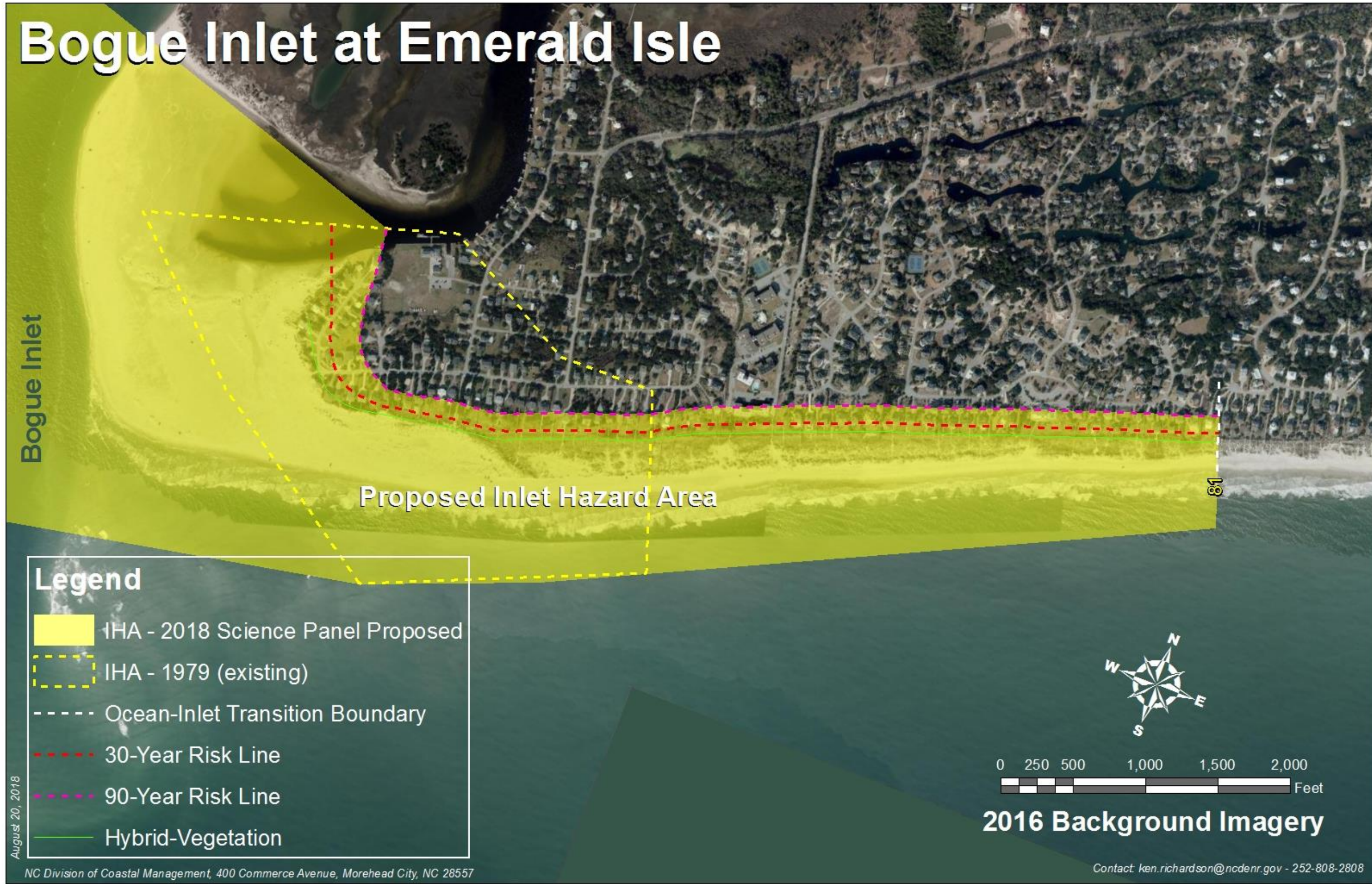


Figure C16. Proposed Inlet Hazard Area at Bogue Inlet (Emerald Isle).

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February 12, 2019

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