Coastal Hazards Infrastructure Vulnerability Assessment

Duck, North Carolina

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Program for the Study of Developed Shorelines
Western Carolina University
Cullowhee, NC 28723

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Cover Photo: Town of Duck commercial center on Currituck Sound (Photo credit: Program for the Study of Developed Shorelines at Western Carolina University).

This Page: Cypress tree in Currituck Sound (Photo credit: Program for the Study of Developed Shorelines at Western Carolina University).

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Executive Summary

Western Carolina University's Program for the Study of Developed Shorelines has completed a **Coastal Hazards Infrastructure Vulnerability Assessment** for the Town of Duck, North Carolina. Vulnerability is generally defined as the extent to which a resource is susceptible to harm from hazards or climate change impacts. For infrastructure (assets), vulnerability is most often calculated as a combination of exposure and sensitivity. Exposure refers to the extent or degree to which climate change or a natural hazard is likely to affect an asset, and sensitivity refers to how it will fare when exposed to a hazard/impact. This assessment evaluated individual buildings and roads, allowing managers to compare the vulnerability of individual assets to develop more detailed adaptation plans and strategies. The coastal hazards evaluated in this study include flooding, storm surge, sea-level rise, and erosion.

This assessment focused on roads and a subset of commercial, professional, retail, and publicly-owned buildings near the town center. Most of the buildings evaluated are concentrated along Duck Road (NC HWY 12) near Currituck Sound. In total, 65 buildings and 308 road segments (almost 32 miles) were included in the vulnerability assessment. Specific scores are reported for each individual asset in the supplied Excel datasheets, and summary data tables can be found in the Appendix. Final exposure and vulnerability results are also provided as GIS maps and layers.

The three highest vulnerability buildings evaluated are Beach Realty, Sunset Grill & Raw Bar, and Kitty Hawk Surf Company. An additional 20 buildings have high-moderate vulnerability. The parcels containing high or high-moderate vulnerability buildings have an estimated value over $24 million, while the associated buildings have an estimated value over $10.5 million. Almost one-third of the evaluated buildings have moderate vulnerability. An additional 21 buildings have low-moderate vulnerability, while the lowest vulnerability building evaluated is Ocean Atlantic Rentals.

The highest vulnerability road segment is a short portion of Duck Road, just north of the Waterfront Shops. An additional 6 road segments (totaling over 1 mile) have high-moderate vulnerability, including several portions of Duck Road. In total, 2.60 miles of road have moderate vulnerability, 13.65 miles of road have low-moderate vulnerability, and 7.31 miles have low vulnerability. Nearly 7 miles of road have minimal vulnerability to coastal hazards (due to lack of exposure).

Compared to many barrier island communities, Duck has relatively low overall vulnerability. This is due to its unique sheltered coastal setting and significant interior elevation. Although Duck has these beneficial factors, it still has significant exposure to coastal hazards: primarily coastal erosion on the oceanfront and flooding on the soundside. Winter nor'easters can also significantly subject this part of the coast to erosion, flooding, and waves over multiple days.

Due to low elevations and soundside shoreline retreat (from loss of wetlands and marsh), much of the infrastructure in the town commercial center is exposed to flooding, erosion, and sea-level rise. Because Duck Road (NC HWY 12) is the only road with a continuous north-south connection, it is the most critical transportation corridor in Duck. The high vulnerability along several segments of this critical road has significant impacts for the entire town, as well as communities to the north. Recommendations for adaptation along the soundside shoreline include the development of a long-term transportation plan for Duck Road, and strategies that restore or slow the loss of marshes and wetlands (e.g., living shorelines).

The vulnerability of existing structures in Duck can be reduced through two primary adaptation measures: elevation and/or relocation. It is also important to consider reducing the vulnerability of any associated utilities, including coordinating with utility providers on the development and installation of more resilient infrastructure. While these adaptation actions may not always be practical, they are

important to consider, as they are the most efficient way to decrease the vulnerability and increase the resiliency of existing infrastructure. These adaptation options should certainly be considered following storms when funds may become available for resilience actions. It is also vital to increase the resilience of any future development in Duck. The safest bet is to place new infrastructure in areas that have minimal exposure to hazards. When that is not possible, adopting higher standards for building elevation and construction can lead to more sustainable infrastructure over the long term.

Vulnerability Assessment Products & Deliverables

1. Excel datasheets: All results are provided in tables, including scoring of individual buildings and roads. The exposure, sensitivity, and vulnerability scores are reported alongside any additional asset attributes, as well as intermediate scores in the analysis.

2. Geographic Information Systems (GIS) Maps and Layers: WCU will provide all GIS data, including the exposure layers, exposure results, and final vulnerability results as a separate file. Digital data sources can be found in the next section of this document.

3. Vulnerability Results Summary Document: This summary document (herein) explains the deliverables, results, and methodology. It briefly summarizes the vulnerability assessment results in the aforementioned datasheets and maps, as well as the methodology utilized. This document does not fully describe **all** results from the analysis; see the Appendix and Excel datasheets for detailed results.

Digital Data Sources

1. FEMA Flood Zones: Preliminary FEMA flood maps were obtained from FEMA's Preliminary Map Products website. According to FEMA, the VE zones are areas subject to inundation by the 1-percent-annual-chance flood event, with additional hazards due to storm-induced velocity wave action, and the AE zones are areas subject to inundation by the 1-percent-annual-chance flood event (determined by detailed methods). The shaded X zone (referred to as 500-year) represents areas between the limits of the base flood and the 0.2-percent-annual-chance (or 500-year) flood.

2. NOAA Sea-Level Rise Inundation Scenarios: Sea-level rise inundation scenarios were obtained from NOAA's sea-level rise viewer.

3. NOAA Storm Surge (SLOSH) Model: Storm surge data were obtained from NOAA's National Hurricane Center.

4. Erosion/Coastal Proximity: Simple coastal proximity buffers of 25, 50, and 100 feet were applied to the soundside shoreline at Duck. Shorelines were digitized by WCU along the marsh/water interface.

Introduction & Project Description

Western Carolina University's Program for the Study of Developed Shorelines has completed a **Coastal Hazards Infrastructure Vulnerability Assessment** for the Town of Duck, North Carolina. Unlike many studies, this assessment evaluated individual buildings and roads, allowing managers to compare the vulnerability of individual assets to develop more detailed adaptation plans and strategies.

In the past, vulnerability has been defined in many ways, but can be generally described as the extent to which a species, habitat, or resource is susceptible to harm from hazards or climate change impacts. For infrastructure, vulnerability is calculated as a combination of two components: exposure and sensitivity.

Vulnerability = Exposure + Sensitivity

- ✓ **Exposure** refers to the extent or degree to which climate change or a natural hazard is likely to affect a resource.
- ✓ **Sensitivity** refers to how a resource will fare when exposed to a hazard/impact.

The ability of a resource to adjust or cope with climate change or natural hazards (referred to as adaptive capacity) is often included as an additional component of vulnerability, particularly in natural resource and socioeconomic studies. However, this concept is difficult to apply in the built environment (i.e., buildings, roads, etc.). For example, buildings cannot inherently adapt to climate change or other hazards, while natural resources often can (a salt marsh can adapt to sea-level rise by migrating upland, whereas a building cannot). Thus, the ability of an asset to adapt to changes is not included in the vulnerability score. This does not mean that understanding the adaptation potential of an asset is not important. Identifying the range of effective adaptations for key vulnerable infrastructure is the logical next step in the hazard/climate change planning process. Effective adaptations will reduce exposure and/or sensitivity, which is the key to reducing vulnerability.

Roads and non-residential buildings were the focus of the infrastructure vulnerability assessment of Duck. Because this assessment calculates vulnerability at the asset level, it was not practical to evaluate all buildings in the town. Therefore, a subset of commercial, professional, retail, and publicly-owned buildings near the town center were chosen for evaluation (after discussions with Town officials). Most of the buildings evaluated are concentrated along Duck Road (NC HWY 12) near Currituck Sound. Roads were evaluated using pre-determined segments obtained from Dare County. In total, 65 buildings and 308 road segments (totaling

Figure 1. Buildings (white dots) and roads (lines) included in the vulnerability assessment of Duck. Duck Road (NC HWY 12) is highlighted in yellow.

almost 32 miles) were included in the vulnerability assessment (Figure 1). Road segments were further categorized into the following groups: 1) primary roads, 2) secondary roads, and 3) tertiary roads. Duck Road (NC HWY 12) is the only road considered primary, as it provides the main north-south access route through the town. All secondary roads branch from Duck Road, and tertiary roads connect to the secondary roads.

Methodology

The **Coastal Hazards Infrastructure Vulnerability Assessment** for Duck has three primary steps: 1) Exposure Analysis and Mapping, 2) Sensitivity Analysis, and 3) Vulnerability Calculation. A detailed description of the scoring information for buildings and roads can also be found in the Excel results sheets that accompany this report.

Step 1: Exposure Analysis & Mapping

The first step in this assessment was to analyze the exposure of the evaluated infrastructure to coastal hazards. Five primary factors or hazards were determined for asset exposure; these factors indicate how exposed an asset is to coastal hazards. The general exposure factors/hazards include flooding potential, storm surge, sea-level rise inundation, coastal proximity/erosion, and historic flooding/damage (for buildings only). Table 1 summarizes these exposure factors/hazards, as well as utilized data sources.

Table 1. Exposure factors/hazards evaluated and data sources.

Exposure Factors/Hazards	Data Sources & Description
☑ **Flooding Potential**	Preliminary FEMA Flood Zones (VE or AE); 1% annual flood chance ± velocity/waves
☑ **Storm Surge**	NOAA SLOSH model; Category 1-5 for buildings, category 3 for roads; LiDAR DEM
☑ **Sea-Level Rise Inundation**	NOAA SLR modeling; 1-6 ft for buildings, 3 ft for roads
☑ **Coastal Proximity/Erosion**	Shoreline proximity buffers; 25 ft, 50 ft, & 100 ft buffers
☑ **Historic Flooding/Damage**	Post-storm damage reports

*SLOSH - Sea, Lake, and Overland Surges from Hurricanes

The exposure analysis utilized data imported into Geographical Information Systems (GIS) format, as exposure is directly dependent on location and mapped hazard data (whether the area near the infrastructure experiences the hazard). Digital hazard data were gathered for each of the exposure factor/hazards, such as the online georeferenced FEMA flood map layers. The only dataset that does not come from a widely available, well established source is historic flooding/damage, which was derived from post-storm damage reports. Each exposure data layer thus represents an exposure factor or hazard zone. Assets located within a particular zone are assigned a higher score than assets located outside of the hazard zone. Scores for each exposure factor are then summed and grouped together (binned) to get a total exposure score. Final exposure scores fall into one of six ranking categories: high, high-moderate, moderate, low-moderate, low, and minimal (asset does not lie within any mapped zone).

Although the exposure factors/hazards are similar for buildings and roads, there are some differences in the specific scoring methodology. This is due to the fact that buildings were analyzed as point features, while roads were analyzed as segmented linear features (road segments were obtained from Dare County). Buildings were compared to multiple categories of storm surge (category 1-5) and sea-level rise scenarios (1-6 feet). However, due the complexity of scoring road segments (varying lengths, linear roads intersecting polygon hazard data, etc.) only one storm surge category (category 3) and one sea-level rise scenario (3 feet) were evaluated.

Step 2: Sensitivity Analysis

The second step in this assessment was to analyze the sensitivity of the evaluated infrastructure to coastal hazards. Similar to exposure, a set of factors was determined for asset sensitivity (Table 2); these factors indicate how sensitive an asset is to coastal hazards. Unlike exposure, sensitivity is evaluated independent of geographic location (only exposure is location-dependent). Sensitivity refers to how that asset would fare when exposed to the hazard, which is a function of the inherent properties or characteristics of the asset. For buildings, sensitivity factors include: protective engineering, building age, first floor elevation (FFE) compared to base flood elevation (BFE), FFE compared to storm surge inundation levels (height above ground), and design/construction. For roads in Duck, only the protective engineering factor was applicable for sensitivity.

Table 2. Sensitivity factors evaluated and data sources.

Sensitivity Factor	Data Sources & Description
☑ **Protective Engineering** buildings & roads	Field/aerial imagery analysis; Town officials
☑ **Building Age** buildings only	Dare county parcel data; Town officials
☑ **FFE vs BFE** buildings only	FFE data estimated using field/imagery analysis & Town officials; BFE data from FEMA
☑ **FFE vs Surge** buildings only	FFE data estimated using field/imagery analysis & Town officials; Surge inundation levels from NOAA
☑ **Design & Construction** buildings only	Field & imagery analysis

The protective engineering factor represents whether an asset is protected by hard structures (e.g., seawalls, bulkheads) or landscape modifications (e.g., significant drainage alteration, major restored landscape). This factor assumes that infrastructure protected with engineering is less likely to be damaged by coastal hazards. For this analysis, this sensitivity factor was only considered if the asset was in a coastal proximity/erosion buffer zone (exposed).

The remaining four sensitivity factors were only applied to buildings (Table 2). The building age factor (scored in 15 year increments) assumes that older buildings are more likely to sustain damage when exposed to coastal hazards. First floor elevation was utilized for two sensitivity factors: 1) comparison to FEMA's BFE, and 2) comparison to NOAA's modeled inundation levels from a category 5 storm surge. Category 5 was chosen because all buildings evaluated are exposed to this surge level, allowing for a uniform comparison ***despite a low probability for this degree of surge exposure in Duck.*** The final sensitivity factor considers a building's robust or resistant design, as well as the complexity of construction and/or finishes.

Because digital sensitivity data are not generally available, the primary data for much of the sensitivity analysis was obtained from field/imagery analysis as well as discussions with town officials (Table 2). A higher score was given for an unfavorable sensitivity factor result (e.g., an older building was scored higher than a newer building). For buildings, the sensitivity scores for each factor were summed to obtain a total raw score, then grouped together (binned) into six categories: high, high-moderate, moderate, low-moderate, low, and minimal. Since only the protective engineering factor was applicable, no specific sensitivity score was calculated for roads. Instead, if a road segment was in a coastal proximity zone and had protective engineering, its raw exposure score was reduced.

Step 3: Vulnerability Calculation

To obtain a vulnerability score, the exposure and sensitivity scores are summed, and then grouped together (binned) into six vulnerability ranking categories. The ranking categories are as follows: high, high-moderate, moderate, low-moderate, low, and minimal vulnerability. Specific scoring ranges for vulnerability can be found within the Excel results sheets.

Results Summary & Discussion

A total of **65 buildings** and **308 road segments** (totaling almost 32 miles) were included in the vulnerability assessment of Duck. Specific scores are reported for each individual asset in the supplied Excel datasheets and summarized in the Appendix; final exposure and vulnerability results are also provided as GIS maps and layers.

Exposure Results

A notable result of the exposure analysis is that over 50% of the buildings evaluated have a moderate exposure or higher. This overall high exposure is partially due to the buildings selected for evaluation, as the town commercial center is situated along the Currituck Sound waterfront (Figure 1), which exposes these assets to more coastal hazards. Ten of the evaluated buildings have the highest exposure, most of which are part of the Waterfront Shops commercial center (Figures 2 & 3).

Over 45% of the evaluated buildings have a low-moderate or low exposure to coastal hazards (Table 3). Most of these buildings are located on the east side of Duck Road, and therefore, are outside the FEMA flood, coastal proximity, and sea-level rise hazard zones. None of the buildings evaluated have minimal exposure, as each of these assets are in at least the category 5 storm surge hazard zone.

Table 3. Exposure results for evaluated buildings and road segments at Duck.

Exposure Rank	# buildings	% all buildings	# road segments	length (miles)	% total road length
High	10	15.4%	2	0.14	0.4%
High-Moderate	18	27.7%	6	1.01	3.2%
Moderate	7	10.8%	36	3.47	11.0%
Low-Moderate	5	7.7%	138	12.73	40.3%
Low	25	38.5%	30	7.66	24.2%
Minimal	0	0.0%	96	6.61	20.9%

Over 4.60 miles of road in Duck have a moderate exposure or higher to coastal hazards (Table 3). However, only 1.15 miles have high or high-moderate exposure, most of which are segments of Duck Road. Over 20 miles of road have a low-moderate or low exposure to coastal hazards, because many of these road segments are located on the higher elevation portions of the community near the center of the island (Figure 4). Over 6.6 miles of road have minimal exposure using this methodology, which means these road segments did not fall within ***any*** of the mapped exposure hazard zones (flooding, storm surge, sea-level rise, or erosion/coastal proximity). Exposure is directly dependent on location; thus, if an asset is located beyond the influence of a particular coastal hazard, its exposure is diminished.

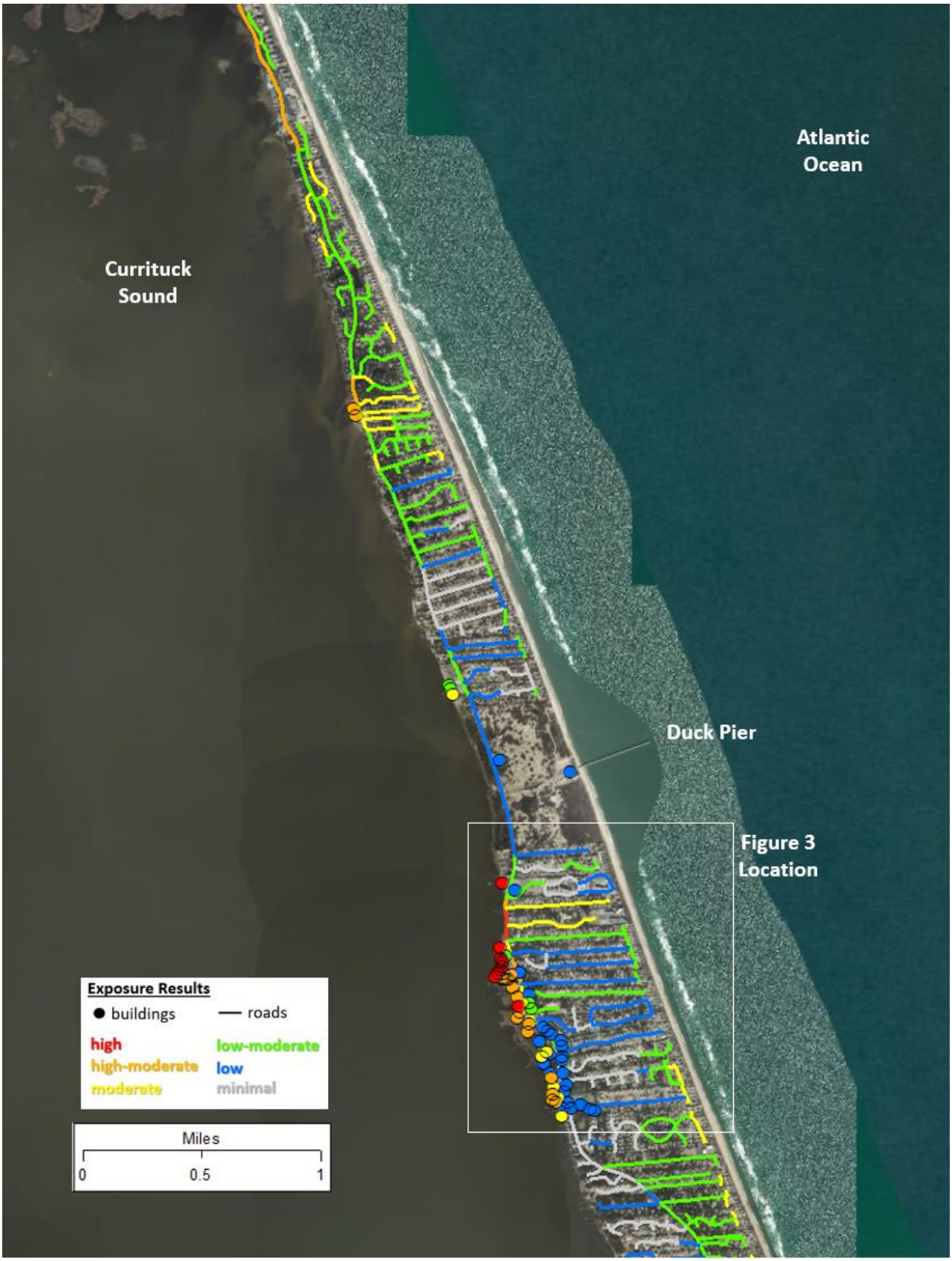

Figure 2. Exposure results for select buildings and roads in Duck.

Figure 3. Exposure results for select buildings and roads in Duck near the town commercial center.

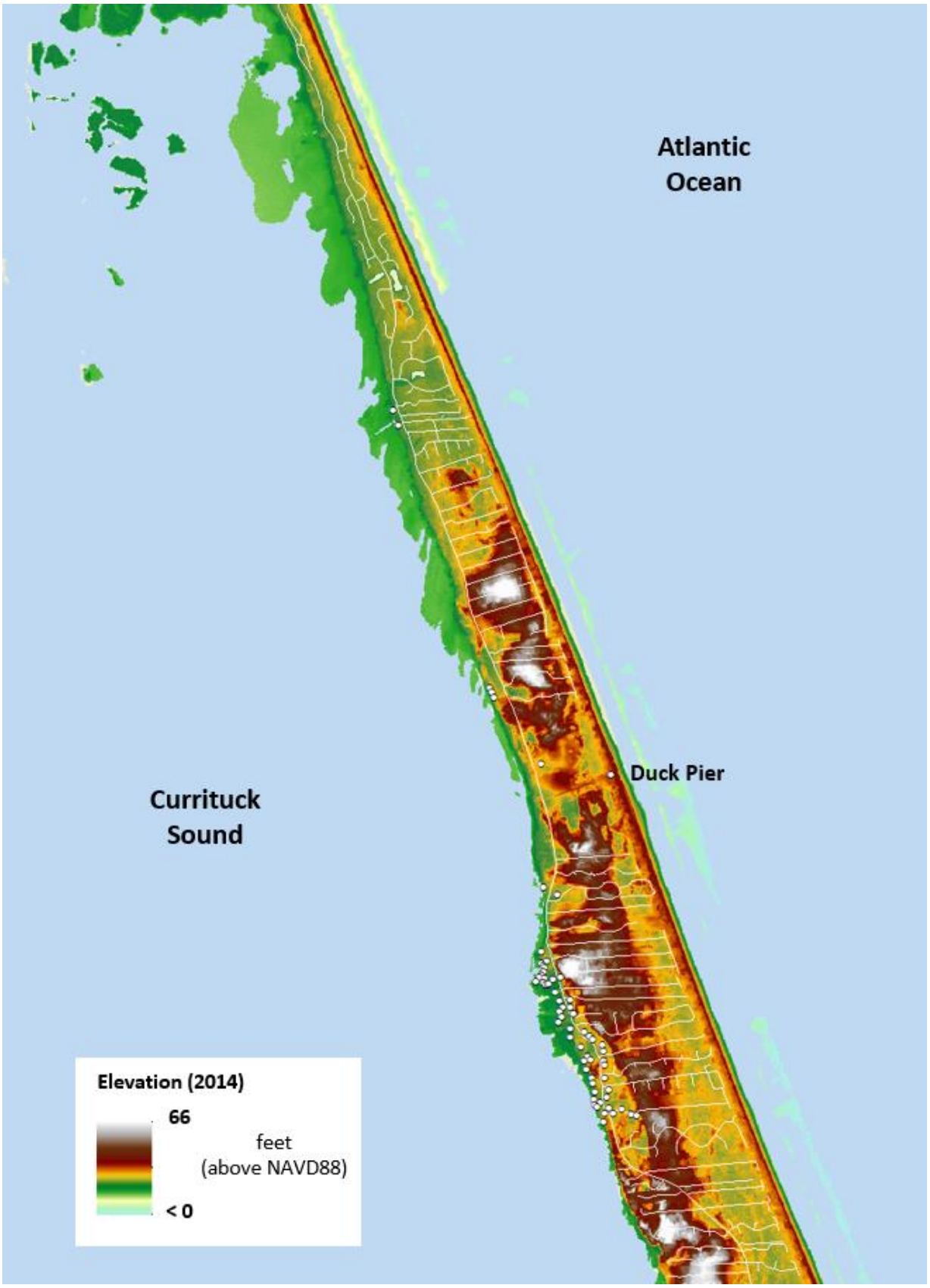

Figure 4. Digital elevation map of Duck with roads (white lines) and select buildings (white dots).

Sensitivity Results

The sensitivity results for buildings show that over one-quarter have either high or high-moderate sensitivity to coastal hazards (Table 4). Four of the evaluated buildings have the highest sensitivity rank, including Beach Realty, Barrier Island Shoppes, Tommy's Natural Foods Market & Wine Shop, and Bob's Bait & Tackle. All of these buildings have a high sensitivity to storm surge inundation, largely due to lower first floor elevations. Almost 40% of buildings have a moderate sensitivity, while approximately one-third have a low-moderate or low sensitivity. The lowest sensitivity buildings are the Village Table & Tavern/Nor'Banks Sailing & Watersports, Ocean Atlantic Rentals, and Aqua. For roads in Duck, only the protective engineering factor was applicable for sensitivity, and therefore is not scored separately.

Table 4. Sensitivity results for evaluated buildings in Duck.

Sensitivity Rank	# buildings	% all buildings
High	4	6.2%
High-Moderate	13	20.0%
Moderate	25	38.5%
Low-Moderate	20	30.8%
Low	3	4.6%
Minimal	0	0.0%

Vulnerability Results

The three highest vulnerability buildings evaluated in Duck are Beach Realty, Sunset Grill & Raw Bar, and Kitty Hawk Surf Company. An additional 20 buildings (31%) have high-moderate vulnerability (Table 5, Figures 5-7). The parcels containing high or high-moderate buildings have an estimated value over $24 million, while the associated buildings have an estimated value over $10.5 million. Over 30% of the evaluated buildings have moderate vulnerability. An additional 21 buildings (32%) have low-moderate vulnerability, while the lowest vulnerability building evaluated in Duck is Ocean Atlantic Rentals (Table 5, Figures 5-7).

Table 5. Vulnerability results for evaluated buildings and road segments in Duck.

Vulnerability Rank	# buildings	% all buildings	# road segments	length (miles)	% total road length
High	3	4.6%	1	0.06	0.2%
High-Moderate	20	30.8%	6	1.04	3.3%
Moderate	20	30.8%	34	2.60	8.2%
Low-Moderate	21	32.3%	141	13.65	43.2%
Low	1	1.5%	29	7.31	23.1%
Minimal	0	0.0%	97	6.96	22.0%

The highest vulnerability road segment in Duck is the portion of Duck Road (NC HWY 12) between Sea Colony Drive and Dune Road, north of the Waterfront Shops (Figure 6). This ~340-foot segment of road is within 25 feet of the shoreline, and is in a low-lying area that is easily flooded. Minor protective engineering (e.g., rip-rap) has been installed along a portion of this road segment. An additional 6 road segments have high-moderate vulnerability. These are primarily portions of Duck Road, including: 1) 2 contiguous segments north of Station Bay Drive, 2) the segment between Oyster Catcher Lane and Ocean Pines Drive, 3) the segment between Olde Duck Road and Sea Colony Drive, and 4) the segment between Cook Drive and Marlin Drive (Figures 5 & 7). The high-moderate vulnerability road segments total just over 1 mile in length. In total, 2.60 miles of road have moderate vulnerability, 13.65 miles of road have low-moderate vulnerability, and 7.31 miles have low vulnerability (Table 5). Nearly 7 miles of road in Duck have minimal vulnerability to coastal hazards (due to lack of exposure).

Road segments were also categorized into primary, secondary, and tertiary roads (Table 6). Just over one mile of Duck Road (the only primary road) has high or high-moderate vulnerability to coastal hazards, particularly where portions of this main highway cross low-lying areas and/or are in close proximity to Currituck Sound. Most the secondary and tertiary roads have low-moderate or lower vulnerability, as most branch off from Duck Road and generally run east-west across the higher elevation portions of island (Figure 4).

Table 6. Vulnerability results for primary, secondary, and tertiary roads in Duck.

Vulnerability Rank	primary* roads (miles)	secondary roads (miles)	tertiary roads (miles)
High	0.06	0.00	0.00
High-Moderate	1.02	0.02	0.00
Moderate	0.40	1.72	0.49
Low-Moderate	2.74	8.78	2.13
Low	0.88	4.92	1.51
Minimal	0.92	4.29	1.74

*Duck Road (NC HWY 12)

Vulnerability Assessment Caveats

1. This assessment analyzes the combined vulnerability of Duck to coastal hazards (e.g. flooding, storm surge, sea-level rise, and erosion). Therefore, a section of the town that has maximum exposure to one or more of these factors will inherently have a higher overall exposure, and thus, vulnerability. At the same time, some of the assets were given a lower vulnerability rank for the analyzed coastal hazards. This does not mean that these assets will not be affected by one, or more, of these hazards in the future, but instead, that the asset is not within the mapped hazard layers utilized (Table 1). It is important to note that on a barrier island, assets could be destroyed by a hurricane within any given year.
2. Approximately one mile of road in Duck has high or high-moderate vulnerability. However, these segments are primarily along Duck Road (NC HWY 12), which is the only road with a continuous north-south connection in the town. In fact, very few secondary roads (which run perpendicular to Duck Road) connect with each other, making detours unlikely.
3. For this study, all roads and a select subset of buildings were analyzed. If more buildings (e.g., residential) were included, the statistics would likely change substantially, as many are located in higher elevations portions of the island (see Figure 4). In addition, other commercial/public assets could be examined in the future, including parking lots, boardwalks, and recreational spaces.
4. Typically, hurricane risk planning focuses on a direct, shore-perpendicular, landfall from a major hurricane on the oceanfront. While this type of storm is a legitimate concern (particularly for oceanfront homeowners), a primary concern for the town commercial center is a hurricane that would produce sustained winds and surge from Currituck Sound. These are typically slow-moving storms that track more oblique to the coast, focusing the strongest winds onto the soundside shoreline.
5. As higher quality data become available for the components of vulnerability (exposure and sensitivity), the final rankings for these assets can be updated (and may change).

Figure 5. Coastal hazard vulnerability results for roads and select buildings in north Duck. Select assets are labeled.

Figure 6. Coastal hazard vulnerability results for roads and select buildings in central Duck. Select assets are labeled.

Figure 7. Coastal hazard vulnerability results for roads and select buildings in south Duck, near the town commercial center. Select assets are labeled.

Conclusions & Potential Adaptation

Compared to many barrier island communities, the Town of Duck has relatively low overall vulnerability. This is due to its unique coastal setting and significant interior elevation. The northern Outer Banks of North Carolina (which includes Duck) are northeast facing, and are sheltered from tropical storms by Cape Hatteras and various shoals to the south. This makes a direct hit from a tropical storm or hurricane much less likely. Rather, northward tracking storms tend to push water from the Currituck Sound towards the estuarine shoreline of Duck. Currituck Sound is much smaller than the neighboring Albemarle and Pamlico sounds, which reduces the amount of fetch (open water distance) available for producing large waves and surge. Duck also has significant elevation across the interior of the island, with relic dune heights up to 50 feet, and largely continuous oceanfront dunes up to 25 feet high (above sea level). Although Duck has these beneficial factors, there is still significant exposure to coastal hazards, primarily through coastal erosion on the oceanfront and flooding on the soundside. Winter nor'easters can also significantly impact this part of the coast, with erosion, flooding, and waves over multiple days.

The town commercial center of Duck is located on the soundside of the barrier island and, therefore, is sheltered from oceanfront processes and hazards. However, due to low elevations and shoreline retreat (from loss of wetlands and marsh), much of the infrastructure on the soundside is exposed to flooding, erosion, and sea-level rise. This is particularly true where infrastructure is close to the shoreline. High exposure to these hazards is concentrated in several areas (e.g., portions of Duck Road near the water, the Waterfront Shops, and roads in the far north where the island is narrow). Because Duck Road (NC HWY 12) is the only road with a continuous north-south connection, it is the most critical transportation corridor in Duck. The high vulnerability along several segments of this critical road has significant impacts for the entire town, as well as communities to the north.

This study focused solely on the public and commercial infrastructure of the town, therefore, the preliminary adaptation recommendations relate only to the soundside (Currituck) shoreline. To address the transportation concerns, it is recommended that the town develop a long-term transportation plan that considers relocation and/or elevation of the highest vulnerability segments of Duck Road. To address the vulnerability of infrastructure along the soundside shoreline, it is also recommended that the town consider strategies that restore or slow the loss of marshes and wetlands. These strategies should focus initially on the establishment of living shorelines. There are several locations where artificial access channels were created through the marsh, which may no longer be necessary (e.g., north of Kitty Hawk Kites and south of Kitty Hawk Surf Co.). Strategies could be implemented that close, restore, and/or preserve these sections of marsh, reducing the vulnerability of nearby infrastructure.

The vulnerability of existing structures in Duck can be reduced through two primary adaptation measures: elevation (raising the level of the first finished floor) and/or relocation (moving the structure). Elevating a building's first floor above potential flood levels reduces its sensitivity, by lowering the likelihood of damage during a storm event. Relocating a building to a less exposed location (e.g., higher ground or further from the water) reduces its exposure, by lowering the likelihood of being impacted by coastal hazards. It is also important to consider reducing the vulnerability of any associated utilities, including coordinating with utility providers on the development and installation of more resilient infrastructure. While these adaptation actions may not always be practical, they are important to consider, as they are the most efficient way to decrease the vulnerability and increase the resiliency of existing infrastructure. These adaptation options should certainly be considered following storms when funds may become available for resilience actions.

In addition to considering adaptation measures on existing infrastructure, it is also vital to increase the resilience of any future development in Duck. The safest bet is to place new infrastructure in areas that have minimal exposure to hazards. When that is not possible, adopting higher standards for building elevation and construction can lead to more sustainable infrastructure over the long term. Many communities have recently implemented stricter local standards for building elevation, such as increasing the required freeboard (how many feet a building's lowest floor is above BFE) in a flood zone to 3 feet or higher. Along much of the soundside portion of Duck, the BFE in the proposed FEMA flood zone (the AE or 100-year flood) is only 4 feet (above the NAVD88 datum, which is approximately mean sea-level), and most of the evaluated commercial buildings are already elevated above this value. However, NOAA's SLOSH model for a category 3 hurricane shows surge along this portion of the shoreline could be much higher, up 7 to 8 feet above the ground. Therefore, it is recommended that future building elevation guidelines consider these additional data sources. Increasing the requirements for elevating buildings could significantly lower the risk of flooding and damage from future storms. We consider the proposed FEMA BFE to be a minimum value and recommend that some freeboard become standard practice for future construction.

Appendices

Table A1. List of commercial, professional, retail, and publicly-owned buildings evaluated in Duck. Buildings are listed generally from north to south.

#	Building Name	Exposure	Sensitivity	Vulnerability
1	Beach Realty	high-moderate	high	high
2	North Duck Watersports	high-moderate	low-moderate	moderate
3	Sun Realty	low-moderate	low-moderate	low-moderate
4	Village Table/Nor' Banks Sailing & Watersports	low-moderate	low	low-moderate
5	Watersports Outbuildings	moderate	low-moderate	moderate
6	Duck Fire Station	low	moderate	low-moderate
7	USACE – Field Research Facility	low	low-moderate	low-moderate
8	Sunset Grill & Raw Bar	high	high-moderate	high
9	Barrier Island Shoppes	low	high	moderate
10	Resort Realty	high	moderate	high-moderate
11	Tommy's Natural Foods Market & Wine Shop	low-moderate	high	high-moderate
12	Blue Point	high	moderate	high-moderate
13	Barr-EE Station	high	moderate	high-moderate
14	Donna Designs	high	moderate	high-moderate
15	Sunset Ice Cream	high	moderate	high-moderate
16	Designs Amity	high	moderate	high-moderate
17	Outer Banks Olive Oil Company	high	moderate	high-moderate
18	Coastal Cantina	high	moderate	high-moderate
19	Duck's Cottage	high-moderate	high-moderate	high-moderate
20	Kayak Corolla Outerbank Adventures	high-moderate	moderate	high-moderate
21	Zen & Zip, Yoga	high-moderate	moderate	high-moderate
22	Islands	high-moderate	low-moderate	moderate
23	Allie June	high-moderate	low-moderate	moderate
24	Stan White Realty	high-moderate	moderate	high-moderate
25	Duck Deli	low	moderate	low-moderate
26	Water Tower	high-moderate	high-moderate	high-moderate
27	Kitty Hawk Kites	high-moderate	high-moderate	high-moderate
28	Brindley Beach Realty	low	low-moderate	low-moderate
29	Life is Good	moderate	moderate	moderate
30	Wee Winks Market and Deli	low-moderate	moderate	moderate
31	Kitty Hawk Surf Co	high	high-moderate	high

Table A1. Continued

#	Building Name	Exposure	Sensitivity	Vulnerability
32	ABC Store	low-moderate	moderate	moderate
33	Dockside N' Duck	high-moderate	high-moderate	high-moderate
34	Donuts on Stick	high-moderate	high-moderate	high-moderate
35	Duck United Methodist Church	high-moderate	low-moderate	moderate
36	Nags Head Hammocks	high-moderate	low-moderate	moderate
37	BP Gas Station/Coastal Cravings	low	high-moderate	moderate
38	Duck Village Outfitters	low	moderate	low-moderate
39	PNC Bank	low	low-moderate	low-moderate
40	Kellogg Supply Company	low	low-moderate	low-moderate
41	Town Hall Garage	low	low-moderate	low-moderate
42	Red Sky Café/Carolina Designs Realty	low	low-moderate	low-moderate
43	Town Hall/Keller Meeting Hall	moderate	moderate	moderate
44	Town Hall Pavilion	low	low-moderate	low-moderate
45	Town Hall Picnic Shelter	moderate	moderate	moderate
46	Roadside Bar & Grill	low	high-moderate	moderate
47	Loblolly Pines Shopping Center/US Post Office	low	high-moderate	moderate
48	Town Hall Amphitheater	low	moderate	low-moderate
49	Ocean Atlantic Rentals	low	low	low
50	Cotton Gin	low	moderate	low-moderate
51	Osprey Landing Shopping Center	high-moderate	low-moderate	moderate
52	Twiddy & Company Realty	low	low-moderate	low-moderate
53	Super Wings	moderate	moderate	moderate
54	Scarborough Faire Shopping Village	low	high-moderate	moderate
55	NC Coast Restaurant	high-moderate	low-moderate	moderate
56	Bob's Bait & Tackle	moderate	high	high-moderate
57	Seagreen Gallery & Plum Crazy	high-moderate	high-moderate	high-moderate
58	Farmers Daughters	high-moderate	moderate	high-moderate
59	Scarborough Lane Shoppes	low	low-moderate	low-moderate
60	Costin Creations	low	low-moderate	low-moderate
61	Outer Banks Surf	low	low-moderate	low-moderate
62	Urban Cottage	low	high-moderate	moderate
63	Finch Construction	low	moderate	low-moderate
64	Twiddy Realty Maintenance	low	moderate	low-moderate
65	Aqua	moderate	low	low-moderate

Table A2. Vulnerability of roads in Duck, in feet.

Road Name	High	High-Mod	Mod	Low-Mod	Low	Minimal
ABRON CT						163
ACORN OAK AVE			652	734		
ALGONKIAN CT						93
AMY LN						306
ARROWHEAD CT						84
AZALEA CT				187		
BALDPATE DR						315
BARRIER ISLAND STATION				964	1,822	2,003
BAUM TRL		93		667		
BAYBERRY DR					1,963	
BEACHCOMBER CT						445
BETSY CT						260
BIAS DR					469	946
BIAS LN				1,207		
BLUE HERON LN				648		
BRANDON CT						152
BUFFELL HEAD RD				1,696	867	
BUNTING LN			99	666		
BUNTING WAY				377		
CANVAS BACK DR						1,424
CARROL DR			555	1,089		
CEDAR DR				291		
CHARLES JENKINS LN				1,161	1,845	
CHEROKEE CT				179		
CHIP CT						519
CHOCTAW CT						200
CHRISTOPHER DR				341	336	1,675
CLAY ST				493		
COFIELD CT						161
COOK DR					2,674	
CYPRESS DR				352		
DIANNE ST				290	587	544
DOCKS CT				211		
DUCK HUNT CLUB LN				893		
DUCK LANDING LN					2,423	
DUCK RD (NC HWY 12)	338	5,380	2,089	14,462	4,623	4,874
DUCK RIDGE VILLAGE CT				673		
DUNE RD				2,627		
DUNES CREST						245
ELM DR				178		
FAWN CT						168
FLIGHT DR			1,447			
FORESAIL CT						58
FOUR SEASONS LN			688	1,440	559	1,173
FRAZIER CT				91		
GANNET CV				235		
GANNET LN			454	211		
GEORGETOWN SANDS RD				1,678		

Table A2. Continued

Road Name	High	High-Mod	Mod	Low-Mod	Low	Minimal
GIFFORD CIR						516
HALYARD CT				456		
HATCH COVER CT						345
HILLSIDE CT				155		
JASMINE CT						137
JAY CREST RD						1,857
LALA CT			161			
LONE WAY				147		
MAGNOLIA CT				221		
MAINSAIL CT						62
MALLARD CT						441
MALLARD DR				1,584		
MANTOAC CT				214		
MAPLE DR				237		
MARLIN CT				278		
MARLIN DR					2,604	
MARTIN LN			911	178		
N BAUM TRL				759		
NASH RD						373
NOR BANKS DR					793	736
OCEAN BAY BLVD			683	858		
OCEAN CREST WAY			383			
OCEAN FRONT DR				745		
OCEAN PINES DR			1,517			
OCEAN WAY			616			
OCEAN WAY CT			495			
OLD SQUAW DR				1,385		
OLDE DUCK RD				2,356		
OSPREY RIDGE RD						1,044
OYSTER CATCHER LN			519	851		
PAMELA CT						231
PELICAN WAY				593		
PINTAIL DR						1,523
PLOVER DR				2,721		
POTESKEET DR				660		1,942
PUFFER CT						31
QUAIL WAY			738			
QUARTERDECK DR				393		
RAKIOCK CT						85
RENE CT				121		
ROCKFISH LN						301
ROYAL TERN LN				460		
RUDDY DUCK LN				718		
SAILFISH CT				30		
SANDCASTLE CT						148
SANDPIPER CV				216		
SANDY RIDGE RD					1,673	
SCARBOROUGH LN					2,701	

Table A2. Continued

Road Name	High	High-Mod	Mod	Low-Mod	Low	Minimal
SCHOONER RIDGE DR					4,348	365
SEA COLONY DR				2,075		
SEA EIDER CT			197			
SEA HAWK CT			234			
SEA HAWK DR				1,468	1,447	
SEA HAWK DR E			191			
SEA TERN DR					1,502	
SEABREEZE DR			255	1,697		
SETTLERS LN						895
SHEARWATER WAY			418			
SHELDRAKE CT						124
SHIPS WATCH DR				835		1,140
SHIPS WHEEL CT						537
SKIMMER WAY			287	1,898		
SNIPE CT						58
SNOW GEESE DR				481	3,199	
SOUND SEA AVE				1,435		
SPECKLE TROUT DR				1,018		
SPINDRIFT CT				152		
SPINDRIFT LN						633
SPINNAKER CT				156		49
SPRIGTAIL DR					1,383	
SPYGLASS RD					763	900
STATION BAY DR				1,059		
SUNFISH CT						61
SUNFLOWER CT				218		
TERESA CT				267		
THRUSH CT			151			
TIDES DR				1,002		
TOPSAIL CT						66
TRINITIE DR				1,309		
TUCKAHOE DR				1,218		1,839
TURNBUCKLE CT						280
UPPOWOC CT						88
VICTORIA CT						271
VIREO WAY				661		
VIVIAN CT				192		
WAMPUM DR				2,757		
WAXWING CT				398		
WAXWING LN				891		
WHISTLING SWAN DR						368
WIDGEON DR						1,509
WILLOW DR				309		
WINAUK CT						189
WINDSURFER CT						143
WIROANS CT						143
WOOD DUCK DR						1,500
YOLANDA TERR				211		