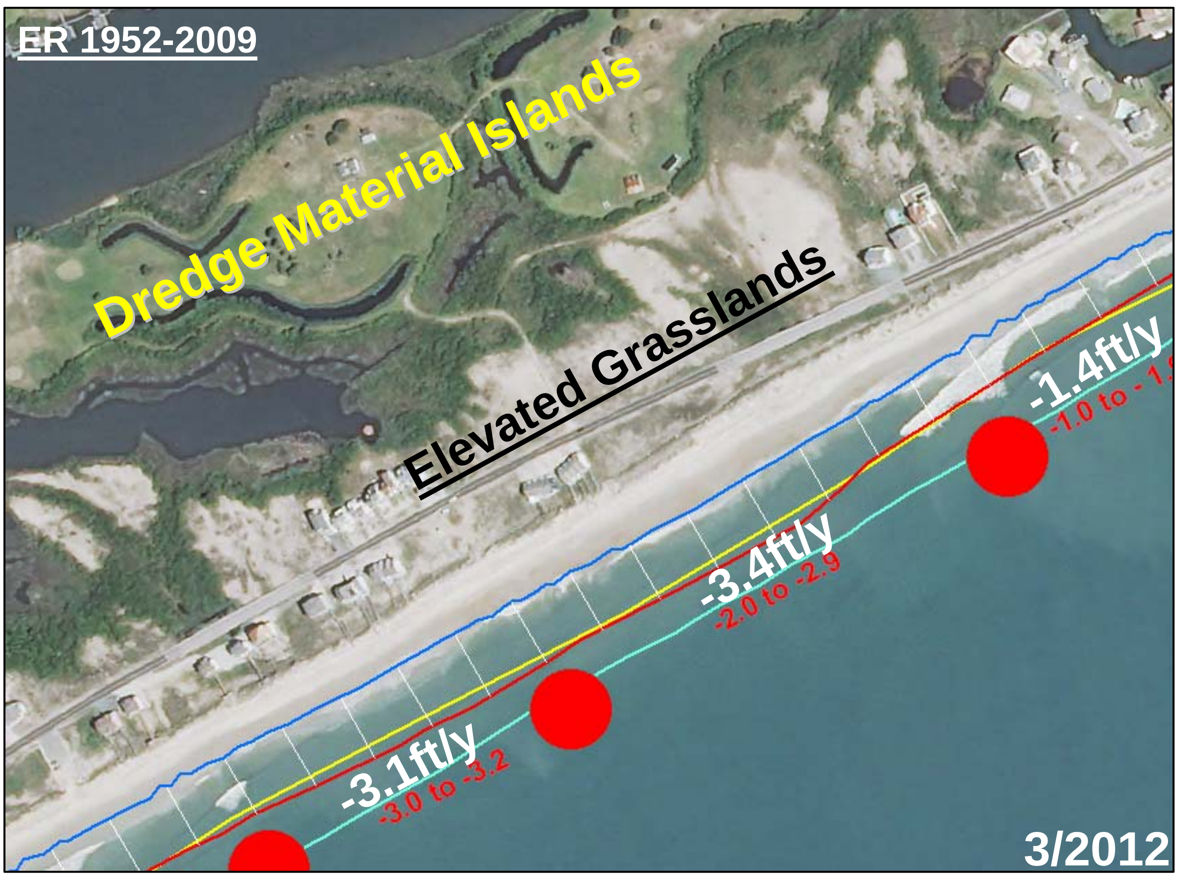
Incident Waves, Historic Hurricane History and North Topsail Beach Shoreline Erosion Rates



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10 January 2015

Characteristics of Incident Waves, Historic Hurricane History and North Topsail Beach Oceanfront Shoreline Erosion Rates

Wave Characteristics

North Topsail Beach, the northern 11.6 mile long segment of Topsail Beach, is located along the central portion of the Onslow Bay, NC shoreline that extends from Cape Lookout to Cape Fear. The northeastern portion of the Onslow Bay compartment is comprised of relatively sand-rich, formerly regressive barrier islands (Beaufort Inlet to Browns Inlet). The boundary separating the regressive barriers and the typical low-lying transgressive barriers of southeastern NC occurs along the northern segment of Onslow Beach. The central portion of Onslow Beach is perched atop Oligocene Limestone that rises within six feet of the marsh surface behind the island. The limestone also lies close to the surface (6-7 ft) of the tidal marsh along North Topsail Beach in vicinity of the sharp bend in the AIWW. These units, as well as others of a similar nature, are exposed on the shoreface and often form moderate to high-relief scarps that impact sediment transport and the incident waves as they approach the shoreline.

Pilkey and Neal (2009) have alluded to the high persistent wave energy (their Table 1) that impacts North Topsail Beach and Topsail Island in general. The following narrative is based upon data derived from NOAA buoy #190, located offshore New River Inlet and buoy # 150, located offshore Masonboro Inlet (Fig. 1).

Wave height is used as a proxy or as an indicator of wave energy which is important because it drives the coastal (longshore) transport system. As wave heights increase the wave energy increases as the square of the wave height and hence the ability to erode and transport beach material also increases. Therefore, slight changes in wave height are important in both the long- and short-term. A comparison of the significant wave height (Hs, the average height of the one-third highest waves) from offshore North Topsail Beach and Wrightsville Beach, located in nearby New Hanover County, shows that the Hs data are similar, and in fact the Hs is slightly lower for North Topsail Beach (Figs. 2

and 3). Figure 2 also shows that the direction of wave approach is slightly different for North Topsail Beach but within the ESE –SE approach direction.

Figure 4 depicts Period Rose diagrams for the above offshore areas. The data show that slightly longer period waves, and hence slightly more energetic waves approach Wrightsville Beach than North Topsail Beach (Figs. 2 and 3). Although the differences are small the data pertaining to the wave characteristics do not support the contention of Pilkey and Neal (2009). Furthermore, the significant difference in the shoreline orientation of North Topsail Beach (N61^{o}E) and nearby Wrightsville Beach (N32^{o}E) in New Hanover County, indicate that due to the combined effect of the slightly higher Hs and the shoreline orientation, erosion and sand transport would be greater for Wrightsville Beach. From a regional perspective, North Topsail Beach is not characterized by persistent high wave energy (Fig. 4). In a relative sense, the wave energy along the shelf sector offshore Onslow County and New Hanover County is slightly greater than the wave energy offshore the Brunswick County barriers due the influence of the Cape Fear Foreland. However, by comparison to the areas north of Cape Hatteras, it is significantly less than that of the shelf sector offshore Dare County, where the storm-dominated barriers are subjected to persistent high wave energy (Fig. 5).

The map imaged on Figure 6 depicts the USGS's risk ranking related to the mean wave height and future sea-level change. Inspection of the map clearly shows that North Topsail Beach has a moderate risk ranking compared to adjacent developed shoreline reaches in Carteret County, portions of Pender County and a significant portion of New Hanover County located to the southwest.

Topsail Island's Stormy Past - Hurricanes and Nor'easters

Little detailed information exists in terms of the hurricane history of Topsail Island, NC prior to the late 1940s when Surf City began to develop. Pilkey and Neal (2009) provided a description of the hurricanes that have impacted Topsail Island during the 20th and 21st Century beginning with Hurricane Hazel in October 1954 and ending with Hurricane

Ophelia in September 2005. They further list a large number of late 18^{th} and 19^{th} century extra-tropical storms that presumably impacted the island. The tracks of the hurricanes that Pilkey and Neal mentioned that occurred in the 1950s, the 1980s and the 1990s are depicted by Figures 7 -9.

Pilkey and Neal (2009) also provide an appendix that contains Table 1A entitled *Storm History for Topsail Island*. The three page table lists historic hurricanes and nor'easters that in their opinion impacted North Carolina between 1775 and 2007. The information for late 18^{th} C and for most of the 19^{th} C storms is based on personal historic observations made at sites other than Topsail Island. Figure 10 depicts NOAA's documented tracks of 32 hurricanes (H1-H4) that passed within 80 nautical miles of North Topsail Beach between 1899 and 2013. Similarly the documented tracks of 45 tropical storms that passed through the area are depicted on Figure 11. With respect to nor'easters, no single source is available that has compiled the historic tracks of all extra-tropical coastal cyclones. The lack is related to the frequency, types and modes of origin of extra-tropical storms. The tracks that are available are those of some of the late 19^{th} to 21^{st} notable century storms that that impacted major population areas or were major weather producing events.

It is extremely misleading to infer that all of the hurricanes and nor'easters listed in their appendix and mentioned in their narrative that supposedly impacted Topsail Island, did not also impact all the islands in Pender and New Hanover Counties located farther to the southwest, as well as those barriers located to the northeast in Carteret County. The documented hurricane tracks imaged on Figures 7-10 and 12 represent a line that connects points (center of the storm) and does not adequately represent the storm's circle of maximum winds around the core or "eye". When any of the storms imaged on Figures 11 and 12 impacted Topsail Island then most assuredly they also impacted to some degree the shoreline reaches along New Hanover County beaches located less than 20 miles to the southwest. While most of the Pilkey and Neal comments pertaining to the structural damages related to the recent hurricanes, that occurred along Topsail Island between 1954 and 2005 are correct, some however are very misleading and others blatantly false, particularly comments related to 20th century historic inlets and the island wide erosion rates.

NOAA's Coastal Services Center, now NOAA's Office of Coastal Management provided a link to the NOAA National Hurricane Center and their portal for acquiring images depicting historic hurricane tracks and other pertinent information. One hurricane -related component that is germane to the above discussion is the availability of data pertaining to hurricane strikes vs coastal counties. Hurricane strike data for selected North Carolina counties were derived from the above web portals and were supplemented by additional unpublished NOAA county strike data in southeastern NC (Table 1).

Inspection of Table 1 shows the NC counties that received either direct or indirect hurricane "hits". These NOAA designations are subjective and are based on the description provided in Table 1 for each category. Figure 13 shows the direct strike data for six NC coastal counties (Brunswick, New Hanover, Pender, Onslow, Carteret and Dare Counties). North Topsail Beach located in Onslow County received nine direct hits between 1900 and 2005, the least number compared to the other southeastern NC counties that received between a total of 10 to 11 direct hits. The graph also shows that Brunswick, New Hanover and Pender Counties all received a direct hit by one category 4 Hurricane (Helene 27 Sep 1958) according to NOAA's data.

The North Carolina County Indirect Strike data are depicted by Figure 14. It is interesting to note that according to the NOAA data, Carteret County located near Cape Lookout had the greatest number of indirect hits (21) while Onslow County received the second-most indirect hits (16). This latter high value is related to the fact that adjacent Carteret County had more direct hits and hence according to NOAA's subjective assignment, those counties (ie. Onslow Co.) located on either side of a direct hit by default were often assigned an indirect hit designation. Figure 15 depicts the summary of total hits (direct and indirect) received by the aforementioned six counties. The NOAA strike data (Figs. 13-15 and Table 1) do not support the opinions expressed by Pilkey and Neal (2009).

North Topsail Beach Erosion Rates

According to Pilkey and Neal (2009) North Topsail Beach (NTB) is subjected to persistent high wave energy and has a storm history where inundation, massive dune and beach erosion, large-scale overwash and inlet openings are commonplace. They also allude to the “fact” that the residents of the Town face high, short- and long-term historic erosion rates because of the above events and associated processes. It is true, that the town was severely impacted by the hurricanes of the 1990s and significant overtopping occurred along all of the Town’s 11.4 miles of oceanfront shoreline but so were all beach communities in southeastern North Carolina that did not have a history of beach nourishment. Although very-short term (event scale) storm-induced beach and dune erosion can be high, as it is elsewhere, both short-term (~ 30 to 40 yrs) and long-term (> 100 yrs) erosion rates are remarkably low.

Figure 16 depicts oblique aerial views of post-Hurricane Fran (September 1996) conditions along four North Topsail Beach shoreline reaches, while Figure 17 depicts March 2012 views of the same four areas. Figure 17 also shows the shoreline erosion rates for the period between 1/1/1949 or 1/1/1952 and 7/11/2009 (red-colored numerals) in each of the photos (Fig. 17A-D). Only one shoreline reach has short-term erosion rates greater that 1.5 ft/yr and that is the northern breach zone (Fig. 17 A), an area that was the focus of media attention in the aftermath of the 1990s storms. The remaining three shoreline sectors (Fig. 17 B-D) are all characterized by very low erosion rates that range from (0.60 to 1.1 ft/yr).

The North Carolina Division of Coastal Management (NC DCM) Policy and Planning Section’s, 2011 Long-Term Average Annual Oceanfront Erosion Rate Update Study-Methods Report was updated 10/30/2012. The primary purpose of updating the erosion rates was for the establishment of oceanfront construction Setback Factors. Figures 18 and 19 are comprised of maps depicting the erosion rates used for calculating Setback Factors. Most coastal residents who use these maps assume that the minimum erosion rate is 2.0 ft/yr and that there are no shoreline reaches that are accreting or “relatively stable” (< -1ft/yr). The NC Division of Coastal Management’s minimum construction setback is 60 ft. Consequently, when a shoreline reach is accreting or eroding at 2ft/yr or less, the Setback Factor by default is two (2).

The bar graph that comprises Figure 20 depicts the total length (miles) of various shoreline segments that are eroding at variable rates. The mid-page insert (Fig. 20), shows that erosion is occurring along a total of 9.8 miles (88.6 %) of the Town's oceanfront while accretion is occurring along 1.2 miles (11.4 %) of the shoreline. These values reflect the 11.1 miles of shoreline analyzed of the 11.4 miles of total length of the Town's oceanfront and inlet-influenced shorelines. In terms of the NC DCM"s updated erosion rates, four erosion rate categories were indentified: 2ft/yr or less, 2-5 ft/yr, 5-8 ft/yr and > 8ft/yr. The bar graph (Fig. 20) reflects the length of shoreline that falls into each category. The most important point germane to the discussion of the Pilkey and Neal (2209) paper is that 8.4 miles (75.2%) of the 11.1 miles of shoreline analyzed is eroding at rates less than 2ft/yr. An additional 1.2 miles (10.9%) of shoreline is eroding at rates between 2-5 ft/yr and the great majority shoreline segments that fall with in this designation are eroding at rates less than 3 ft/yr. The values derived from the NC DCM recent erosion rate update clearly are in direct opposition to the contention made by Pilkey and Neal (2009) that persistent high erosion rates are the norm for North Topsail Beach.

Figures 21-27 are maps depicting the shoreline change rates for the period between the baseline year that varied with location (1933, 1949 or 1952) and 2009. The baseline year (earliest shoreline) is indicated on each map depicted (Figs. 21-17). The values depicted on each of the maps on the above mentioned figures, were derived from NC DCM's Oceanfront Interactive Map Viewer that illustrates historic oceanfront data and from downloadable GIS files (Transects 50-meter *(includes raw, smoothed, & blocked erosion rate data).* The above maps (Figs. 21-27) clearly show that the shoreline erosion rates along the great majority of North Topsail Beach are low, and along several short non inlet-influenced shoreline sections minor accretion has occurred. These maps clearly do not support the assertion of Pilkey and Neal (2009) that high erosion rates are the norm for North Topsail Beach.

Figure 28 is a map that depicts a July 2009 photograph with the historic shoreline positions for 1856, 1934 and 1952. The above maps depicted by Figure 28 were used to determine the shoreline changes along a shoreline segment that transitioned from a non-inlet influenced reach to a one where the New River Inlet ebb-tidal delta changes controlled the shoreline change during the past 60 yrs. The red-colored numbers (1-17) represent transect locations that were used for the measurement of shoreline change for three periods (1856 - 1934, 1934 - 1952 and 1952 - 2009). The shoreline reach depicted in Figure 28 is ~2.4 miles in length and is comprised of a ~1.5 mile-long shoreline reach influenced by changes associated with the New River Inlet System.

Figure 29 depicts the shoreline changes (distance) for the three periods mentioned above. During the relatively storm-free period between 1934 and 1952, the shoreline located between Transect 3 and Transect 9 retreated at an average of 14.7 ft during the 18.2 yr time interval. The average erosion rate for this non-inlet influenced shoreline segment was 0.86 ft/yr during this storm-free period. In contrast, the average shoreline retreat during the subsequent period, between 1952 and 2009, amounted to 59.7 ft during a 57.3 yr long period. The average erosion rate was 1.13 ft/yr for the period when numerous major storms impacted the area.

Figure 30 illustrates the average annual change rates for the above mentioned time-intervals for the shoreline segments depicted on the maps comprising Figure 28. The majority of the shoreline segment (T9-T17) imaged on Figure 28 A has historically been strongly influenced by the location of New River Inlet's ebb-tidal and its shape changes since the 1950s. The colored dots (Fig. 28) delineate the ebb-tidal delta's southwestern limit and the lateral extent of its influence along North Topsail Beach. Inspection of Figure 28 A shows that between 1954 and 1987 (colored dots) the ebb-tidal delta's influence steadily shifted to the southwest. During this period of time the oceanfront shoreline (~T9-17) prograded (accreted). A reversal in the shift direction occurred in the early 1990s when the outer portion of the ebb channel began deflecting to the northeast and as a consequence the extent of the ebb-tidal delta shifted toward the northeast and the mouth of the inlet. The locations of the 1998 and 2003 colored dots reflect the above mentioned northeasterly shift. As a result of the northeasterly shift, the once-accreting shoreline after a short-time lag began to erode.

An inspection of Figure 29 shows that during the period 1934 to 1952, the shoreline located between T14 and T17 accreted as much as 178 ft at rates as high as 9.8 ft/yr (Fig. 30). The accretion occurred concurrent with the erosion of the shoreline located between T3 and T13. The above shoreline change trends reflected the enlargement of the ebb-tidal delta and its gradual southwesterly shift along the downdrift shoreline, as New River Inlet (ebb channel) migrated in a southerly direction. The period between 1952 and 2009, brackets the interval when the ebb-tidal continued to enlarge (1952) and when it ultimately reach its most southwesterly extent (1987), and the interval (1990-2009) when the ebb-tidal gradual shifted to the northeast. An examination of Figure 29 shows that during the above period, the shoreline between T10 and T17, accreted by as much as 104 ft at rates of 1.8 ft/yr. It is beyond the scope of this brief report to expand the narrative dealing with the influence of the inlet, suffice to say it plays an important role in the shoreline change patterns along a minimum of 1.5 miles of the North Topsail Beach oceanfront.

The highest erosion rates along the shoreline imaged on Figure 28 occurs along the shoreline segment located between T1 and T3. This area was the site of massive cross-island washover features that formed during the hurricanes of the mid-late 1990s. The erosion rates for the period 1952-2009 in this area range from 2.0 to 3.2 ft/yr. By comparison the shoreline segment that extends from T3 to the T10 (inlet-influenced) is characterized by erosion rates that range from -0.6 ft/yr to -2.0 ft/yr. The average erosion rate along the aforementioned shoreline reach (T3-T10) is -1.4 ft/yr. These data as well as those previously described, clearly refute the assertions and opinions of Pilkey and Neal (2009).

Unlike the northernmost portion of the North Topsail Beach oceanfront shoreline, the southern portion of the town's oceanfront is characterized by very low rates of shoreline change. Figure 32 depicts a 1,820 feet-long oceanfront reach in the area where we have been photographing shoreline changes in vicinity of two homes during the past 25 years. The homes are referenced by red-colored circles in vicinity of the intersection of 4th Avenue and Topsail Drive. Historic shoreline positions (1856, 1933, and 1949) are color coded. The HWL imaged on the 7/2009 base photograph was the latest shoreline utilized in shoreline change measurements. The insert (Table 1) in Figure 33 A lists the shoreline change rates for four periods of time. Both the long- and short-term change rates are very low and do not exceed -0.7 ft /yr. The low erosion rates since 1952 are surprising given that the area has been overtopped during a number of storm events causing total destruction of the fronting dunes and concurrently the erosion and lowering of the upper portion of the foreshore. Figure 33 B (4/9/93) depicts the area approximately three years before the landfall of Hurricane Bertha (7/96). Figure 33 C-D shows the shoreline reach in the aftermath of Hurricane Bertha when the area was overtopped.

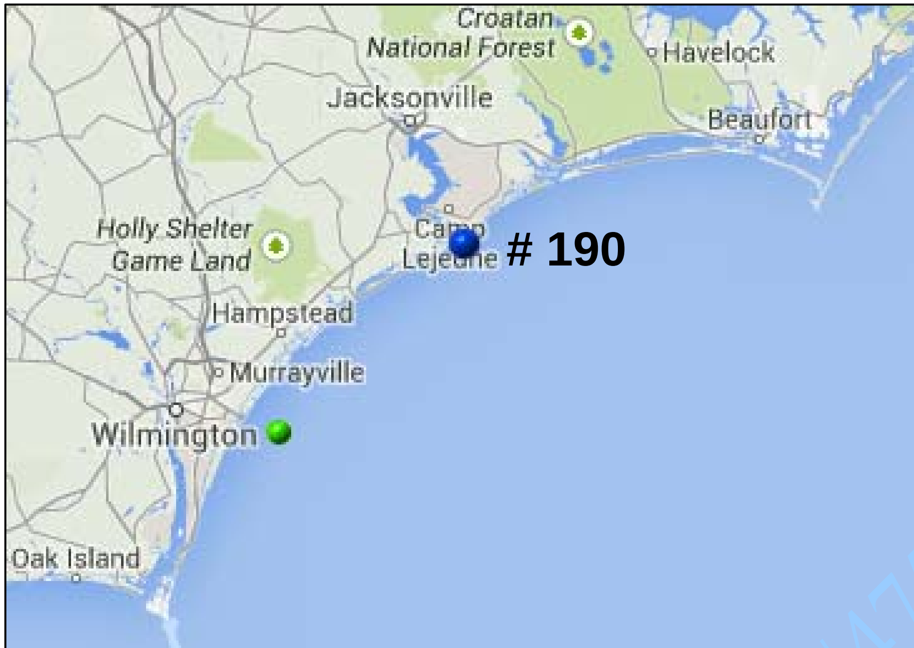
Figure 34 A-D shows the erosion of the dune line and the flattening of the profile during Hurricanes Fran, Bonnie and Floyd. In the aftermath of each of the storms, the washover sand deposition extended to the highway. Figure 35 A-D depicts the homes straddling a refurbished dune line. Figure 35 C depicts an extensive exposure of high-marsh peat with cedar stumps and shrub roots that underlies the lower foreshore portion of the profile. This unit crops out along a lengthy portion of the southern portion of North Topsail Beach, particularly in a northeasterly direction. Figure 36 A-C depicts the homes as of 8/6/2014 near a low tide condition. The position of the HTL (wrack line) is variable as evidenced by the images. The reason the shoreline in this area has been retreating very slowly during the past century (See Fig. 32A insert) is difficult to explain considering the storm history of the island. What effect the extensive peat unit has on the low retreat rate is unknown and is beyond the scope of this report.

The United States Geological Survey (USGS) has developed several methods that describe the vulnerability of a particular coastal segment to future sea-level rise. One of the methods is termed the Coastal Vulnerability Index (CVI). The CVI is pertinent to this discussion of North Topsail Beach’s vulnerability as opined by Pilkey and Neal (2009). The USGS’ coastal classification index is based upon an analyses six physical variables that include: geomorphology, regional coastal slope, tidal range, wave height, relative sea-level rise and shoreline change (+/-) rates. Two of the above variables are germane to this discussion and include mean wave height which was previously mentioned during the discussion of wave characteristics. The second variable is the short- and long-term shoreline change rates for North Topsail Beach.

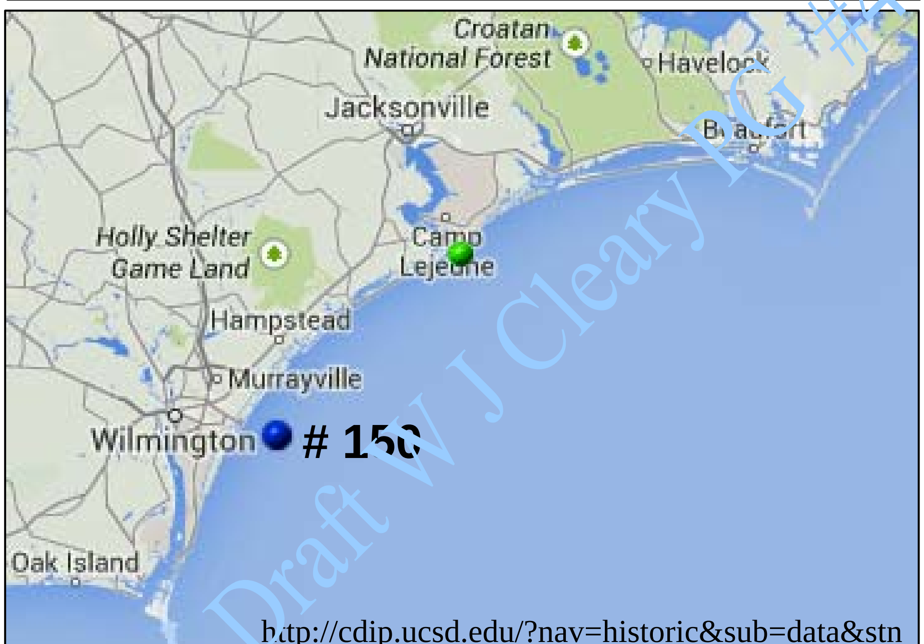
Figure 37 depicts a map of Topsail Island that shows the short-term shoreline change rates for the period between 1973 and 1997. The map was downloaded from the USGS Coastal Change Portal –Southeast Atlantic Short-Term Shoreline Change Rates and then subsequently modified. The above time period captures the short-term impacts of Hurricanes Bertha and Fran. The unit used by the USGS is meters/year (m/yr). An inspection of the map shows that the majority of North Topsail Beach is characterized by erosion rates that range between -1m/yr and +1 m/yr. A previously described the erosion rates are less than 0.6m/yr for the great majority (~75 %) of the North Topsail Beach oceanfront. The highest erosion rates (Fig. 37) along the Town's oceanfront are adjacent to the inlet and near the bend in the AIWW and southward, where major dune breaches and overwash-related swash channels formed during the above mentioned hurricanes. The rates along the latter shoreline reach are ~1.0 m/yr.

The map that comprises Figure 38 was also downloaded from the USGS Coastal Change Portal –Southeast Atlantic Short-Term Shoreline Change Rates and then subsequently modified. Figure 38 shows that the long-term shoreline change rates for the period between 1856 and 1997 for North Topsail Beach and the remainder of Topsail Island ranges between -1m/yr to +1m/yr.

In terms of the US Geological Survey's CVI for North Topsail Beach, an analysis of the shoreline change data described above as well as the previously described mean wave height data in combination with the other physical variables furnished a broad overview of the vulnerability ranking of the various coastal segments that comprise the North Carolina coastline. Figure 39 is a modified map that was derived from the USGS Coastal Change Portal –Atlantic Coast. Inspection of the map (Fig. 39) shows that the majority of the coastline segments in Southeastern North Carolina have the lowest CVI risk ranking (moderate) in comparison to other coastal reaches along the coast of North Carolina. The moderate risk designation assigned to Topsail Island (and North Topsail Beach) clearly does not support nor validate the opinion of Pilkey and Neal (2009).



 # 190 - New River Inlet, NC
Water Depth: 13.2 m
Location: ~3.3 nm SE of NRI,NC
Nautical Chart : 11539



 # 150 - Masonboro Inlet, ILM2, NC
Water Depth: 15.7m
Location: 6.5 nm off the Coastal Reserve
Nautical Chart : 11539

Figure 1. Maps depicting the Buoy Locations for Wave Data. Modified after CDIP (Integrative Oceanography Division).

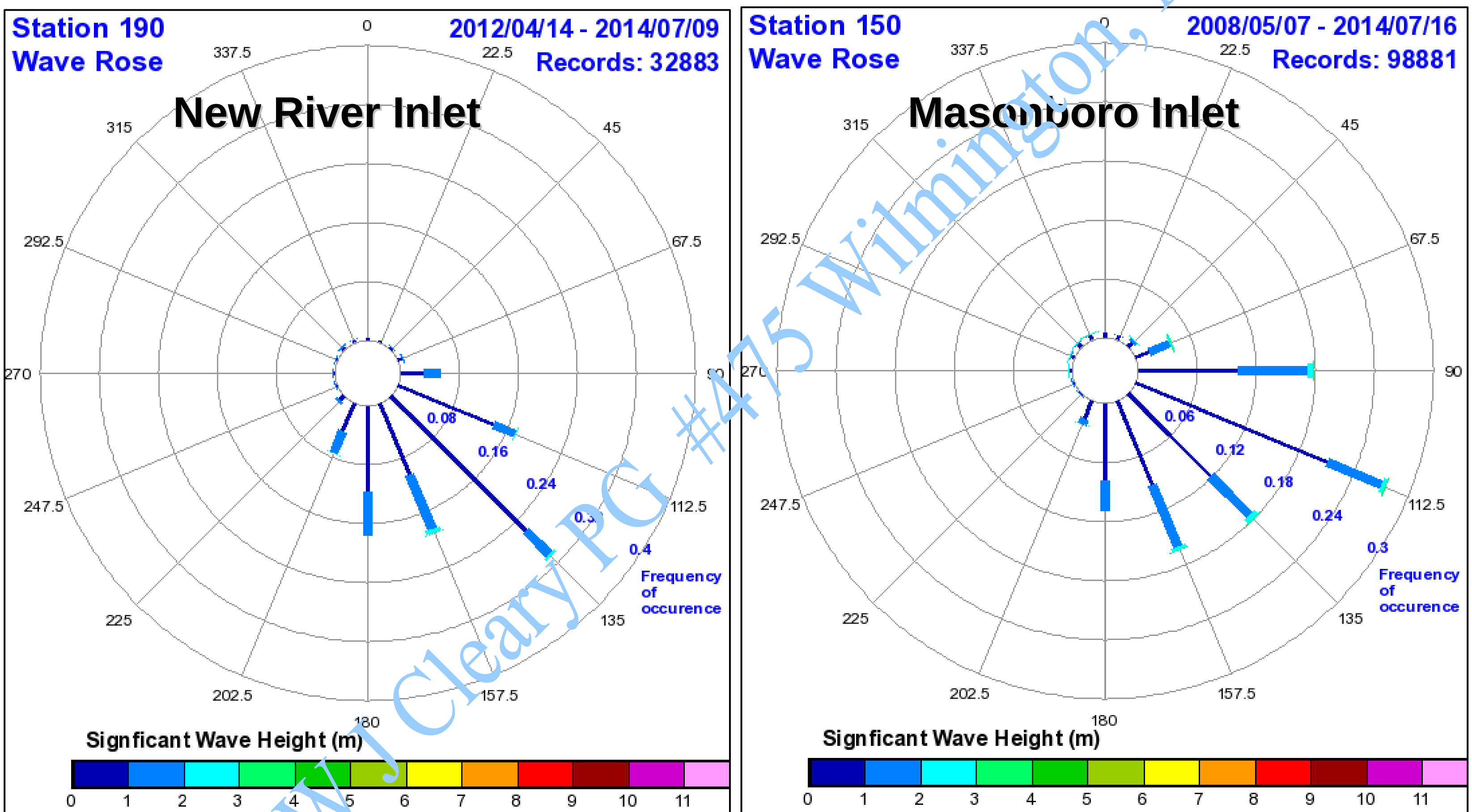
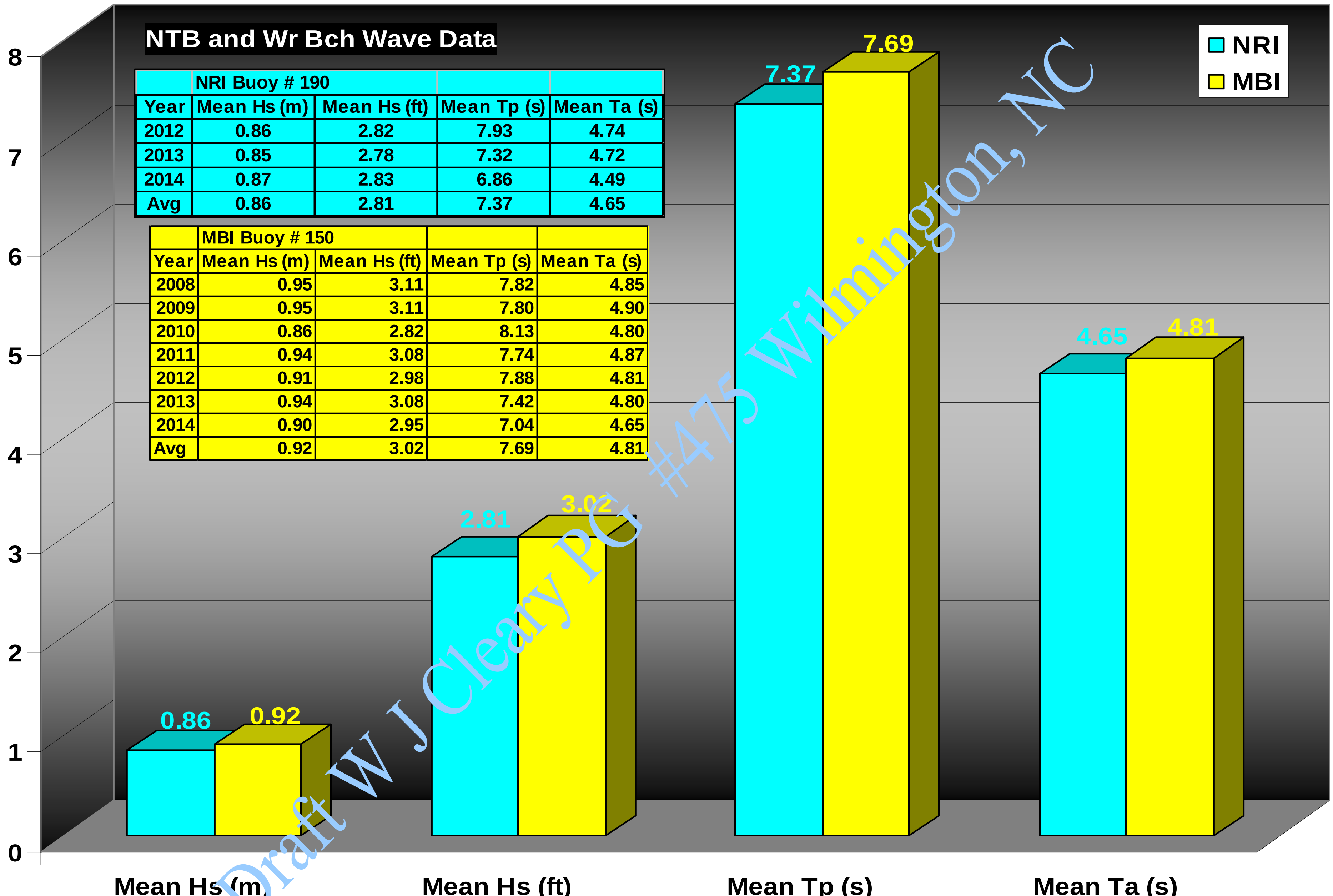


Figure 2. Rose diagrams depicting the significant wave heights recorded at Station # 190 (New River Inlet) and Station # 150 (Masonboro Inlet). The length of a petal portion corresponds to the frequency of occurrence. The significant wave height categories (m) are color coded. Modified after CDIP (Integrative Oceanography Division).



	NRI Buoy # 190			
Year	Mean Hs (m)	Mean Hs (ft)	Mean Tp (s)	Mean Ta (s)
2012	0.86	2.82	7.93	4.74
2013	0.85	2.78	7.32	4.72
2014	0.87	2.83	6.86	4.49
Avg	0.86	2.81	7.37	4.65

	MBI Buoy # 150			
Year	Mean Hs (m)	Mean Hs (ft)	Mean Tp (s)	Mean Ta (s)
2008	0.95	3.11	7.82	4.85
2009	0.95	3.11	7.80	4.90
2010	0.86	2.82	8.13	4.80
2011	0.94	3.08	7.74	4.87
2012	0.91	2.98	7.88	4.81
2013	0.94	3.08	7.42	4.80
2014	0.90	2.95	7.04	4.65
Avg	0.92	3.02	7.69	4.81

Figure 3. Bar Graph of depicting a comparison of wave characteristics for North Topsail Beach and Wrightsville Beach. Data were derived from offshore Buoy # 190 (New River Inlet) and Buoy # 150 (Masonboro Inlet). Modified after CDIP (Integrative Oceanography Division).

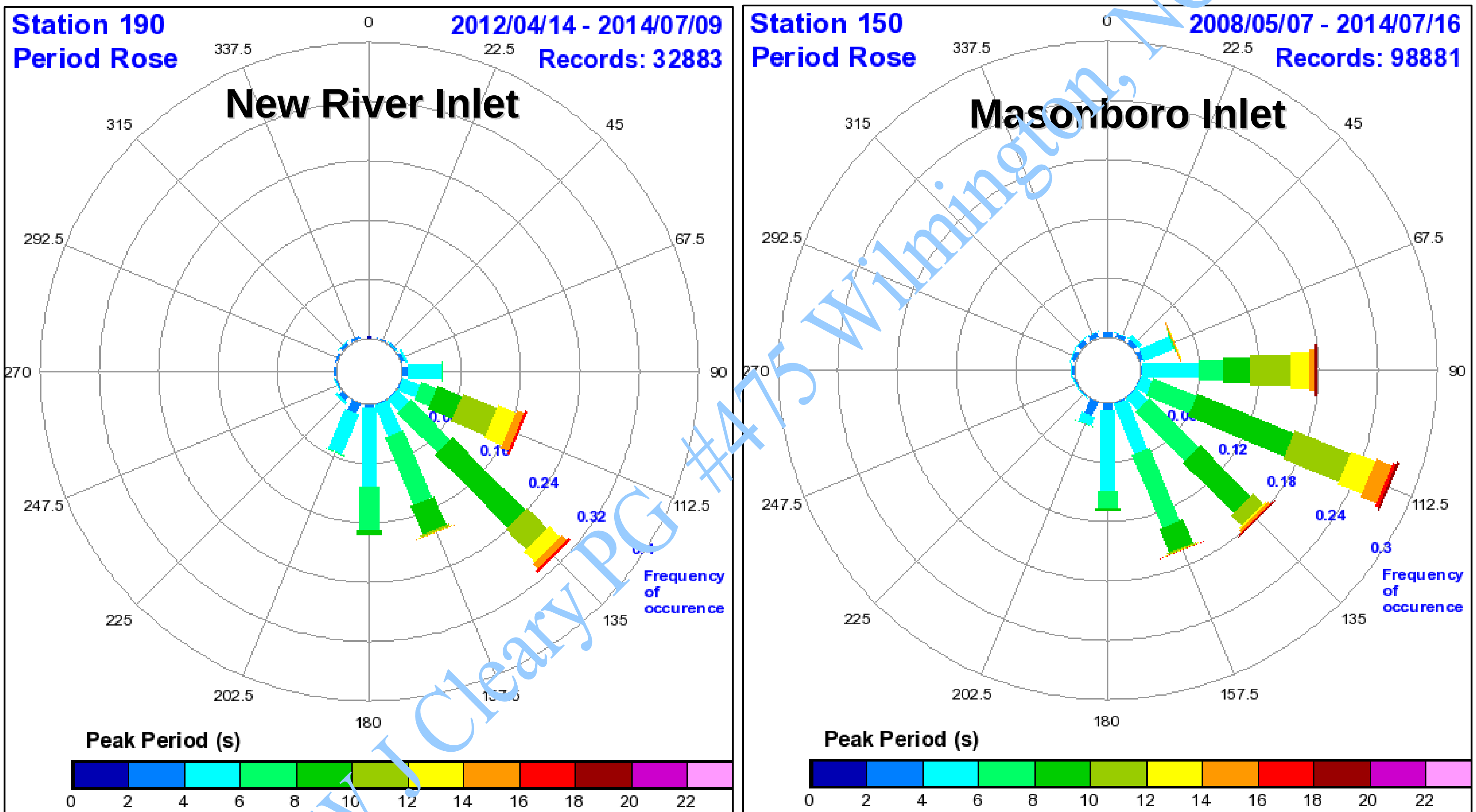


Figure 4. Rose diagrams depicting the peak periods recorded at Station # 190 (New River Inlet) and Station # 150 (Masonboro Inlet). The length of a petal portion corresponds to the frequency of occurrence. The peak period categories (secs) are color coded. Modified after CDIP (Integrative Oceanography Division).

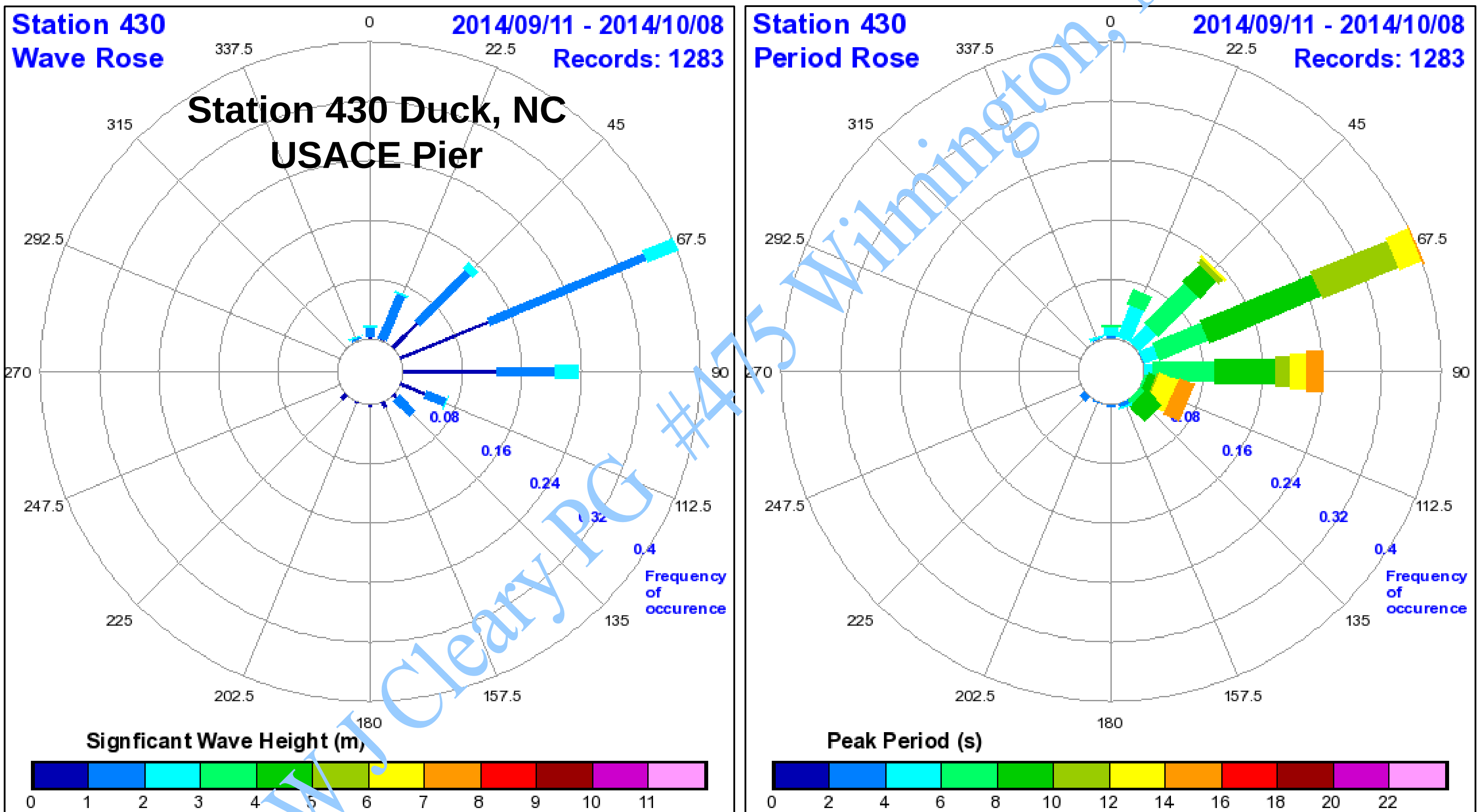


Figure 5. Rose diagrams depicting the significant wave height (Hs) peak period recorded at Station # 430 (USACE FRF Pier Duck, NC). The length of a petal portion corresponds to the frequency of occurrence. The peak period categories (secs) are color coded. Modified after CDIP (Integrative Oceanography Division).

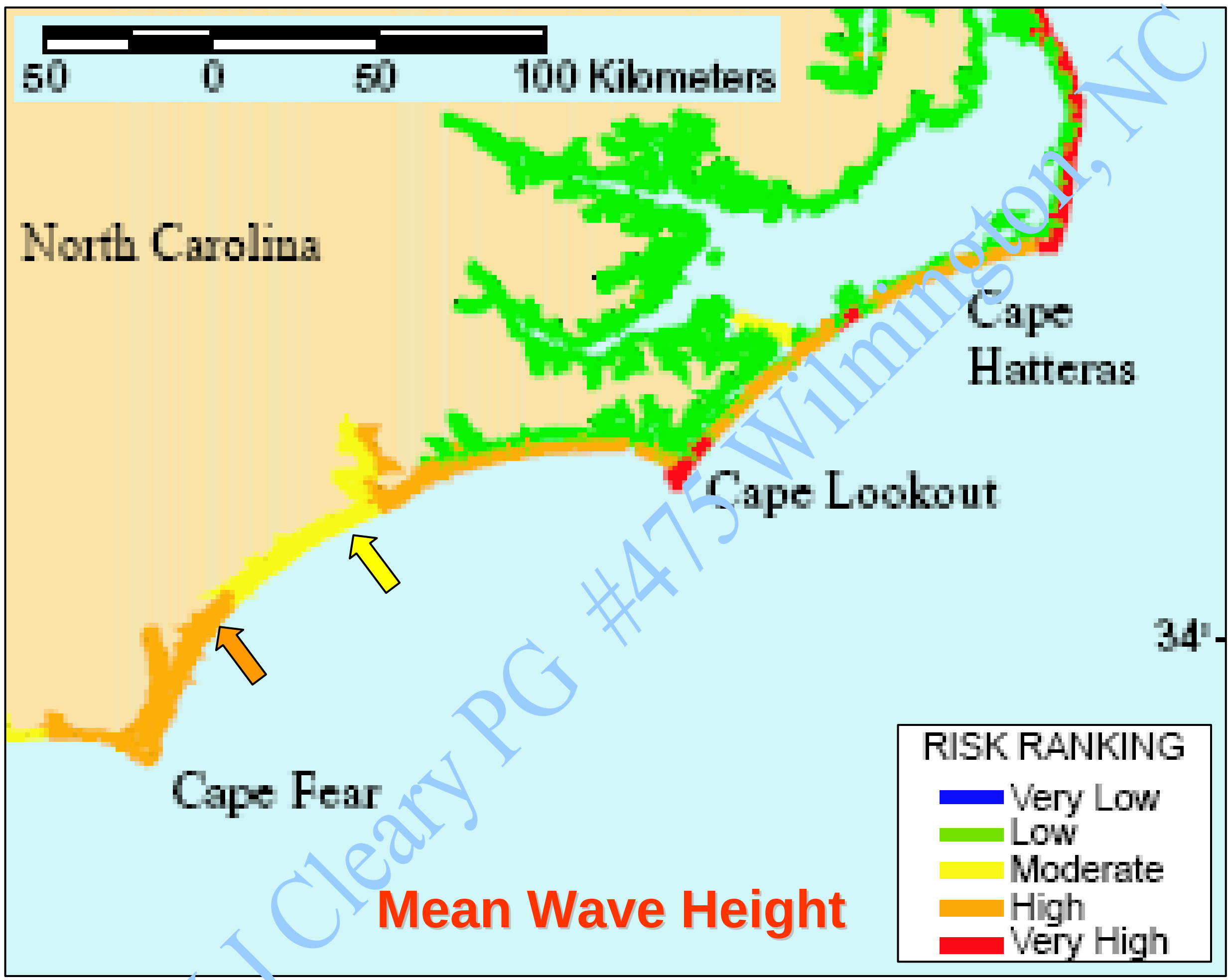


Figure 39. Map depicting the future risk related to the mean wave height for North Carolina due to future sea-level change. Mean wave height is one of the physical variables that contribute to coastal change and the CVI rankings. Wave energy increases as the square of the wave height and hence the ability to erode and transport beach material increases due slight changes in wave height. After Thieler, E.R., and Hammar-Klose, E.S., 1999. *National Assessment of Coastal Vulnerability to Future Sea-Level Rise: Preliminary Results for the U.S. Atlantic Coast*. U.S. Geological Survey, Open-File Report 99-593, 1 sheet. http://pubs.usgs.gov/of/of99-593

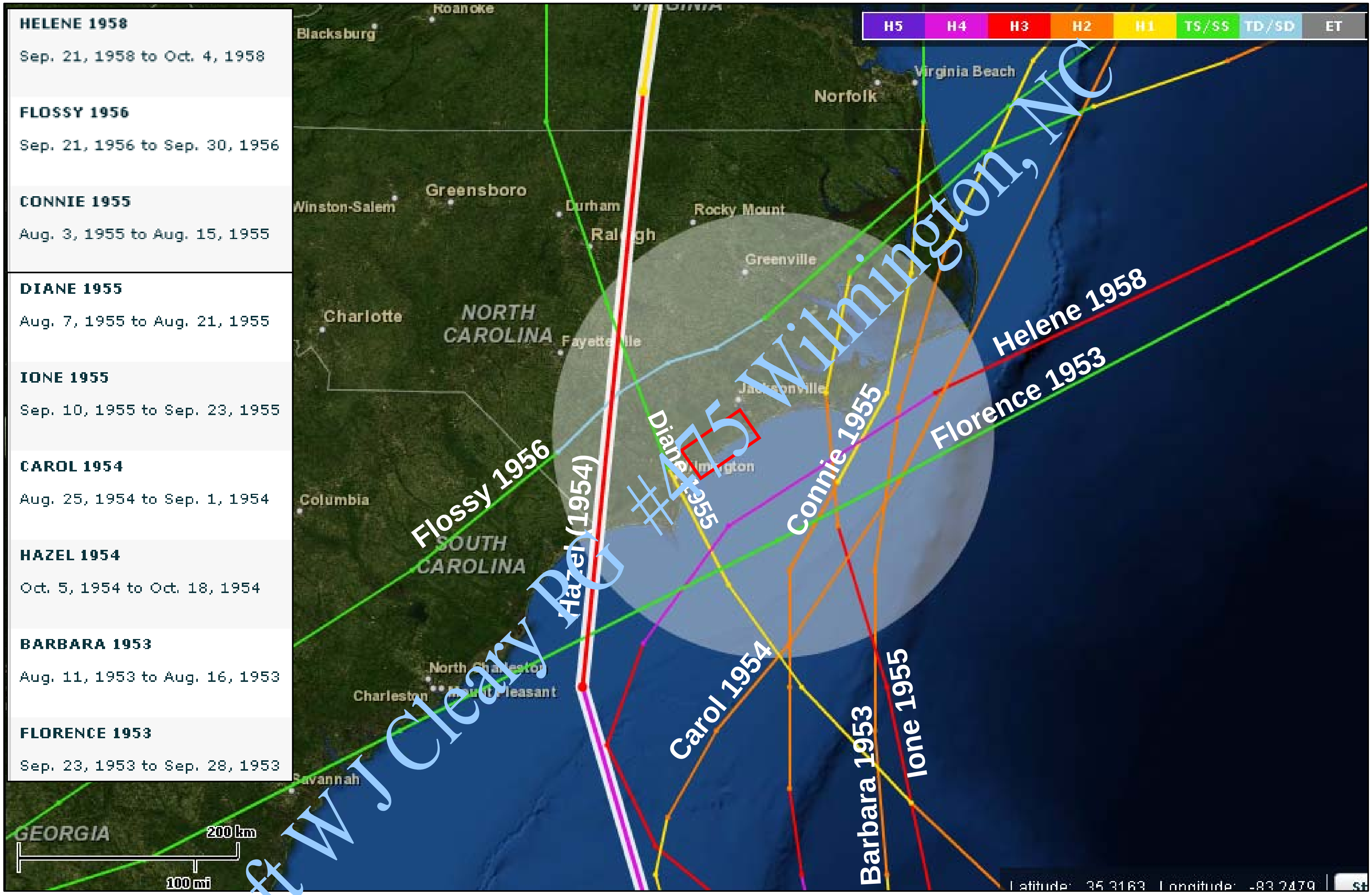


Figure 7. Map depicting tracks of tropical storms within 75 nautical miles of North Topsail Beach in the 1950s. Modified after NOAA Coastal Services Center, Historical Hurricane Tracks. (http://csc.noaa.gov/hurricanes/#).

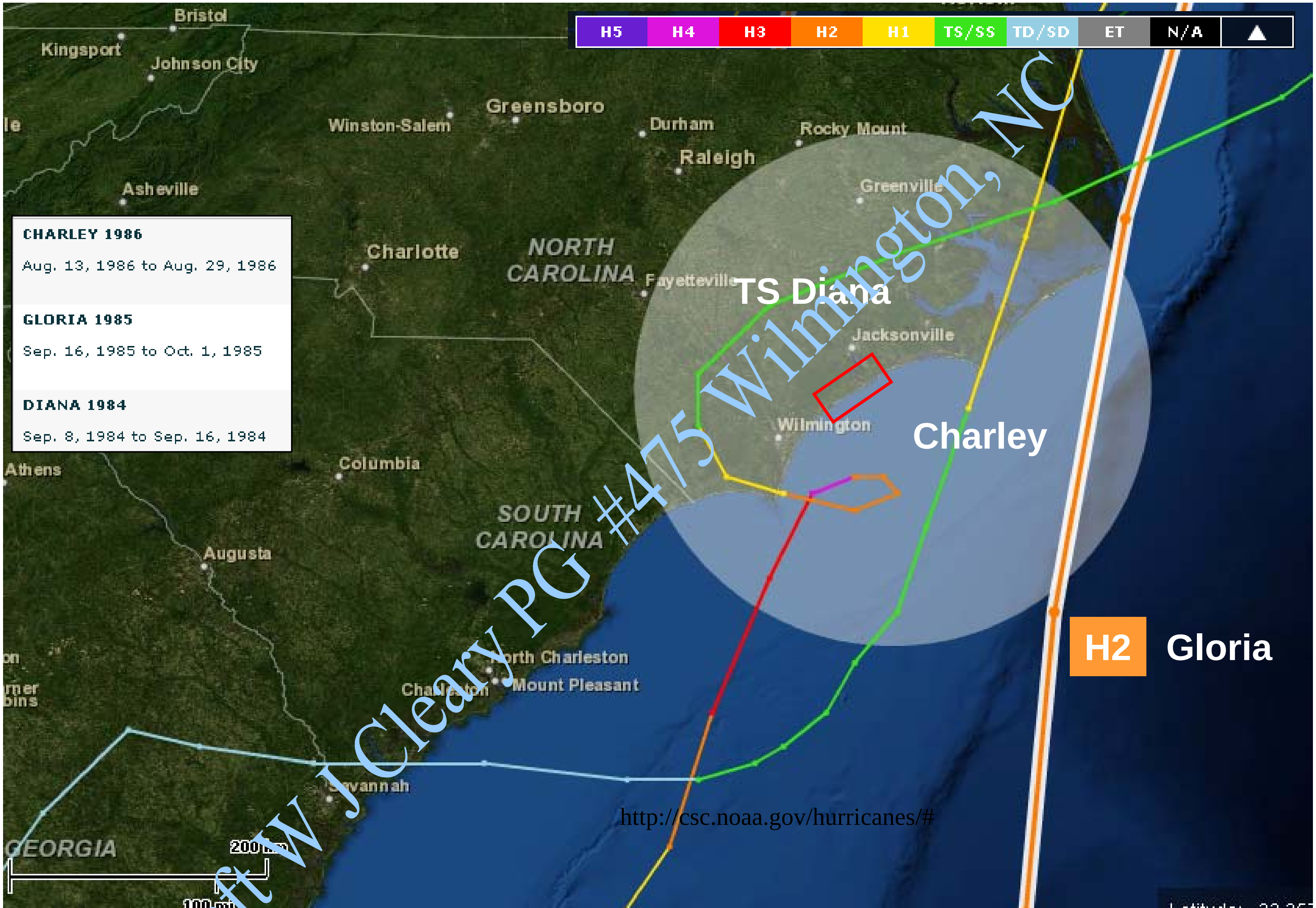


Figure 8. Map depicting tracks of tropical storms within 75 nautical miles of North Topsail Beach in the 1980s. Modified after NOAA Coastal Services Center, Historical Hurricane Tracks. (http://csc.noaa.gov/hurricanes/#).

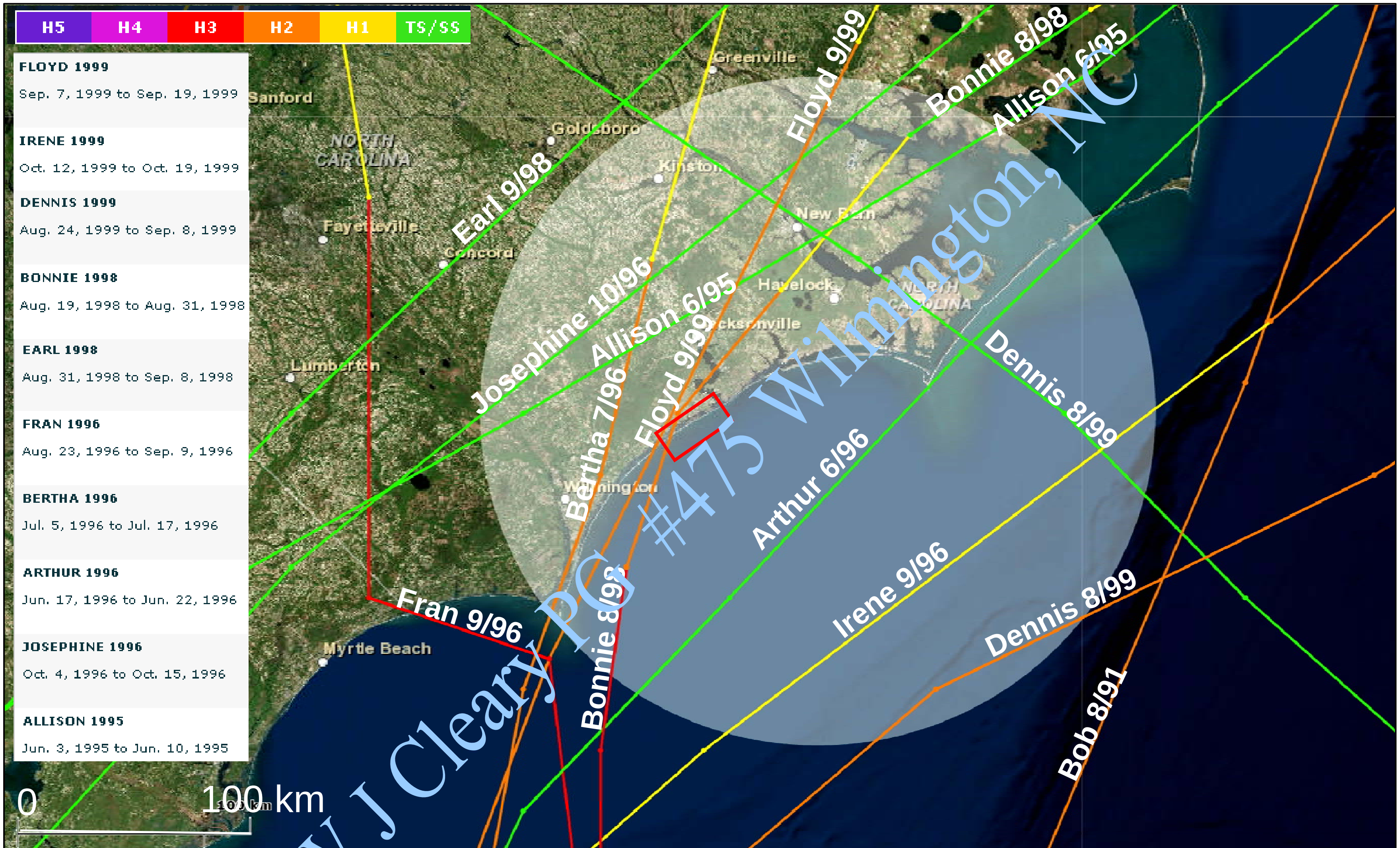


Figure 9. Map depicting tracks of tropical storms within 75 nautical miles of North Topsail Beach in the 1990s. Modified after NOAA Coastal Services Center, Historical Hurricane Tracks. (http://csc.noaa.gov/hurricanes/#).

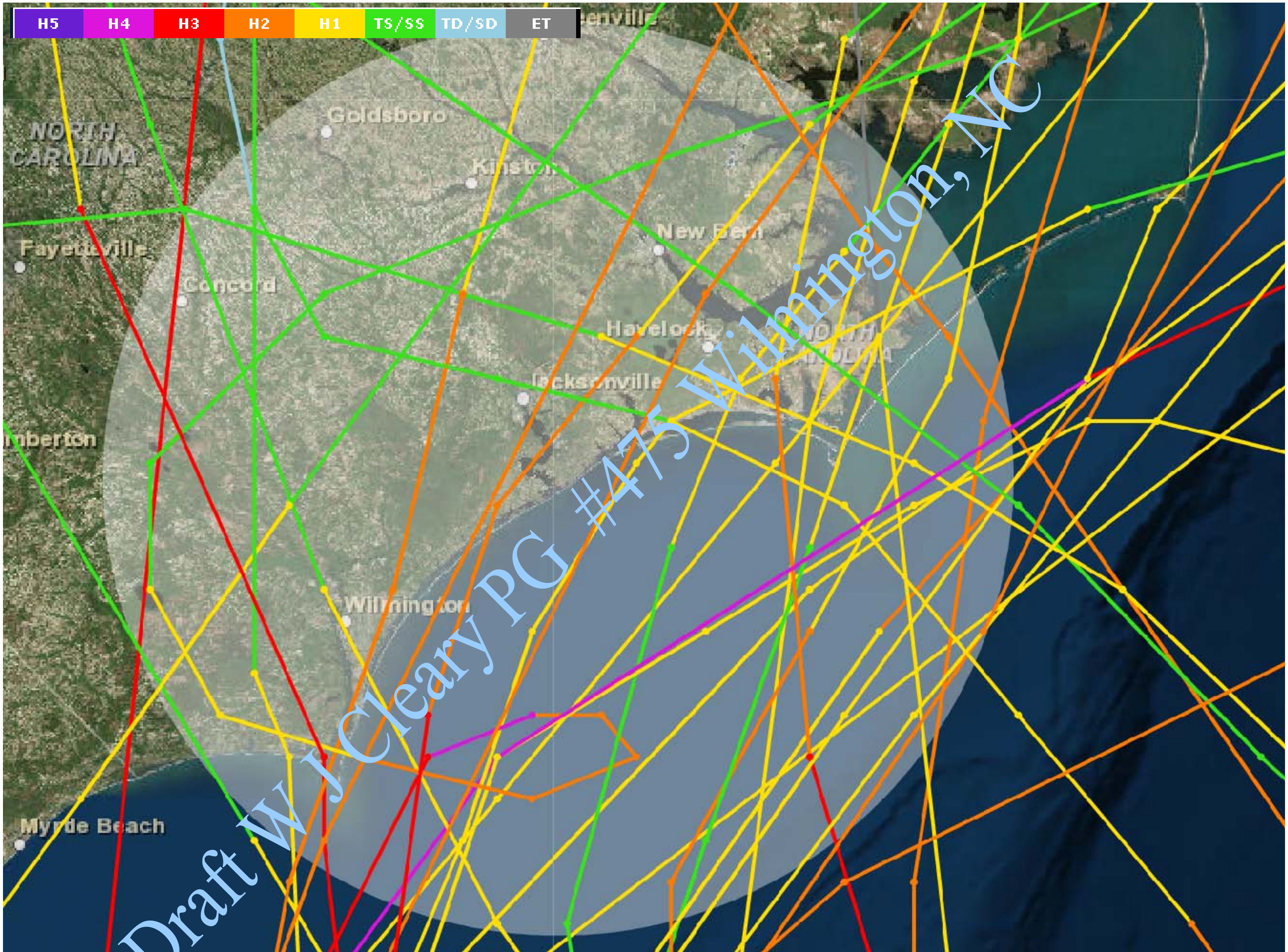


Figure 10. Map depicting tracks of 32 Hurricanes (Category 1-4) within 80 nautical miles of North Topsail Beach during the period 1899-2013. Modified after NOAA Coastal Services Center, Historical Hurricane Tracks. (http://csc.noaa.gov/hurricanes/#).

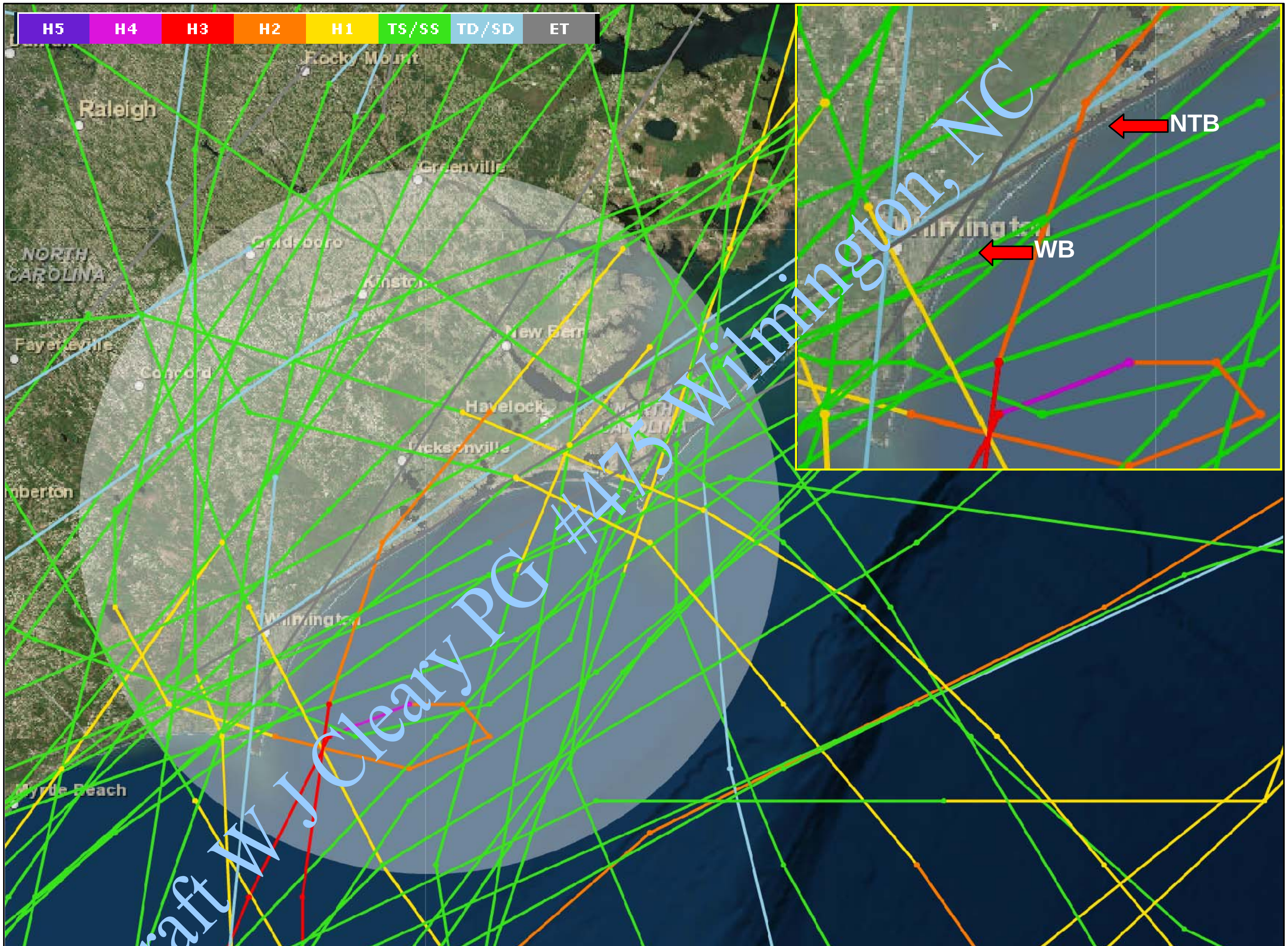


Figure 11. Map depicting tracks of 45 tropical storms (green lines) within 80 nautical miles of North Topsail Beach during the period 1899-2013. Modified after NOAA Coastal Services Center, Historical Hurricane Tracks..(http://csc.noaa.gov/hurricanes/#).

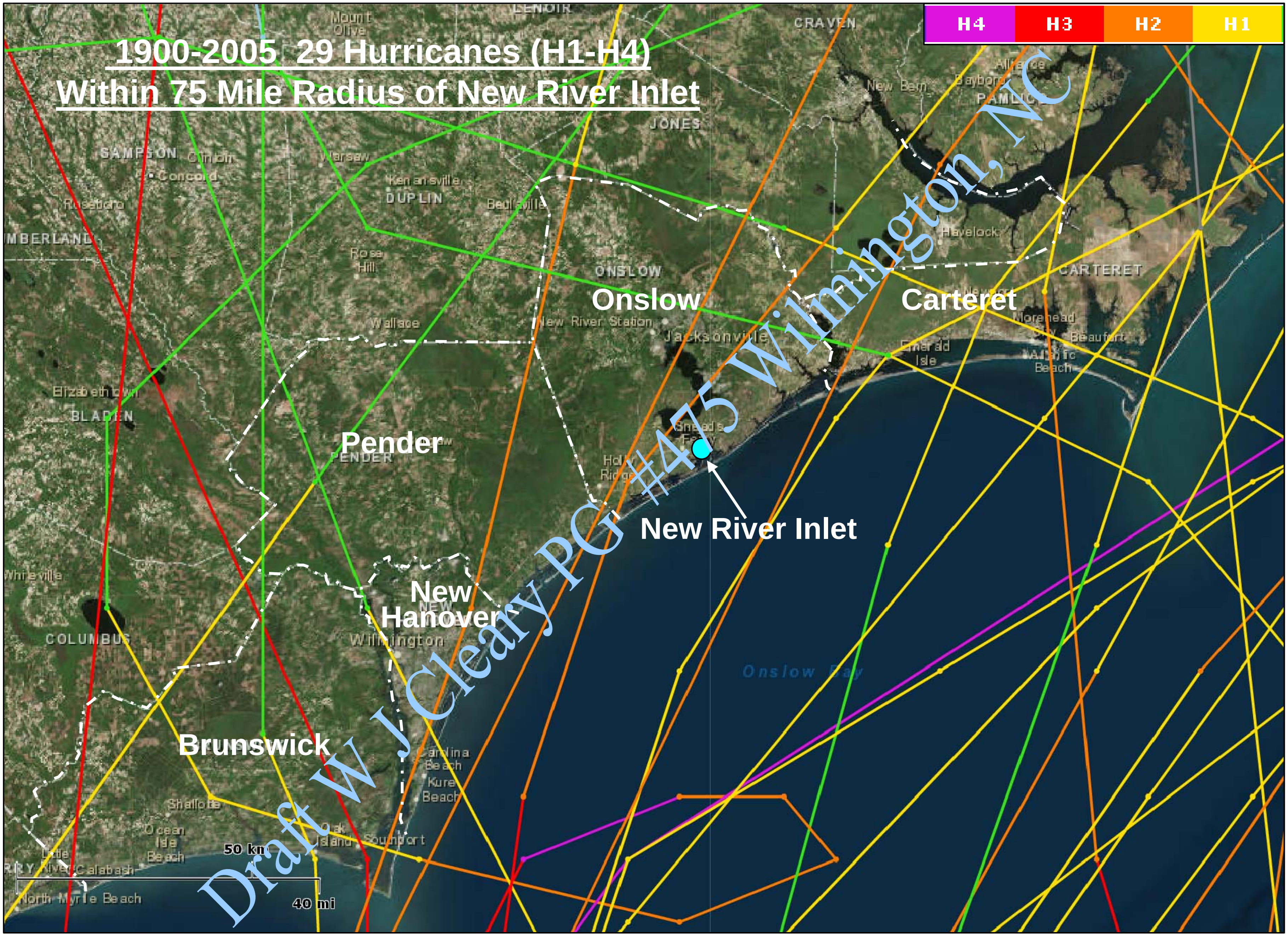


Figure 12. Satellite image of southeastern North Carolina that depicts the tracks of 29 hurricanes that occurred within a radius of 75 nautical miles of New River Inlet, NC between 1900 and 2005. Compare the county storm landfalls and data in Table 1 and Figures 13-15 bar graphs.

NC County Hurricane Hits 1900-2005

Hurricane Hits	Brunswick	New Hanover	Pender	Onslow	Carteret	Dare
Direct Total	13	11	10	9	11	18
Category 1	5	4	4	3	8	7
Category 2	4	4	3	4	1	4
Category 3	3	2	2	2	2	7
Category 4	1	1	1	0	0	0
	Brunswick	New Hanover	Pender	Onslow	Carteret	Dare
Indirect Total	2	2	2	7	10	6
Category 1	0	0	0	2	0	1
Category 2	1	1	1	1	4	3
Category 3	1	1	1	3	6	2
Category 4	0	0	0	1	0	0
Total all Strikes	15	13	11	16	21	24
Co. Area sq. mi.	1,050	328	933	909	1,341	1,562
Co. Shoreline mi.	43.9/*6.7**	33	14.5	25	82.9/*34.6**	84.6

Table 1.Select NC County hurricane strikes (Direct & Indirect) between 1900 and 2005. Data derived from NOAA Technical Memorandum NWS NHC -46 and unpublished NOAA hurricane strike data compiled 2/4/2010. Courtesy D. Marcy, NOAA Office for Coastal Management. Red colored numbers refers to county shoreline within Onslow Bay.

Quote from NOAA Technical Memorandum NWS NHC -46 *As with the assignment of scale numbers, a certain amount of subjectivity was inescapable at times in determining which counties received direct or indirect hits during the various hurricane situations. However, certain arbitrary guidelines for these classifications were used as listed below.*

Direct Hit - *When the innermost core regions, or "eye, "moved over a county, it was counted as a direct hit. "R" is defined as the radius of maximum winds in a hurricane (the distance in miles from the storm's center to the circle of maximum winds around the center). A county is regarded as receiving a direct hit when all or parts of a county fall within about 2R to the right and R to the left of a storm's landfall. This assumes an observer at sea looking toward shore. On the average, this direct hit zone extended about 50 miles along the coastline(Rz15 miles). Of course, some hurricanes were smaller than this and some, particularly in higher latitudes, were much larger. Cases were judged individually, and many borderline situations had to be resolved.*

Indirect Hit -*These were based primarily on a hurricane's strength and size and on the configuration of the individual county coastline. Here again, much subjectivity was necessary often complicated by storm paths and geography. Generally, those areas on either side of the direct hit zone which received hurricane force winds or tides of at least 4 to 5 feet above normal were considered to be indirect hits.*

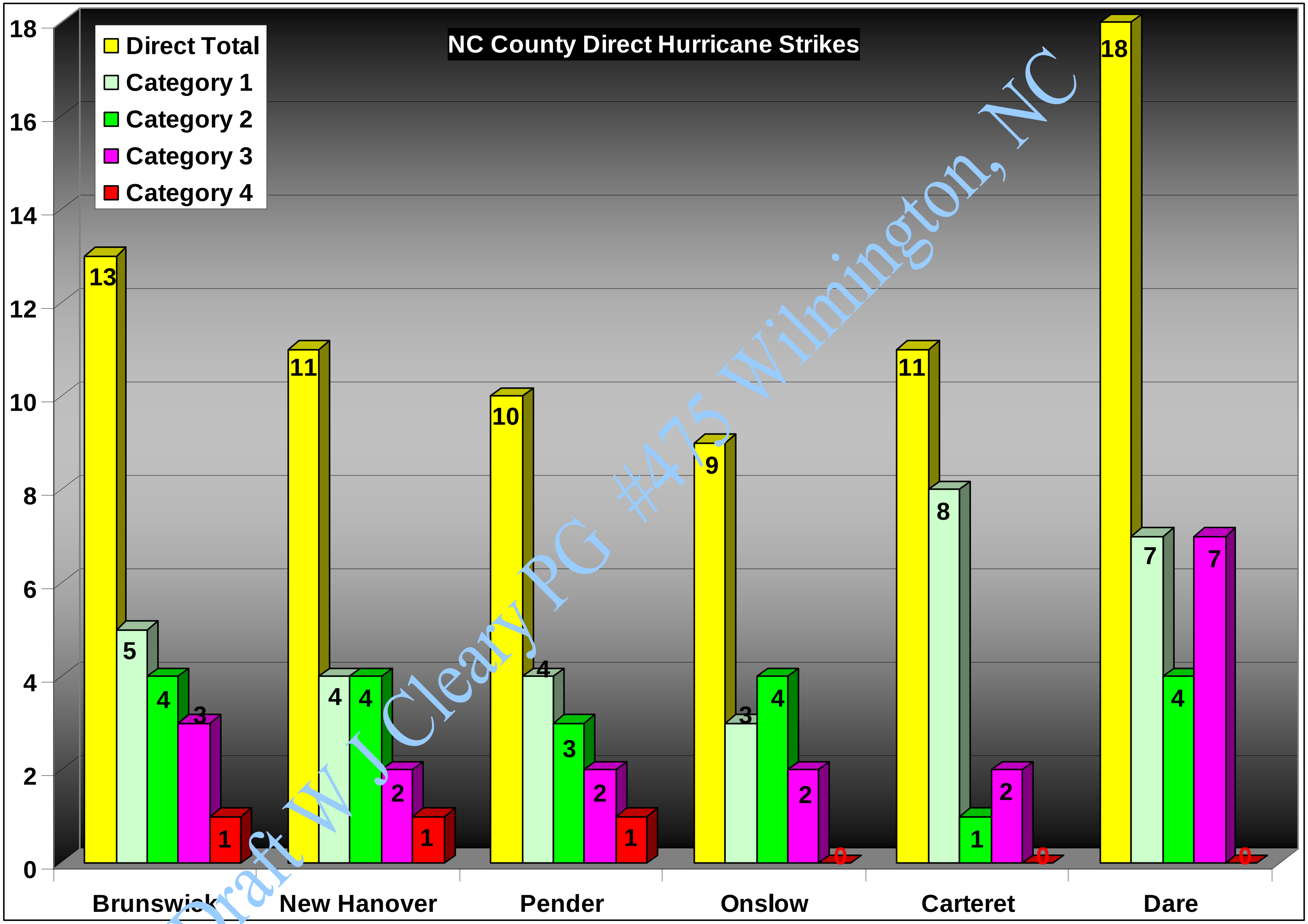


Figure 13. Bar graphs depicting Select North Carolina Counties Direct Hurricane Strikes for Hurricanes H1-H4 (1900-2005). Data derived from NOAA Technical Memorandum NWS NHC - 46 and unpublished NOAA hurricane strike data compiled 2/4/2010. Courtesy D. Marcy, NOAA Office for Coastal Management

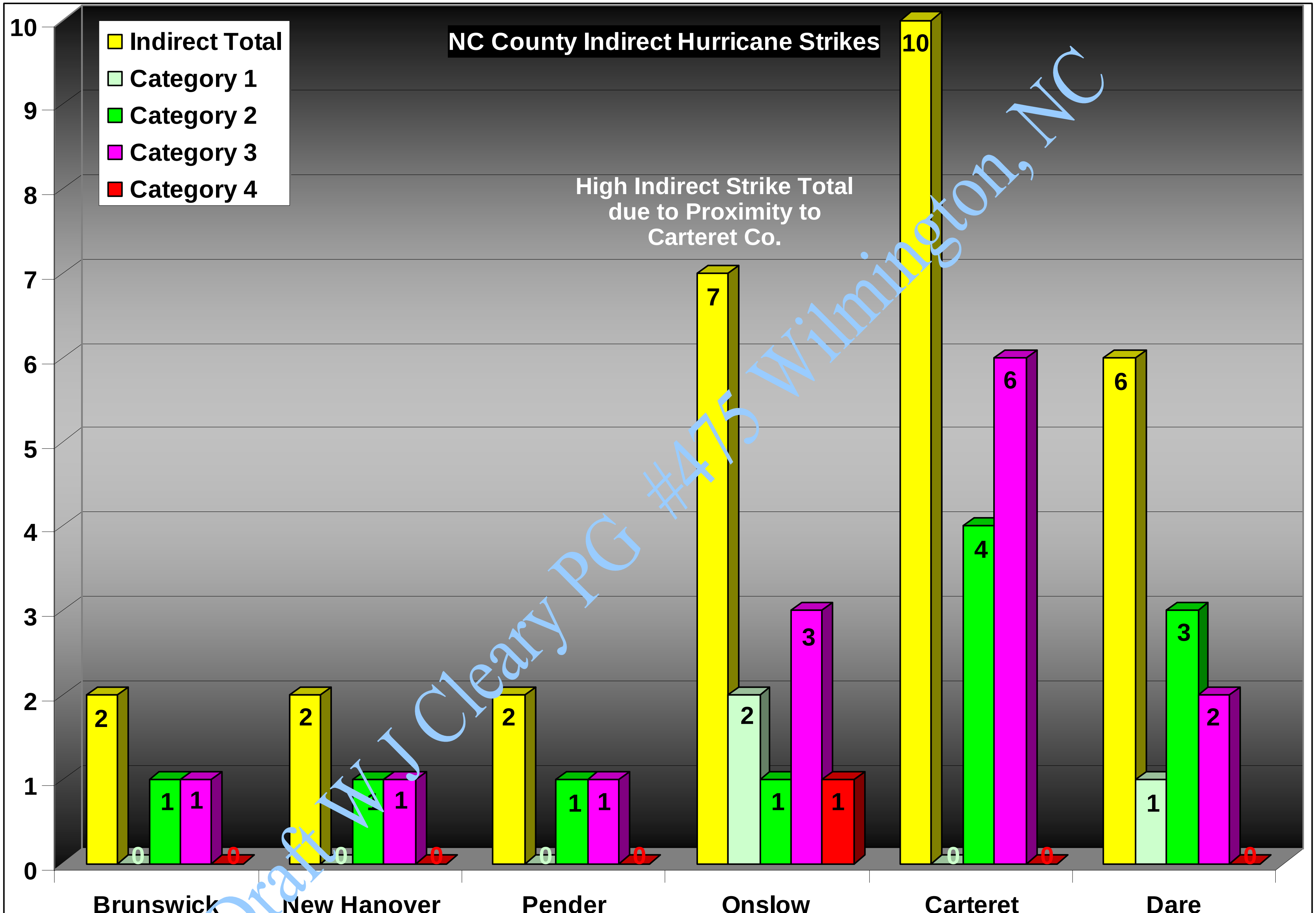


Figure 14. Bar graphs depicting select North Carolina Counties Indirect Hurricane Strike for Hurricanes H1-H4 (1900-2005). Data derived from NOAA Technical Memorandum NWS NHC -46 and unpublished NOAA hurricane strike data compiled 2/4/2010. Courtesy D. Marcy, NOAA Office for Coastal Management

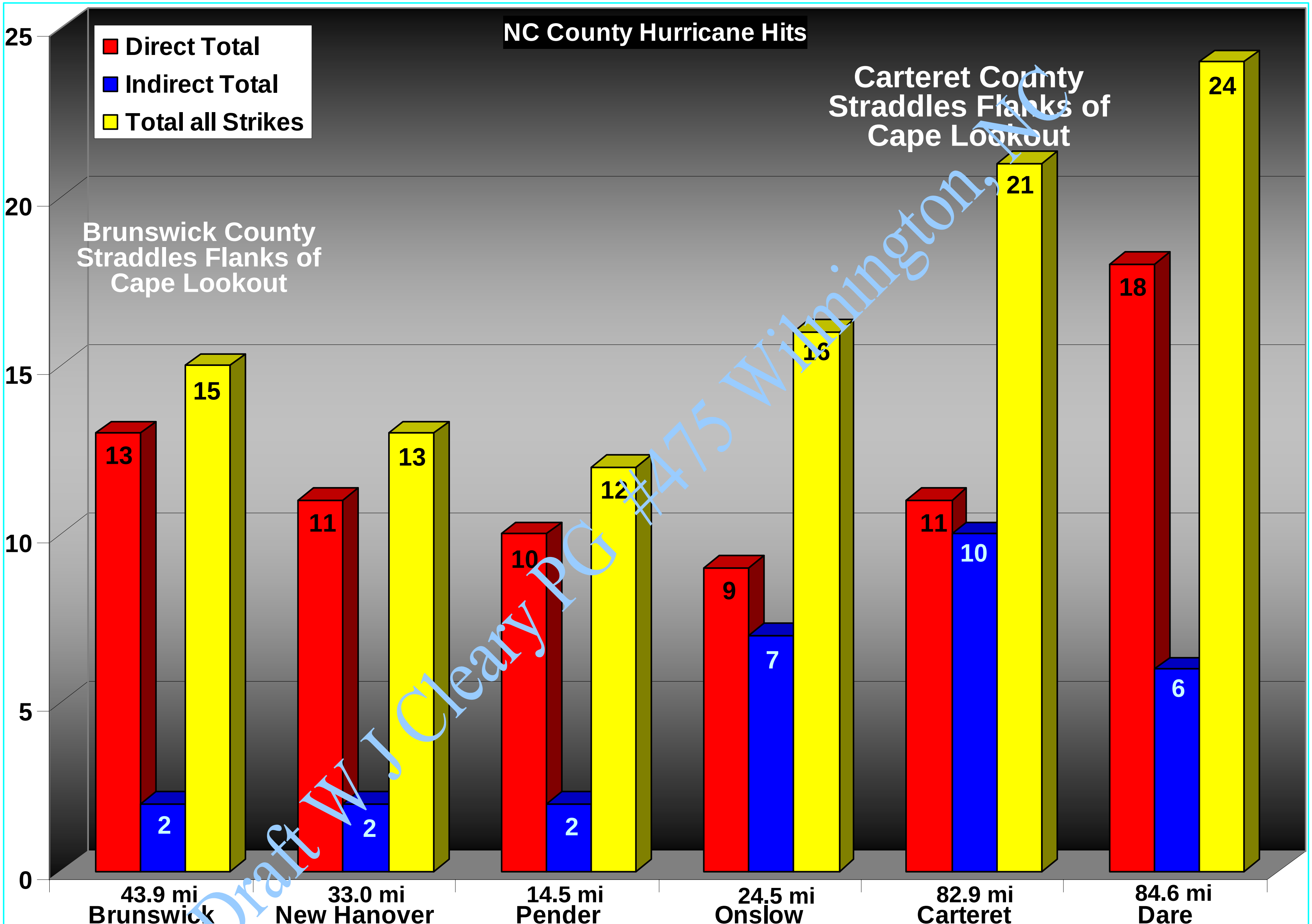


Figure 15. Bar graphs depicting select North Carolina Counties Hurricane Strikes Direct, Indirect and Total for Hurricanes H1-H4 (1900-2005). Data derived from NOAA Technical Memorandum NWS NHC -46 and unpublished NOAA hurricane strike data compiled 2/4/2010. Courtesy D. Marcy, NOAA Office for Coastal Management. See Table 1 for Brunswick and Carteret County miles of shoreline within Onslow Bay (Cape Lookout to Cape Fear).

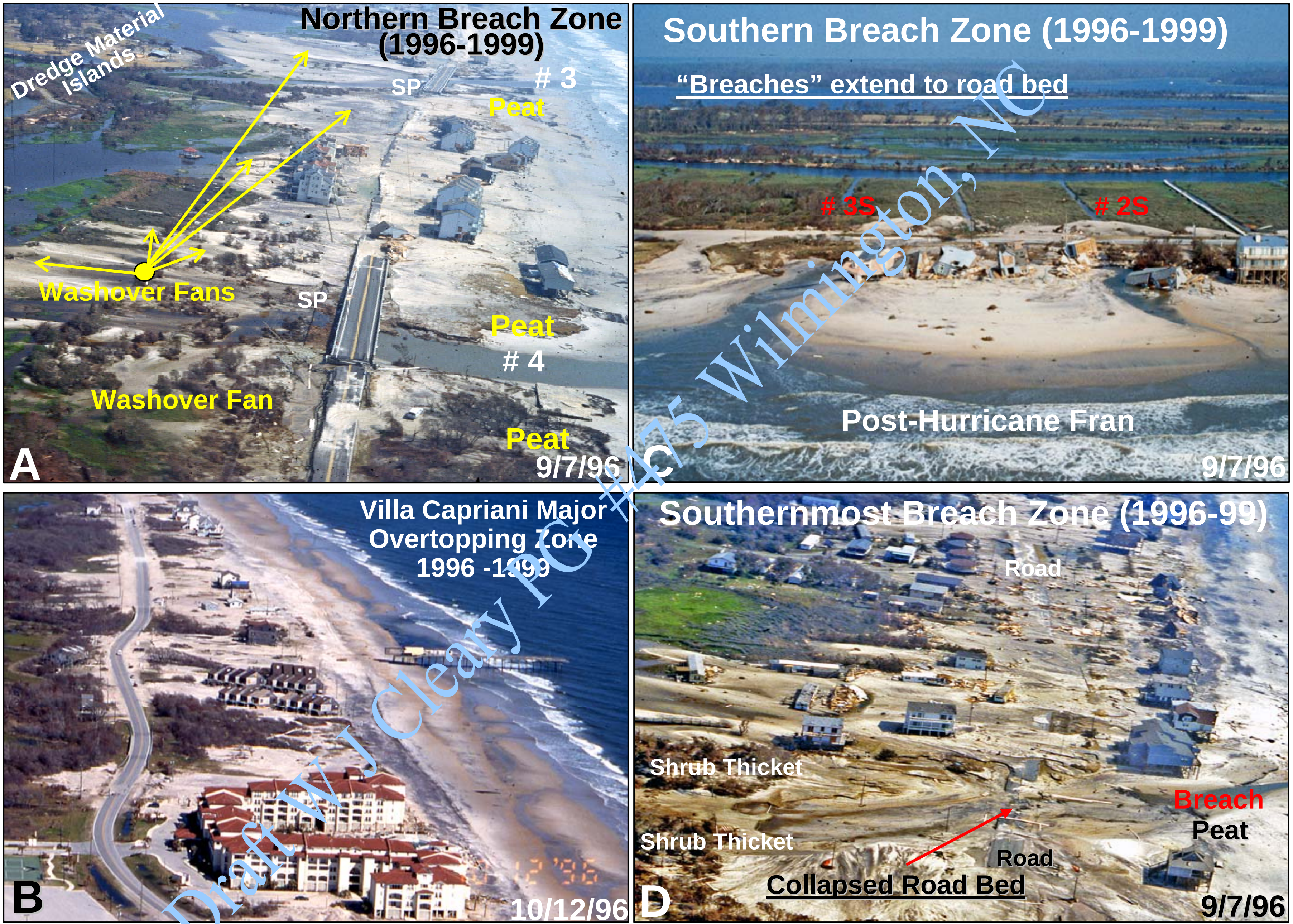


Figure 16 Oblique aerials views of Hurricane Fran-related erosion along NTB. A. North view of massive beach & dune erosion, washover fans and scour channels. B. Northerly view of Vila Capriani, washover fans and beach & dune erosion C. Landward view of southern breach zone with two scour channels. D. Northward view of southernmost NTB breach zone with island-wide washover fans, beach & dune erosion and shallow scour channel. See Figure 17 for comparison.

Figure 17. Aerial views (3/2012) of Hurricane Fran impacted areas along NTB. A. Northern breach zone now infilled with elevated grasslands. ER varies from -1.0 to 3.2 ft/yr. C. Aerial view of southern breach now infilled. ER =0- -0.65 ft/yr. D. Aerial view of southernmost NTB breach zone where ER varies from -0.62 to -1.13 ft/yr. See Figure 16 for comparison.

Figure 18. Photographs (2009) depicting erosion rates along the northern portion of North Topsail Beach. Modified after NC DCM 2011 ER update. Bold red colored line separates the early start years (baseline years).

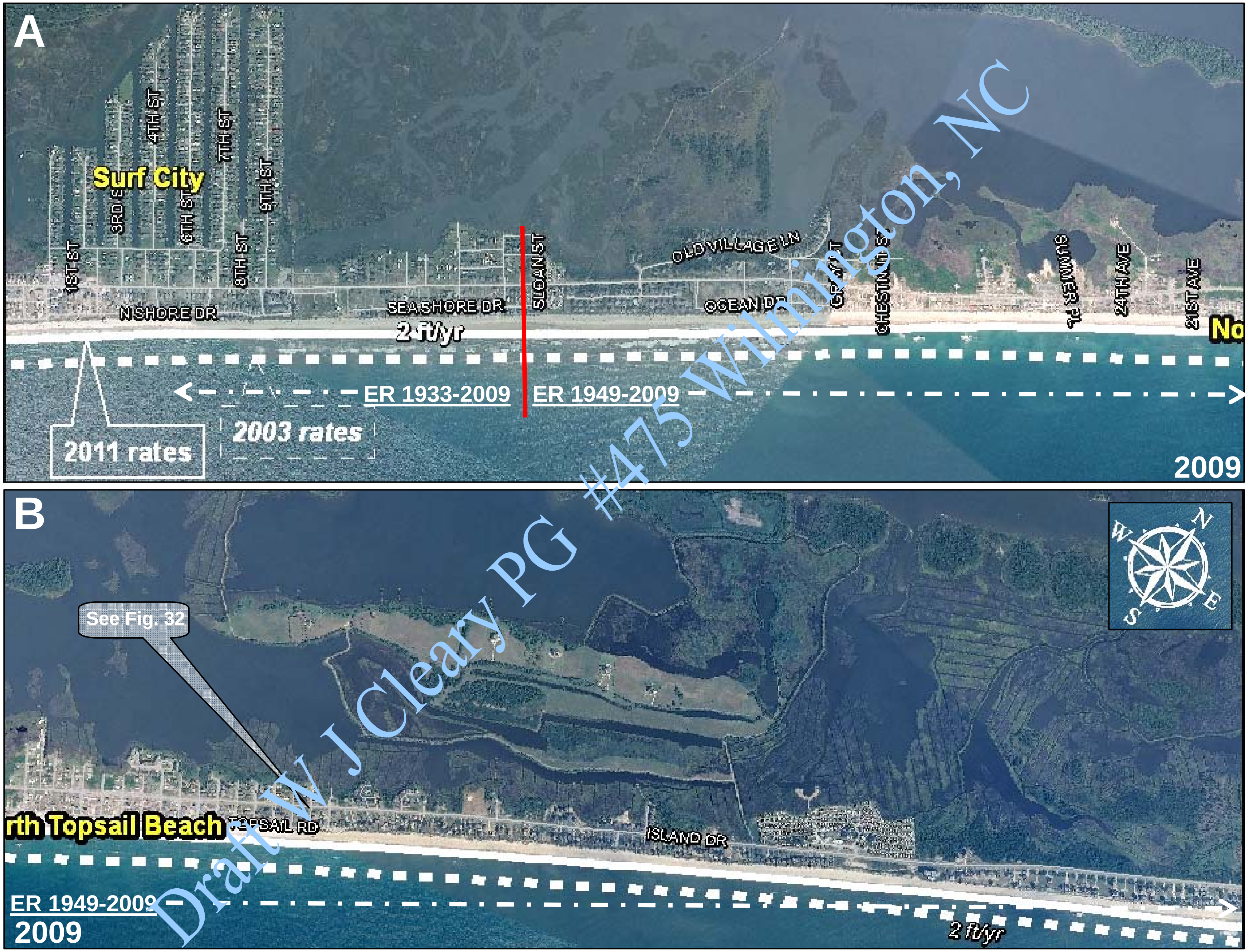


Figure 19. Photographs (2009) depicting erosion rates along the southern portion of North Topsail Beach. Modified after NC DCM 2011 update. Bold red colored line separates the early start years (baseline years).

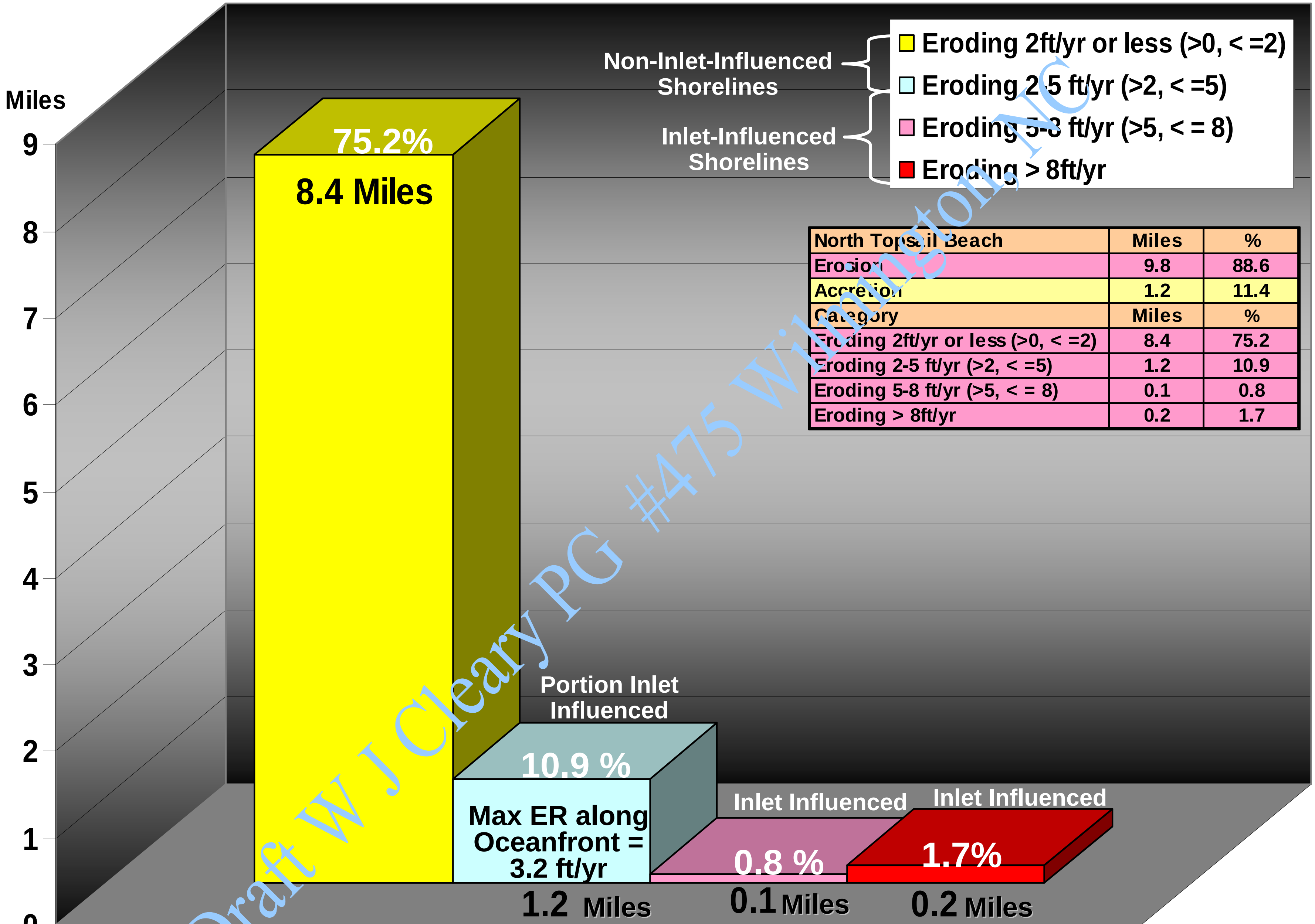


Figure 20. Bar graph depicting the NC DCM data for Erosion Rate categories for North Topsail Beach in miles of shoreline and % of Town's shoreline. Shoreline segments that are accreting or eroding at less than 2.0 ft/yr are by default (for construction setbacks) designated as eroding at 2.0 ft/yr

Figure 21. Map depicting 7/11/2009 photograph of the northernmost segment of North Topsail Beach with NC DCM transects used for measuring erosion rates (2011 updated). Shoreline change rates reflect changes between 1952 and 2009. Transect spacing = 50m. Data derived from NC DCM's Oceanfront Setback Factor Portal and available GIS files from 2013 (transects 50m shapefile, 2009 shrl shapefile and Early shrl shapefile (composite shrl file for 1933, 1949 and 1952). Additional information was provided by Ken Richardson (NC DCM). http://portal.ncdenr.org/web/cm/oceanfront-construction-setback.

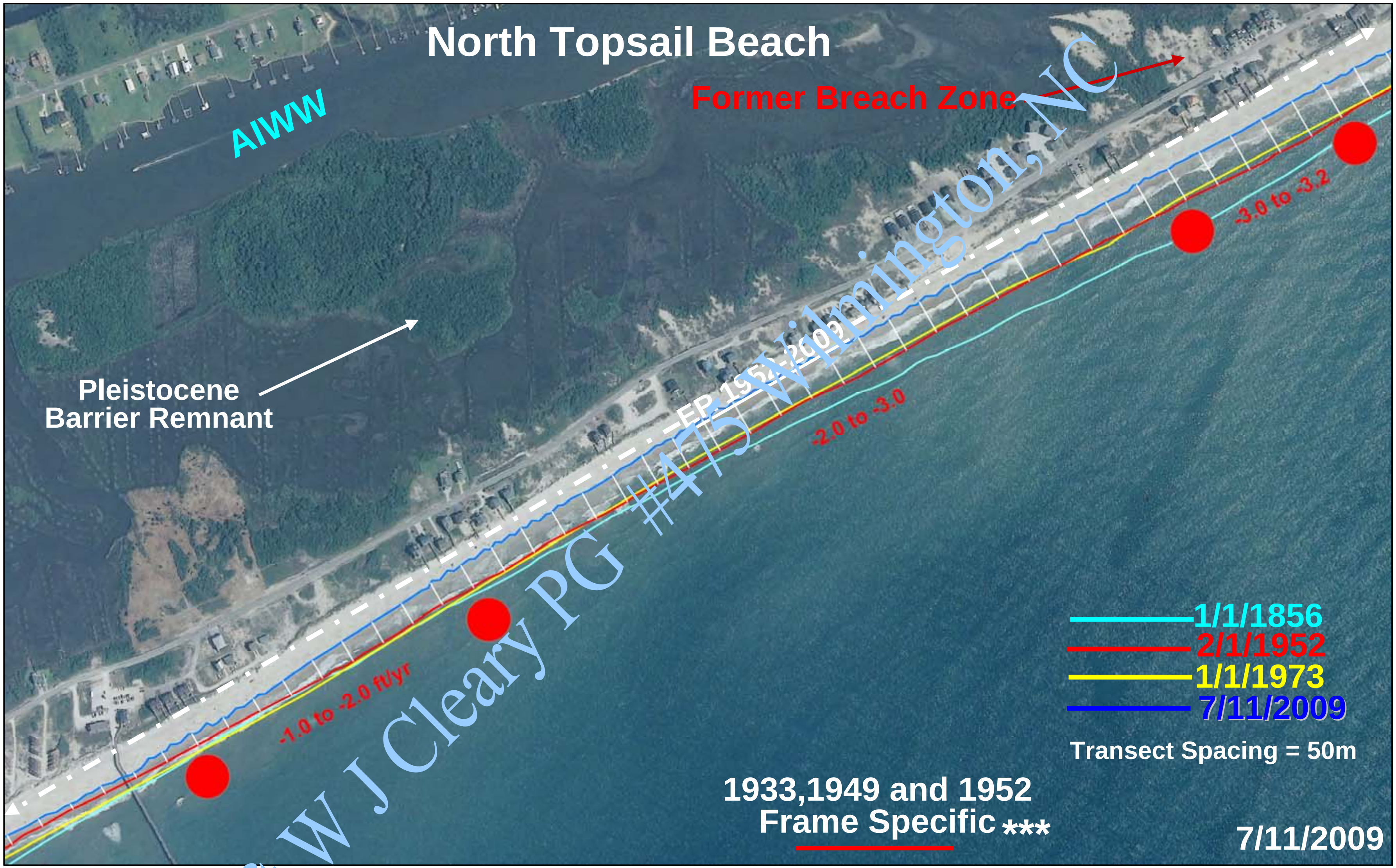


Figure 22. Map depicting 7/11/2009 photograph of the segment located immediately southwest of Figure 21 with NC DCM transects used for measuring erosion rates (2011 updated). Shoreline change rates reflect changes between 1952 and 2009. Transect spacing = 50m. Data derived from NC DCM's Oceanfront Setback Factor Portal and available GIS files from 2013 (transects 50m shapefile, 2009 shrl shapefile and Early shrl shapefile (composite shrl file for 1933, 1949 and 1952). Additional information was provided by Ken Richardson (NC DCM). http://portal.ncdenr.org/web/cm/oceanfront-construction-setback.

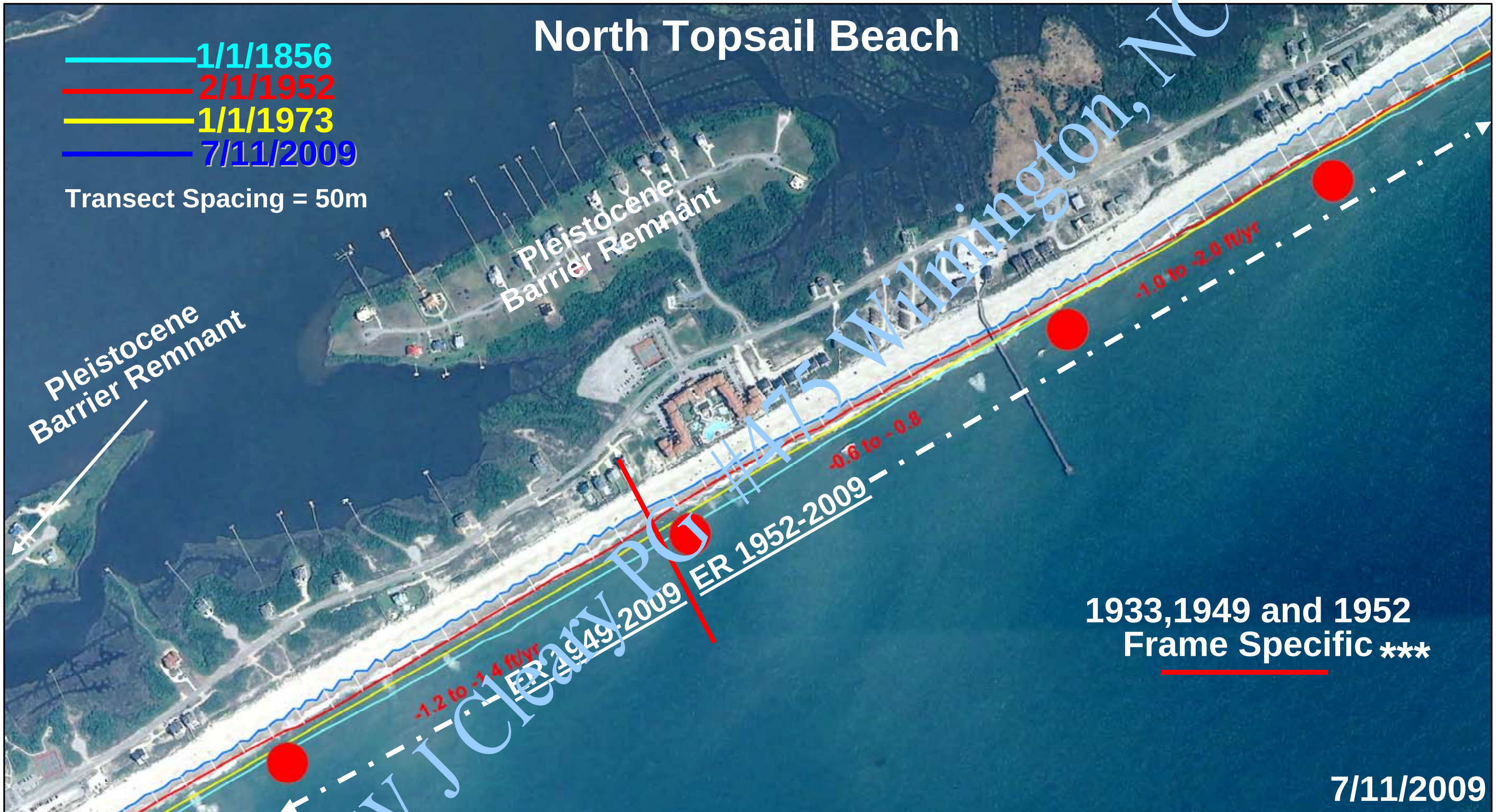


Figure 23. Map depicting 7/11/2009 photograph of the segment located immediately southwest of Figure 22 with NC DCM transects used for measuring erosion rates (2011 updated). Shoreline change rates reflect changes between 1952 and 2009 1949-2009. Transect spacing = 50m. Data derived from NC DCM's Oceanfront Setback Factor Portal and available GIS files from 2013 (transects 50m shapefile, 2009 shrl shapefile and Early shrl shapefile (composite shrl file for 1933, 1949 and 1952). Additional information was provided by Ken Richardson (NC DCM). http://portal.ncdenr.org/web/cm/oceanfront-construction-setback.

Figure 24. Map depicting 7/11/2009 photograph of the segment located immediately southwest of Figure 23 with NC DCM transects used for measuring erosion rates (2011 updated). Shoreline change rates reflect changes between 1949-2009. Transect spacing = 50m. Data derived from NC DCM's Oceanfront Setback Factor Portal and available GIS files from 2013 (transects 50m shapefile, 2009 shrl shapefile and Early shrl shapefile (composite shrl file for 1933, 1949 and 1952). Additional information was provided by Ken Richardson (NC DCM). http://portal.ncdenr.org/web/cm/oceanfront-construction-setback.

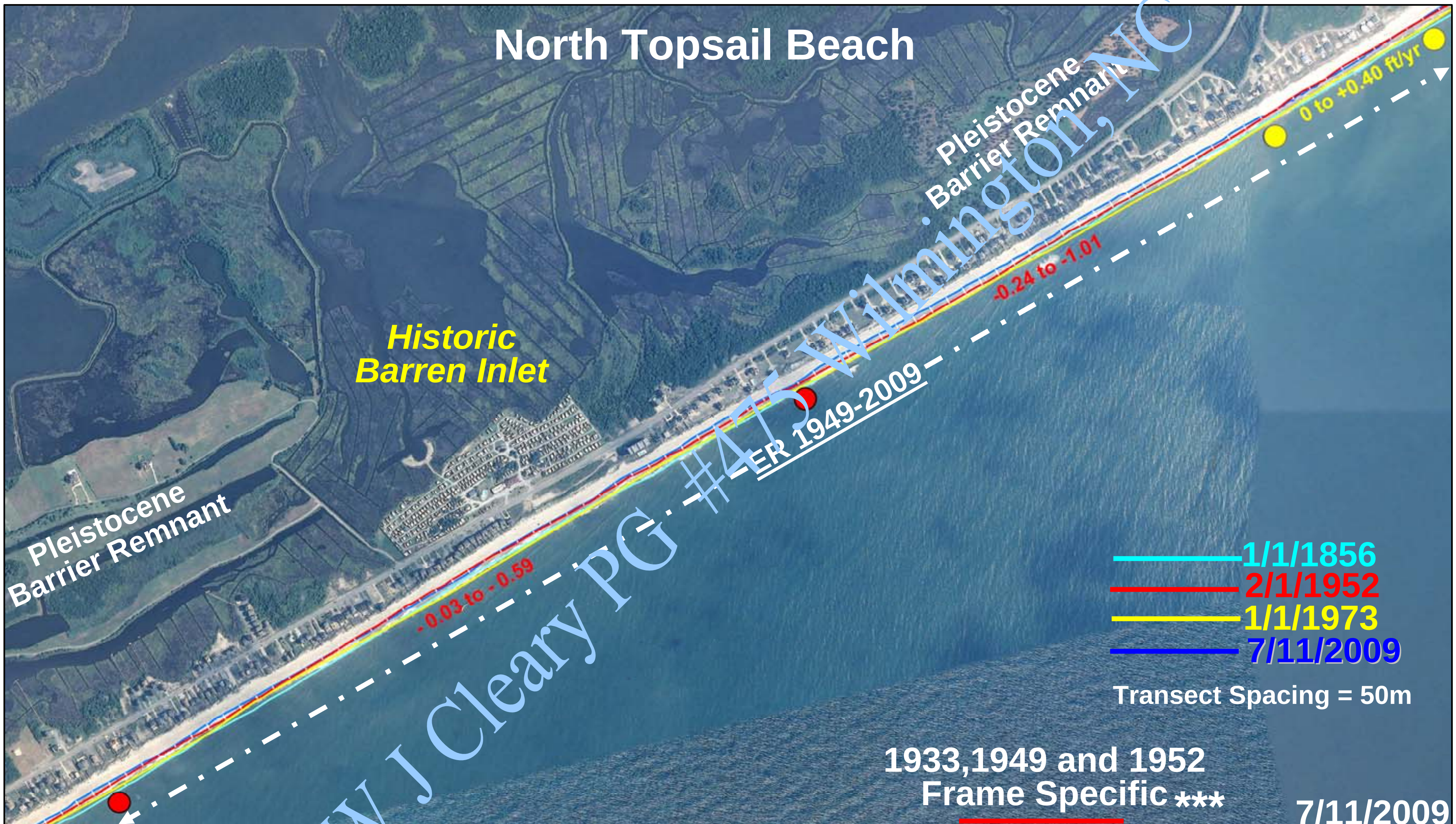


Figure 25. Map depicting 7/11/2009 photograph of the segment located immediately southwest of Figure 24 with NC DCM transects used for measuring erosion rates (2011 updated). Shoreline change rates reflect changes between 1949-2009. Transect spacing = 50m. Data derived from NC DCM's Oceanfront Setback Factor Portal and available GIS files from 2013 (transects 50m shapefile, 2009 shrl shapefile and Early shrl shapefile (composite shrl file for 1933, 1949 and 1952). Additional information was provided by Ken Richardson (NC DCM). http://portal.ncdenr.org/web/cm/oceanfront-construction-setback.

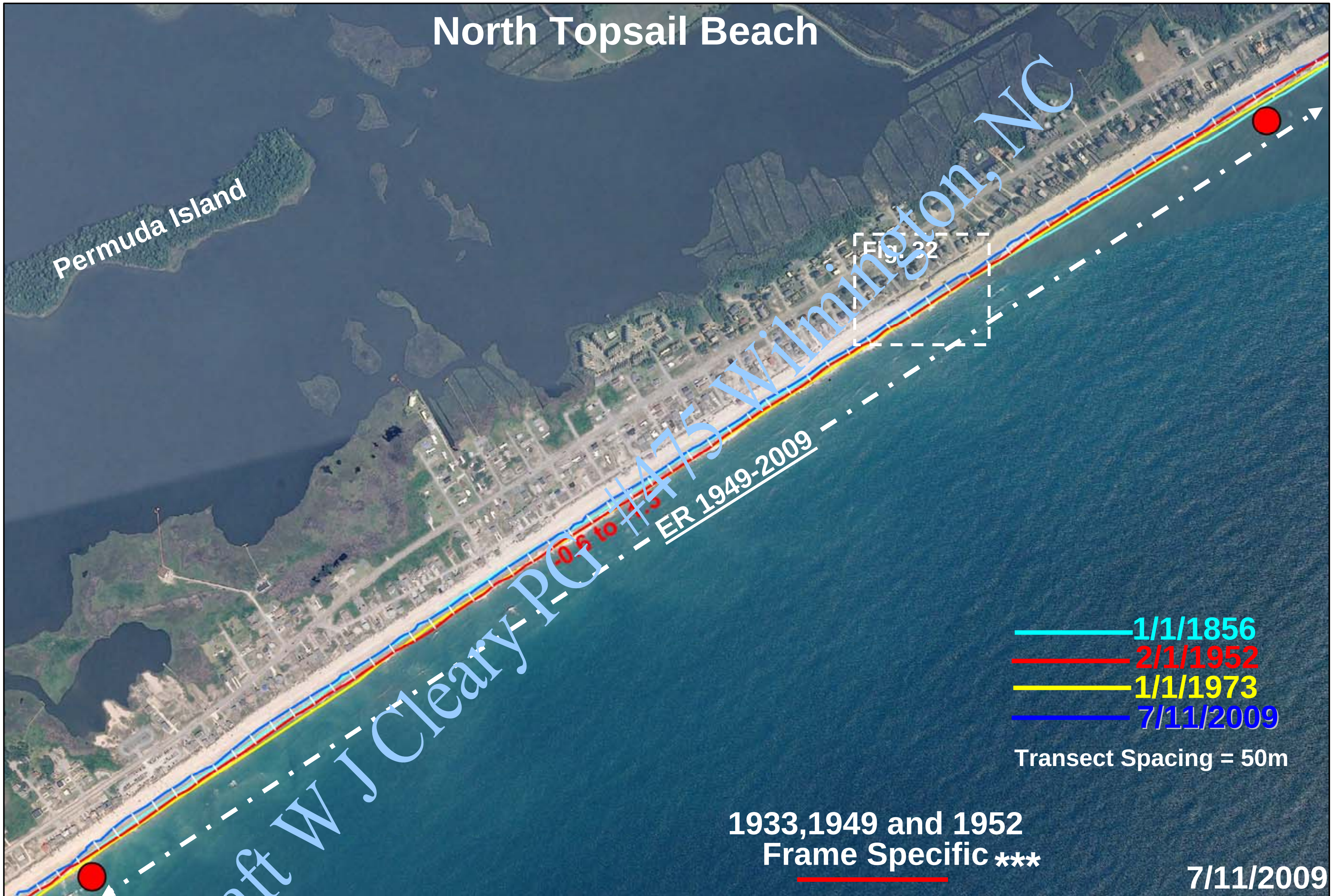


Figure 26. Map depicting 7/11/2009 photograph of the segment located immediately southwest of Figure 22 with NC DCM transects used for measuring erosion rates (2011 updated). Shoreline change rates reflect changes between 1949-2009. Transect spacing = 50m. Data derived from NC DCM's Oceanfront Setback Factor Portal and available GIS files from 2013 (transects 50m shapefile, 2009 shrl shapefile and Early shrl shapefile (composite shrl file for 1933, 1949 and 1952). Additional information was provided by Ken Richardson (NC DCM). http://portal.ncdenr.org/web/cm/oceanfront-construction-setback.

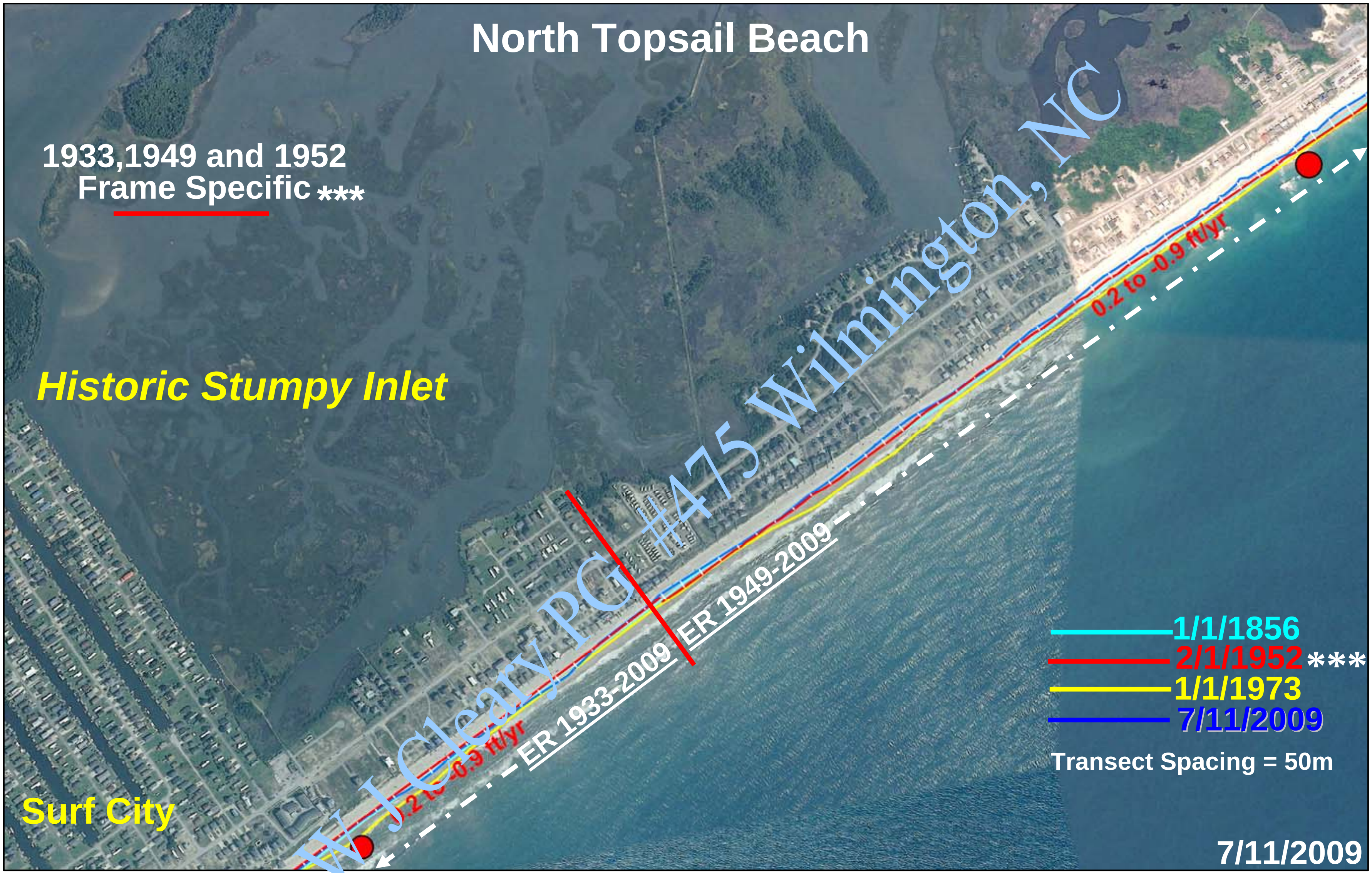


Figure 27. Map depicting 7/11/2009 photograph of the southernmost segment of NTB (located immediately southwest of Figure 22 map) with NC DCM transects used for measuring erosion rates (2011 updated). Shoreline change rates reflect changes between 1933 and 2009 and 1949-2009. Transect spacing = 50m. Data derived from NC DCM's Oceanfront Setback Factor Portal and available GIS files from 2013 (transects 50m shapefile, 2009 shrl shapefile and Early shrl shapefile (composite shrl file for 1933, 1949 and 1952). Additional information was provided by Ken Richardson (NC DCM). http://portal.ncdenr.org/web/cm/oceanfront-construction-setback.

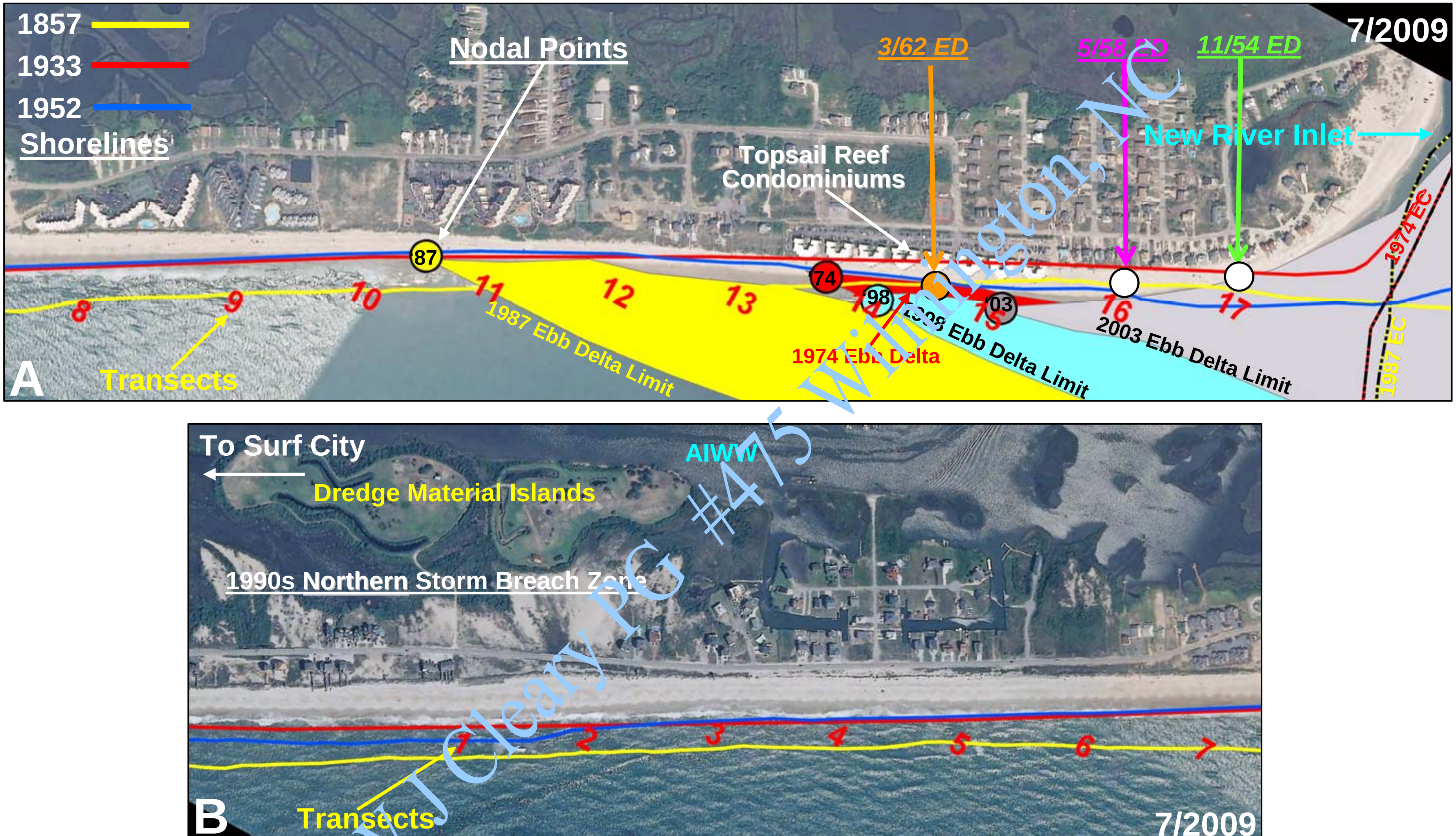


Figure 28. Maps of the northern portion of the North Topsail Beach oceanfront shoreline (2209) and positions of historic shorelines (1857, 1933 and 1952). Maps (A and B) depict transect locations (1-17) that were used to determine shoreline changes for three periods between 1857 and 2009. Spacing between adjacent transects = 655 ft. Small colored circles refer to nodal points associated with the ebb-tidal delta's limit of influence (colored polygons).

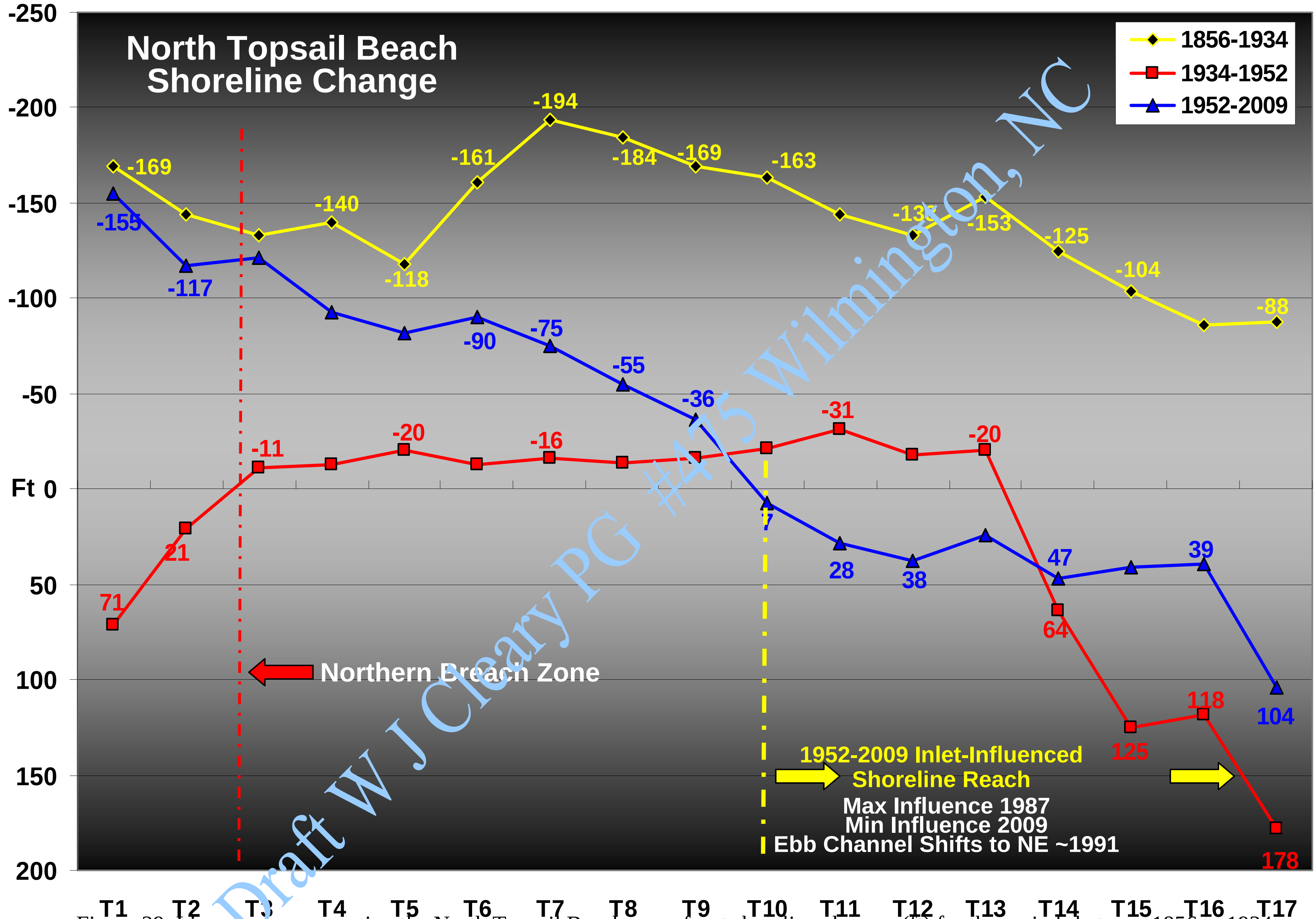
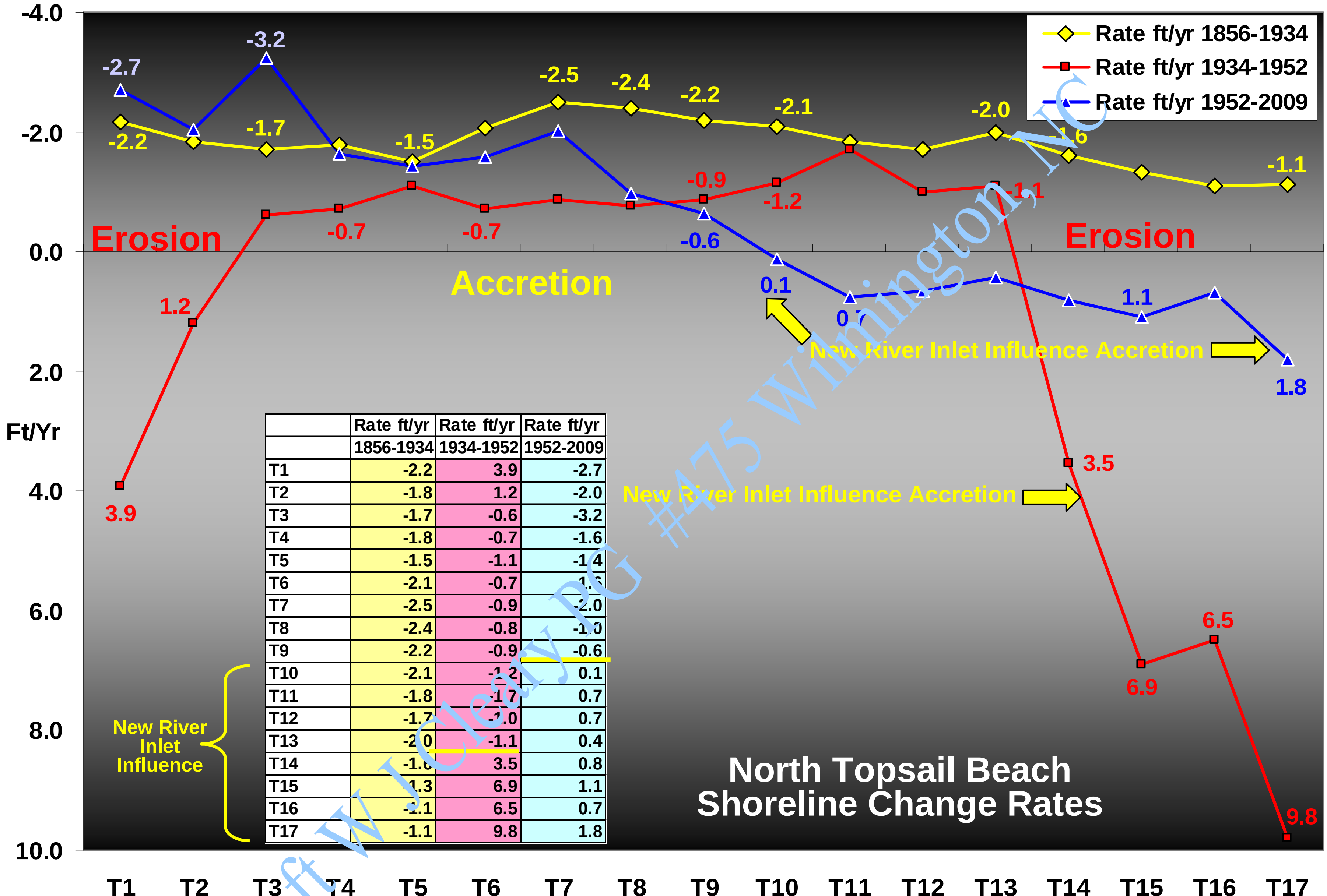


Figure 29. Line graph representing the North Topsail Beach oceanfront shoreline changes (ft) for the periods between1856 to 1934, 1934 to 1952 and 1952 to 2009. The accretion along the shoreline between transects 14 and 17 reflects the initial positive influence of New River Inlet during the period between 1934 and 1952. Note the increased length of the shoreline influenced by the inlet (T10-T17) during the latest period (1952-2009).



	Rate ft/yr 1856-1934	Rate ft/yr 1934-1952	Rate ft/yr 1952-2009
T1	-2.2	3.9	-2.7
T2	-1.8	1.2	-2.0
T3	-1.7	-0.6	-3.2
T4	-1.8	-0.7	-1.6
T5	-1.5	-1.1	-1.4
T6	-2.1	-0.7	-1.6
T7	-2.5	-0.9	-2.0
T8	-2.4	-0.8	-1.0
T9	-2.2	-0.9	-0.6
T10	-2.1	-1.2	0.1
T11	-1.8	-1.7	0.7
T12	-1.7	-1.0	0.7
T13	-2.0	-1.1	0.4
T14	-1.6	3.5	0.8
T15	-1.3	6.9	1.1
T16	-1.1	6.5	0.7
T17	-1.1	9.8	1.8

Figure 30. Line graph depicting the North Topsail Beach oceanfront shoreline change rates (ft/yr) for the periods between 1857 and 1934, 1934 to 1952 and 1952 to 2009. Between 1934 and 2009 the erosion rates for nearly all transects were less than 2.0 ft/yr. Along the inlet-influenced shoreline reach accretion rates for the period 1934 to 1952 ranged from 3.5 -9.8 ft/yr reflecting the initial adjustment of the shoreline near the newly relocated inlet (ca 1940). Rates of progradation are significantly lower along the inlet influenced for the period between 1952 and 2009 due the deflection and realignment of the ebb channel that began in the early 1990s

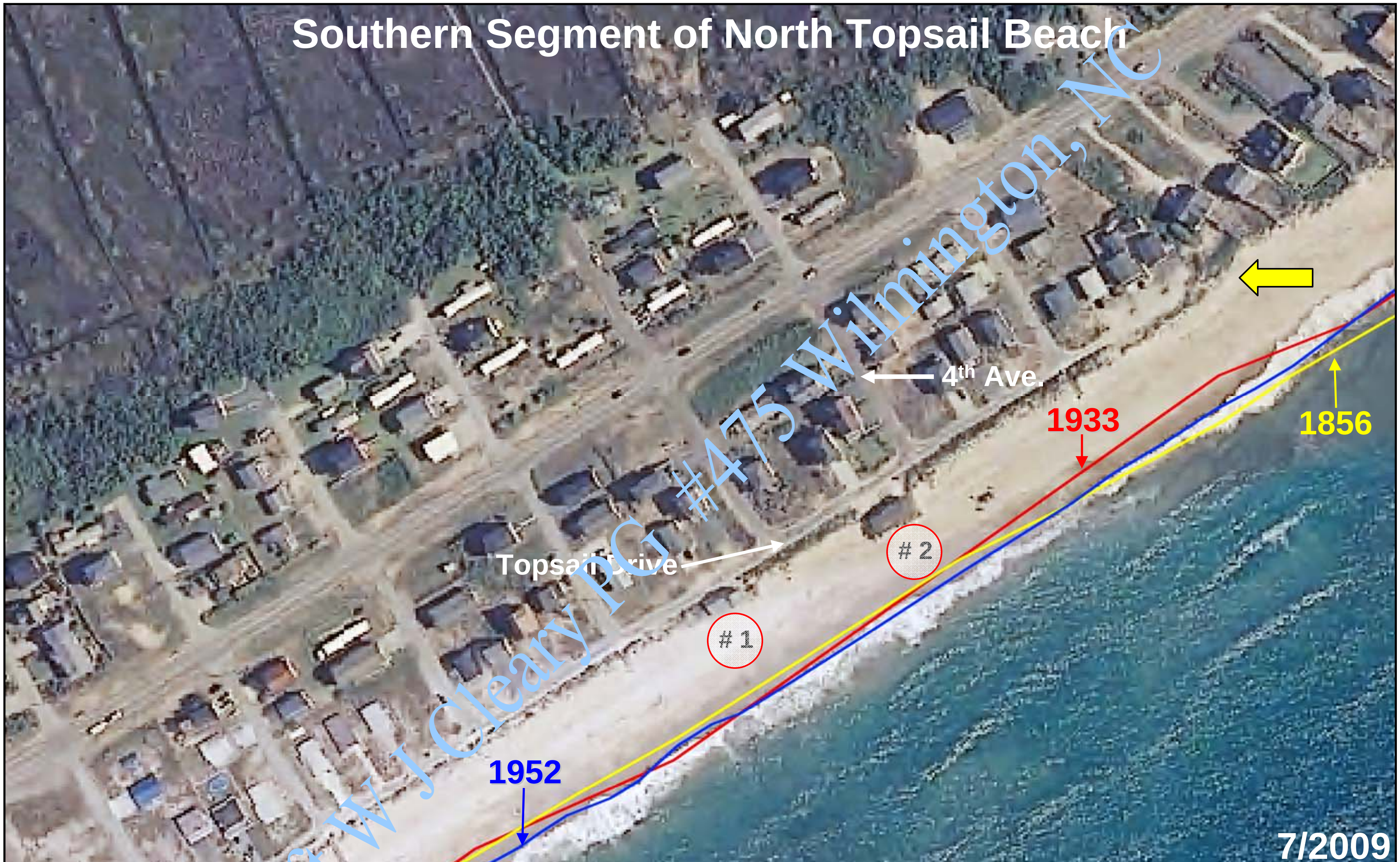
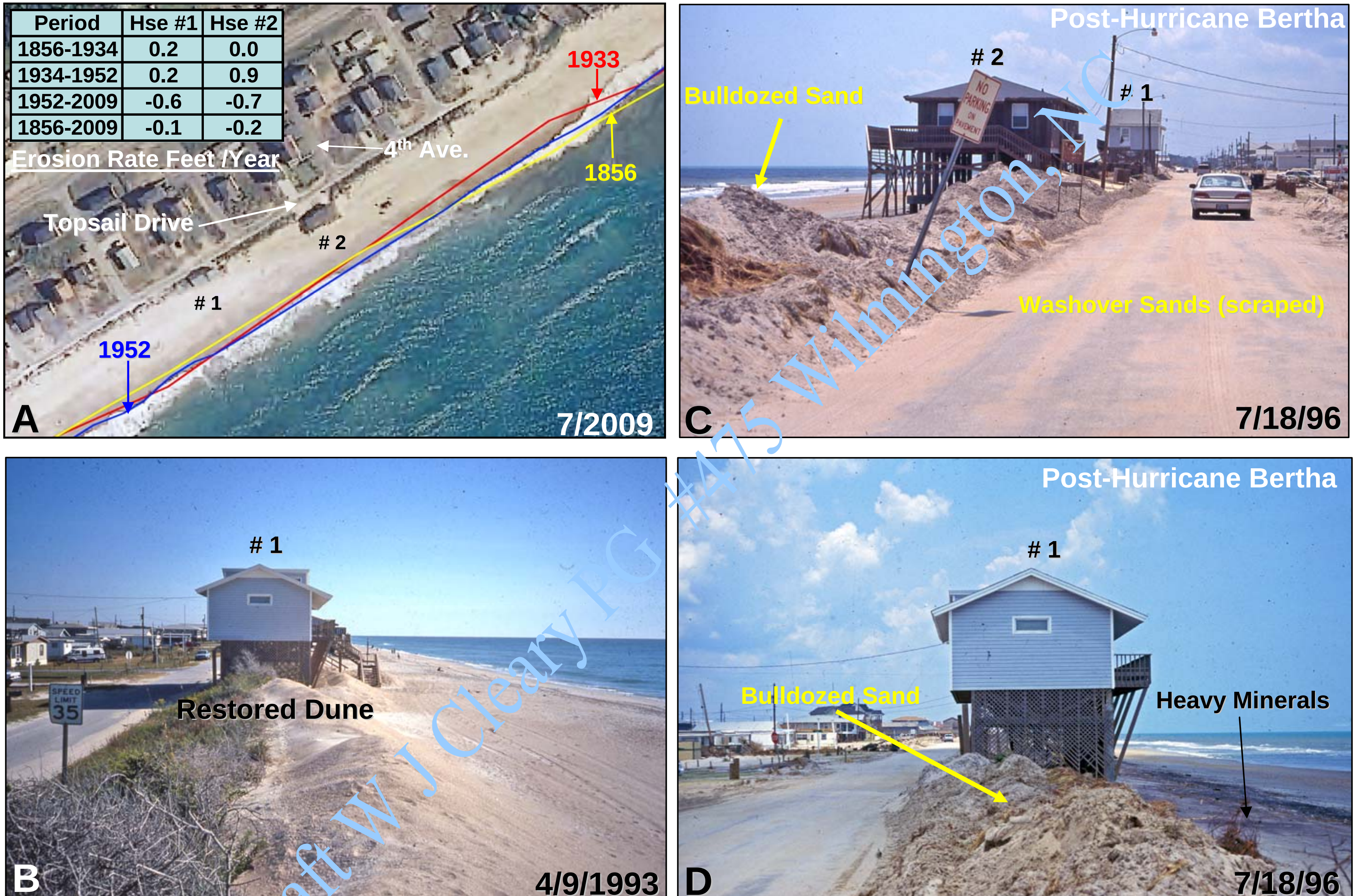


Figure 31. Map (7/2009) depicting shoreline conditions along the southern portion of North Topsail Beach with selected historic shoreline positions and houses (# 1 and # 2 reference locations). The NTB shoreline in this area is characterized by very low, average erosion rates although the area has been frequently overtopped.



Period	Hse #1	Hse #2
1856-1934	0.2	0.0
1934-1952	0.2	0.9
1952-2009	-0.6	-0.7
1856-2009	-0.1	-0.2

Figure 32. Shoreline changes along southern portion of North Topsail Beach between April 1993 and July 1996. A. Map (7/2009) depicting shoreline conditions along southern oceanfront of North Topsail Beach with selected historic shoreline positions and houses (# 1 and #2 Reference locations). Insert is a table of shoreline change rates for various periods between 1856 and 2009. The NTB shoreline is characterized by low average change rates. B. North view (4/9/1993) of Home (# 1) that rests atop the restored dune ridge. C. Post-Hurricane Bertha view (7/18/96) of overtopped restored dune line and road. D. Post-Hurricane Fran view (9/7/96) of the refurbished dune line and washover-related sediments strewn across street.

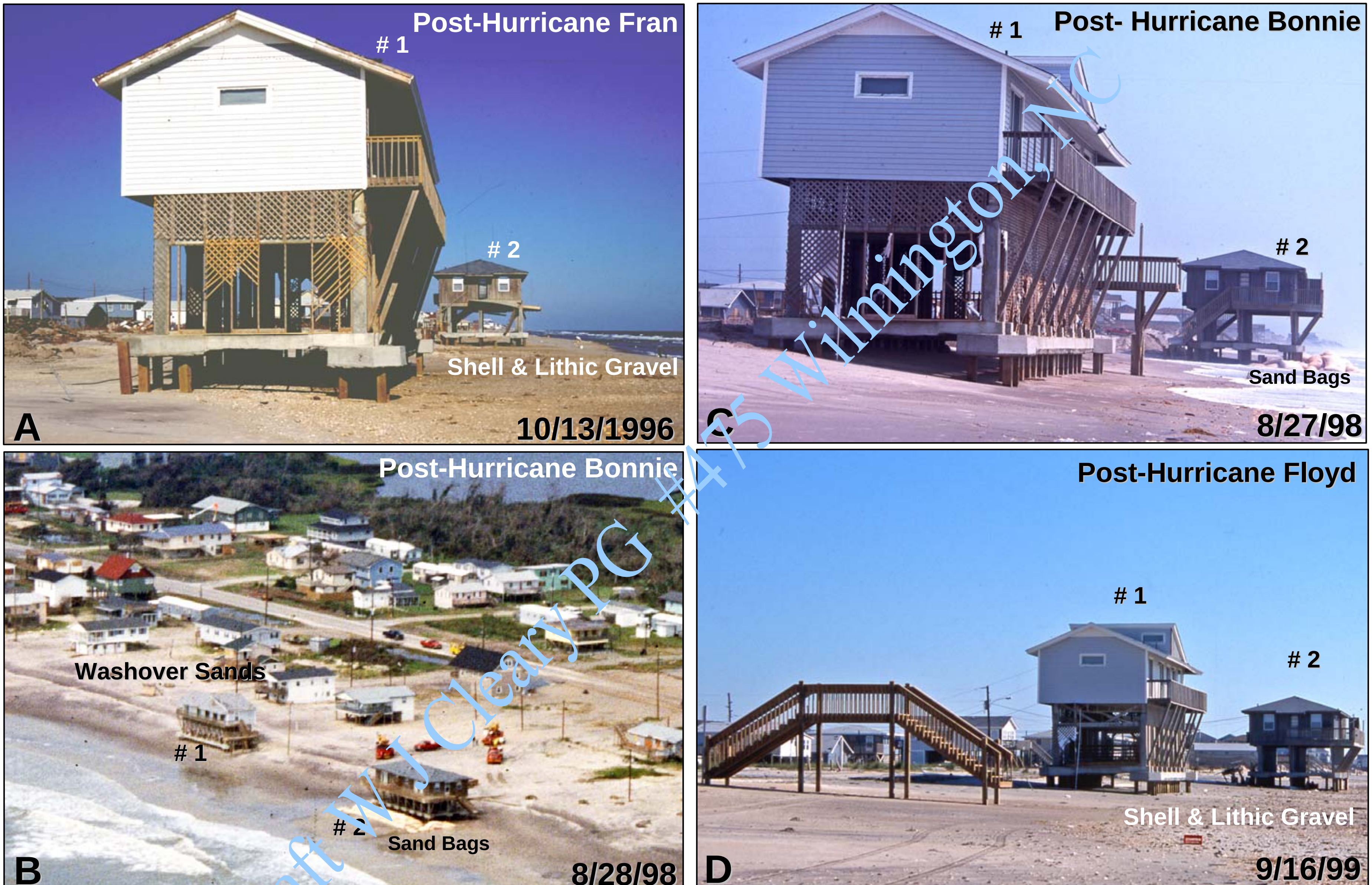


Figure 33. Shoreline changes along southern portion of North Topsail Beach between October 1996 and September 1999. A. Post-Hurricane Fran northerly view (10/12/96) of houses with foundation slabs and pilings exposed. Note lack of dunes. B. Landward aerial view (8/28/98) of Post-Hurricane Bonnie's impact. Note washover-related sediments extend to highway and no dunes are present. Foundations of houses are exposed. C. Northerly view (8/27/98) of homes with foundations exposed. Post-storm upper fore-shore profile is steeper than the post-storm profile following Hurricane Fran (A). D. Landward ground level view (9/16/99) of homes following Hurricane Floyd. Note lack of a dune line.

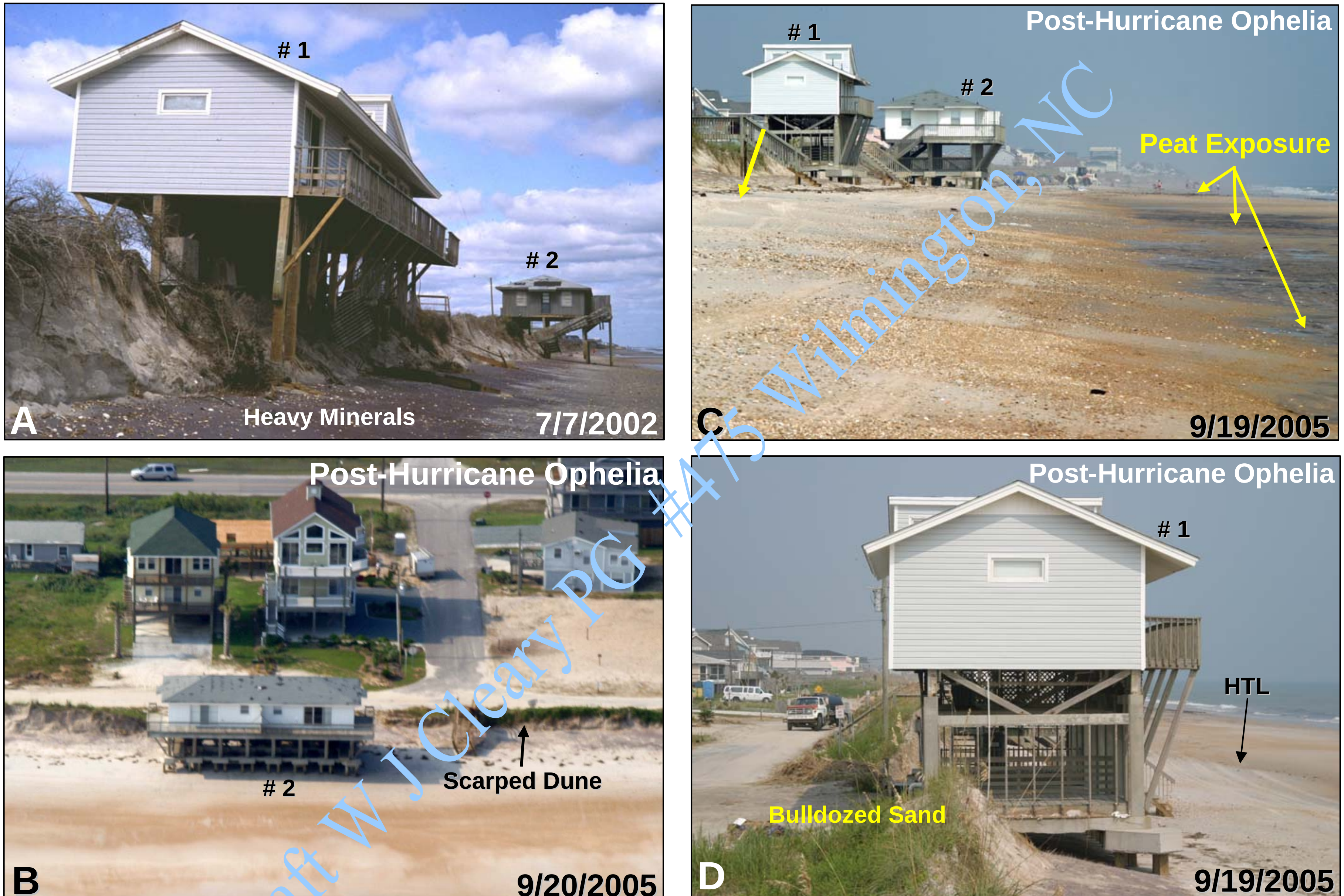


Figure 34. Shoreline changes along southern portion of North Topsail Beach between July 2002 and September 2005A. Northerly view (7/7/02) of homes perched along artificial dune line. Note pilings are exposed near HT swash line. B. Aerial view (9/20/05) depicting the minimal impact of Hurricane Ophelia. Note scarped dune line and position HT line. C. Northerly view (9/19/05) of homes with exposed foundation slabs. Note gravel strewn foreshore. Coarse shell and lithic fragments were derived from residual sediment accumulations that mantled hardbottoms. Extensive high-marsh peat exposures front much of this area. D. Northerly view of home # 1 along restored dune line. Despite numerous tropical storms, hurricanes and extra-tropical storms, some of which produced surges that inundated the island, the HTL position has changed very little since 1952. Erosion rates in this vicinity range from 0.6 to 0.7 ft/yr. See Figure 32 A.

Figure 35. The NTB shoreline during a rising Spring tide on 8/6/14. A. Northerly view of home #2 perched along the dune. Note position of the HT swash line. B. Northerly view of homes #1 and #2 along dune line. High tide swash line lies near base of dune. C. Southerly view of homes # 1 and # 2. Despite numerous storms that eroded the dunes, the HTL position has changed little during the past 25 years.

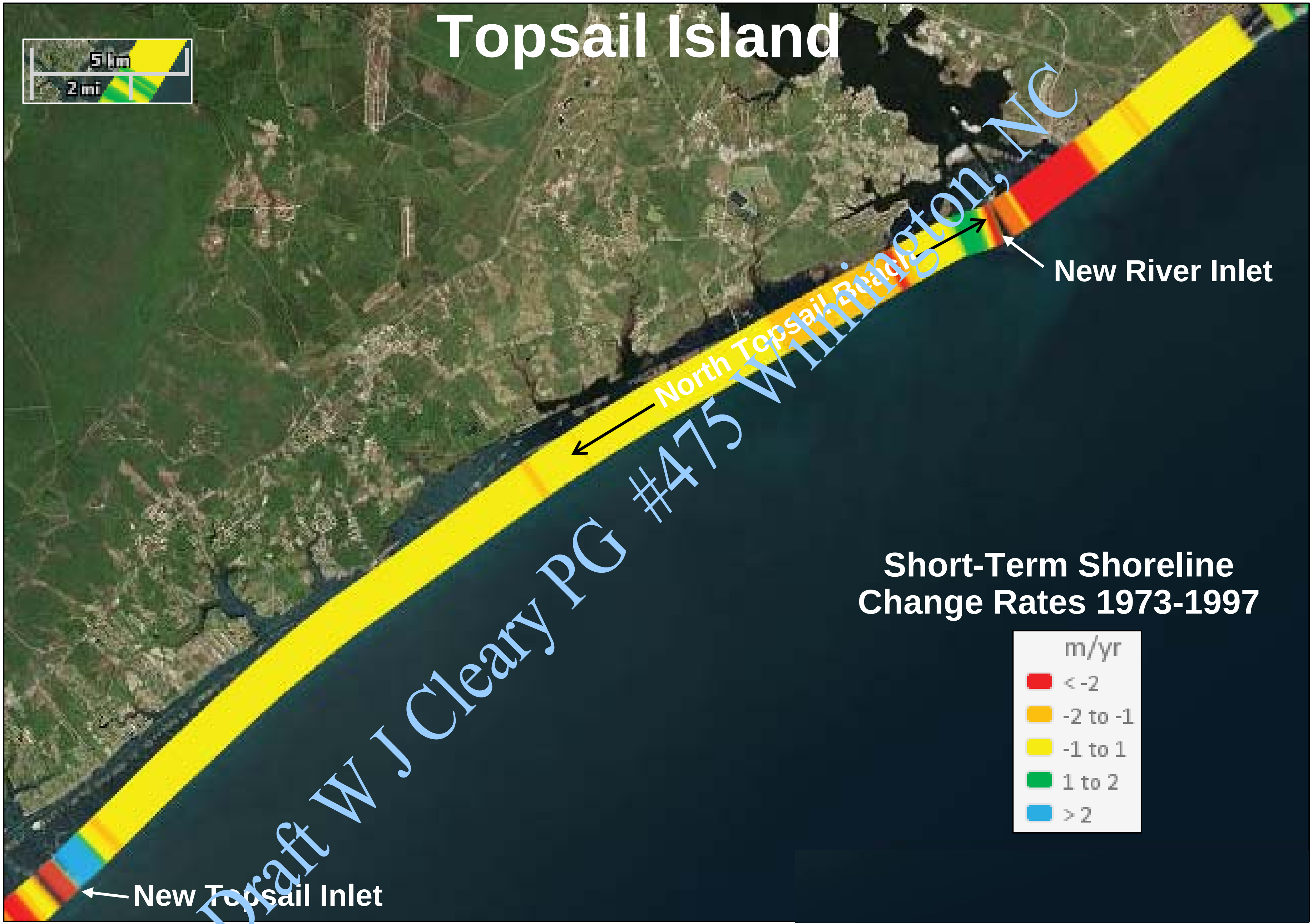


Figure 36. Map depicting short-term shoreline change rates for Topsail Island for the period 1973 -97. The 24 year long period includes several stormy intervals characterized by event-scale erosion and the reversal in the inlet-related accretion trends downdrift of New River Inlet. Map downloaded and modified after USGS Coastal Change Hazard Portal- SE Atlantic Short-Term Shoreline Change Rates (m/yr). http://marine.usgs.gov/coastalchangehazardsportal/

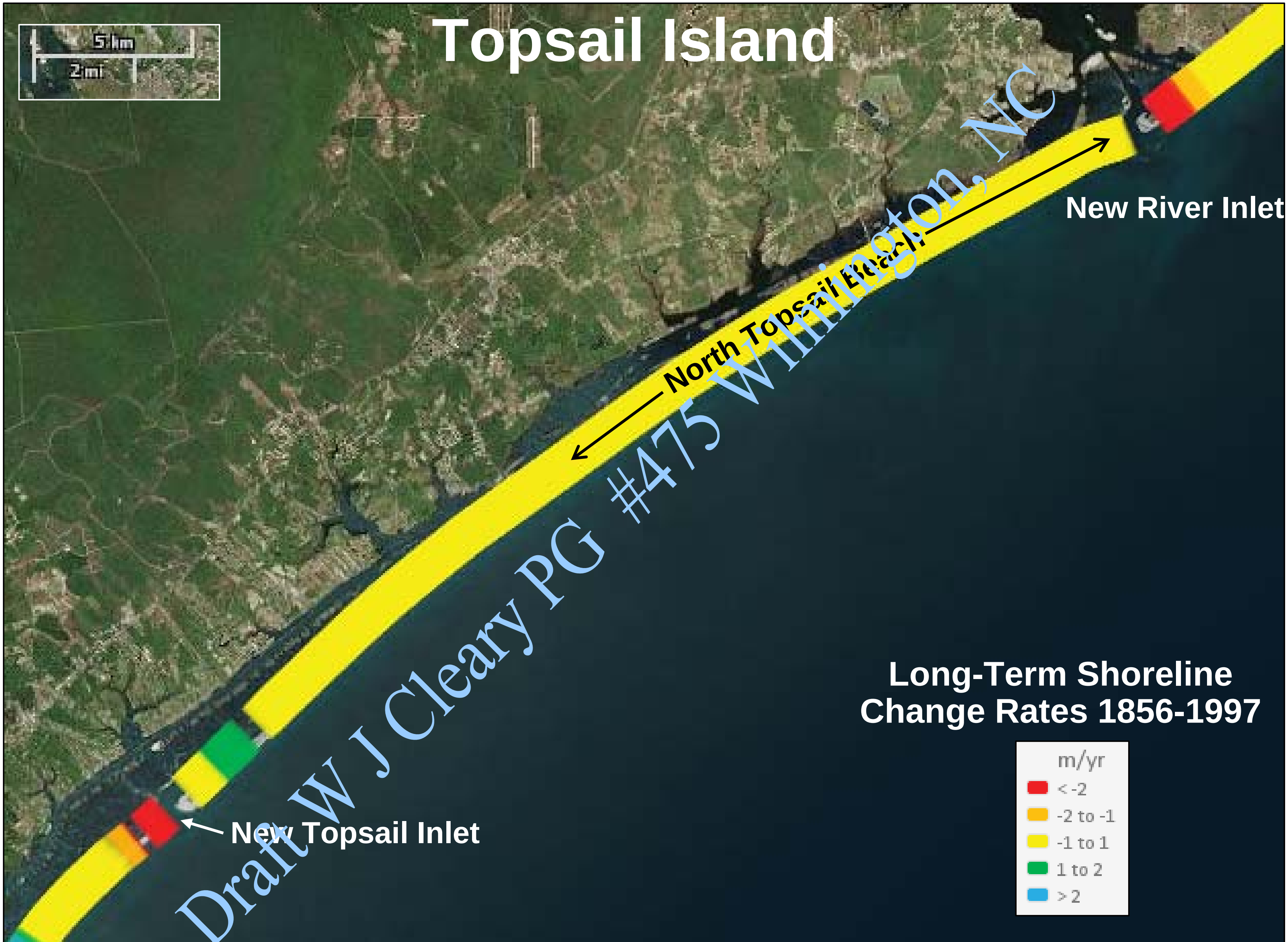


Figure 37. Map depicting long-term shoreline change rates for Topsail Island for the period 1856 -1997. Map downloaded and modified after USGS Coastal Change Hazard Portal- SE Atlantic Long-Term Shoreline Change Rates (m/yr). http://marine.usgs.gov/coastalchangehazardsportal/

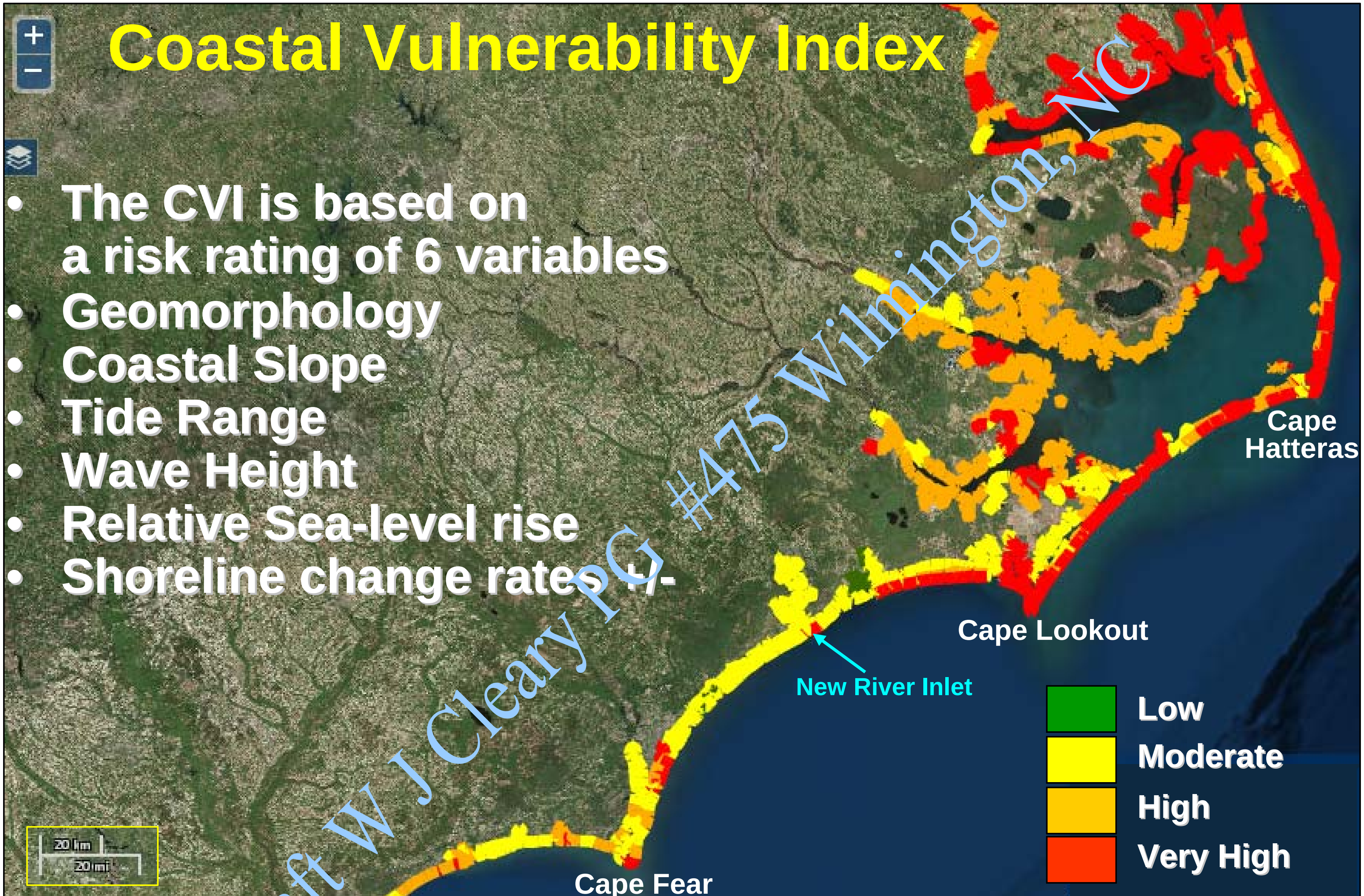


Figure 38. Map of NC Coastal Vulnerability Index (CVI) for North Carolina. The Index shows the vulnerability (risk) of the NC Coast to changes due to future rise in sea-level. Area rankings are from low to very high risk that are based on an analysis of a variety of physical variables that contribute to coastal changes. Note the North Topsail Beach moderate risk ranking is a commonplace designation along the SE NC shoreline. Modified after Thieler, E.R., and Hammar-Klose, E.S., 1999. *National Assessment of Coastal Vulnerability to Future Sea-Level Rise: Preliminary Results for the U.S. Atlantic Coast*. U.S. Geological Survey, Open-File Report 99-593, 1 sheet. http://pubs.usgs.gov/of/of99-593