

Coastal Engineering Services for QuickReef® Product Development & Enhancement

Summary of Findings Report

September 2025

Prepared For:



Prepared By:



2251 Drusilla Lane Suite D | Baton Rouge, LA 70809

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1.0 INTRODUCTION

Native Shorelines, A Davey Company, has deployed QuickReef® throughout North Carolina to slow marsh erosion rates for various landowners. Native Shorelines has permitted and constructed nearly 4 miles of living shorelines at over 100 properties, many of these in coordination with the North Carolina Coastal Federation and partially funded by state and federal grants. Based on visual inspections, QuickReef® technology has been effective in reducing erosion and in oyster spat recruitment on the structures.

While qualitative results can be telling, Native Shorelines recognized the need for more quantitative, process-based results. In November of 2023, Native Shorelines, retained Southern Shores Engineering, LLC (SSE) to provide coastal engineering services for the continued development & enhancement of their patented QuickReef® Product. More specifically, the goals of the study are to evaluate all four (4) QuickReef® design variations with respect to overall stability and wave attenuation performance. Additionally, SSE recommended aerial survey scans of existing QuickReef® deployments over time to quantify oyster spat recruitment and structure development/growth. SSE proposed to conduct the following tasks in support of quantifying these characteristics:

1. Coastal Engineering Analyses – Desktop Study & Final Report
2. Wave Flume Study Support Services – Coordination and Oversight
3. Standard Plans & Specifications Development
4. FLOW-3D Modeling – CFD Validation
5. Wave Gauge Deployment & Analysis
6. Aerial Surveying Services (McKim & Creed) – Oyster Spat Recruitment & Growth – Marsh Edge Position

This summary of findings document, in accordance with the proposal submitted by SSE dated October 31st, 2023 (Revised November 15th, 2023), is intended to provide a detailed overview of the work and analyses performed in completing this study as well as a quantitative review of results. This report will also go on to provide recommendations based on the findings described herein.

2.0 COASTAL ENGINEERING ANALYSES

The first stage of the analysis entailed a desktop study and literature review where available nautical, current, wind, wave, and tidal data near existing deployments were documented. Additionally, all existing QuickReef® deployments were identified and mapped for consideration.

2.1 Existing QuickReef® Deployments

Many existing deployments are in North Carolina, which can be generally characterized as a semi-diurnal (2 high tides and two low tides per day), high micro-tidal to low meso-tidal regime. SSE evaluated existing QuickReef® deployment sites in North Carolina to identify three (3) representative sample locations. The following characteristics were evaluated when selecting representative sites: QuickReef® design variation, goals/monitoring details, project life, oyster growth, effective fetch lengths, wave climates/water levels, boat traffic, and shoreline orientation, as well as any available survey data at project sites.

2.2 Tidal Datum Analysis

Tidal datums were calculated based on available water level data from nearby NOAA tide gauges. Gauges were evaluated for proximity to QuickReef® installments and the amount of data available. Approximately four (4) gauge locations along the North Carolina coast were utilized including Wrightsville Beach (8658163), Wilmington (8658120), Beaufort, Duke Marine Lab (8656483), and USCG Station Hatteras (8654467). **Figure 1** below displays the locations of each NOAA gauge evaluated in relation to QuickReef® installments.

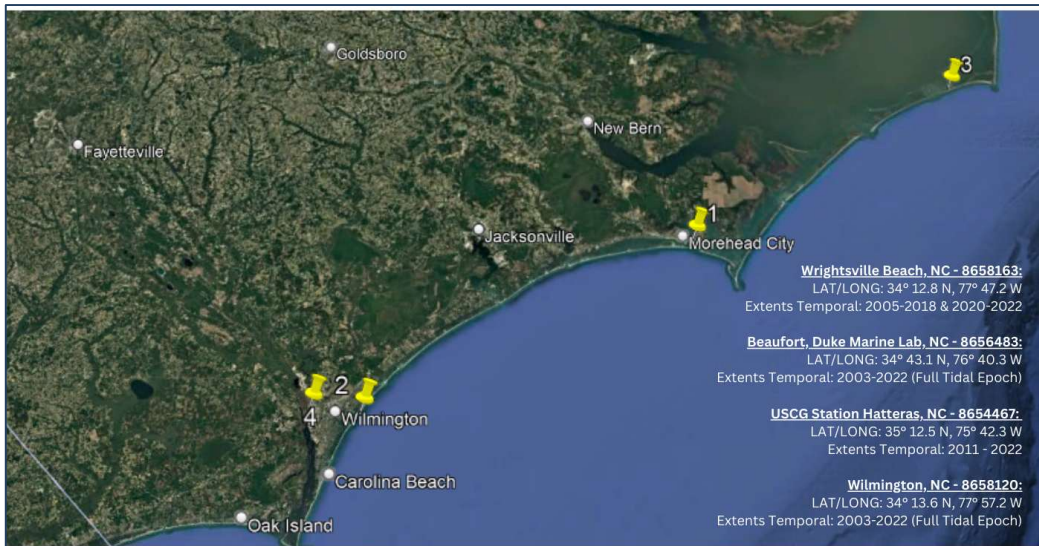


Figure 1: NOAA Tide Stations

Both the Wilmington and Duke Marine Lab stations have collected a full 19 year of tidal data epoch (2003-2022); however, the Wrightsville Beach and USCG Hatteras Stations did not have a full 19 years of recent data. Therefore, analyses were performed using the Wilmington and Duke Marine Lab gauges as control stations in an effort to correlate the partial stations to a full 19-year tidal epoch using the modified-range ratio method (NOAA, 2003) and internally developed tide discretization programs.

Upon further investigation, the team decided to solely use the Duke Marine Lab gauge for tidal datum definitions moving forward considering the wind and tide data availability and proximity to deployment locations. The tidal datum definitions are presented in **Table 1**.

Table 1: Tidal Datum Definition

NAVD88 (GEOID18)	
MHW ₌	1.77
MLW ₌	-1.81
MTL ₌	-0.02
R ₌	3.59

2.3 Wind Data & Wave Estimation

The vast majority of QR deployments are situated within sounds and estuaries, sheltering them from the Atlantic swells. However, sustained winds over large water bodies generate waves capable of impacting the adjacent shoreline and any structures that may protect it. These wind-generated waves tend to be irregular in shape/size and typically consist of shorter wave lengths and periods. The cumulative persistence of these waves can result in a net retreat of the marsh edge, particularly during extreme events. Therefore, it is crucial to determine design wave heights and periods that most accurately depict a critical combination of forces on the structure for evaluation purposes (EM 1110-2-1614). In the evaluation of any shoreline protection feature where nearby wave data is limited, wind-data and water depths can be used to reasonably predict wave climates with respect to significant heights. Where applicable, SSE engineers will evaluate the wind data to derive and translate waves in the onshore direction. Part of this process includes identifying effective fetch scenarios. Wave characteristics are determined for deep water and analytically propagated landward to the structure locations. This analysis allows engineers to determine theoretical wave forces during different stages of a tidal cycle and ultimately yield insight to the optimal structure design height, with consideration given to optimal elevation for oyster sustainability. Wind data was analyzed from the Duke Beaufort Marine Lab Station and is shown as a wind rose in **Figure 2**.

This desktop engineering study will also allow us to evaluate various wave/ water level scenarios using empirical formulas from the USACE Coastal Engineering Manual (CEM) to theoretically evaluate structural stability. The structure will be analyzed as a whole instead of by individual units. The University of South Alabama (USA) performed the flume setup and study with oversight & input from SSE; scaling was performed by USA with input from SSE. To summarize, the desktop study provided necessary information for model scaling (Wave Flume Study), wave forcing conditions (Wave Flume Study & Empirical Analyses) and determining ideal test sites and conditions (Field Operations).

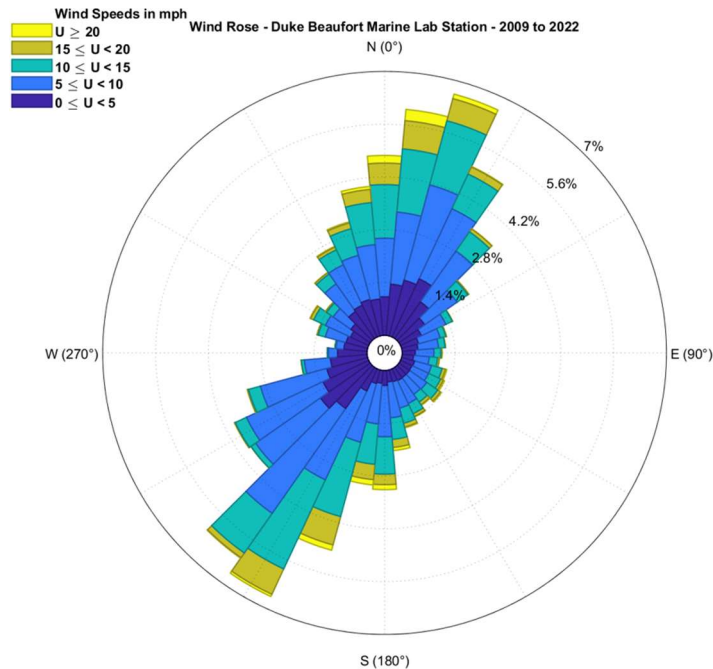


Figure 2: Wind Rose Analysis – Duke Beaufort Marine Station

3.0 PHYSICAL MODEL – USA FLUME STUDY

The flume testing and report were completed by Dr. Bret Webb at the University of South Alabama (USA). The final report describes the results of reduced scale physical experiments to evaluate the performance and hydrodynamic stability of QuickReef® products. Experiments were carried out in the University of South Alabama’s Large Wave Flume (LWF) facility within the Center for Applied Coastal Engineering and Science. A brief description of the flume dimensions and methodology will be described in the following sections. However, it is recommended that the reader reference the QuickReef® testing report (ACES-24-003) for more details of the flume study.

3.1 Flume Specifications

Flume details are shown below in **Figure 3** and **Table 2**.

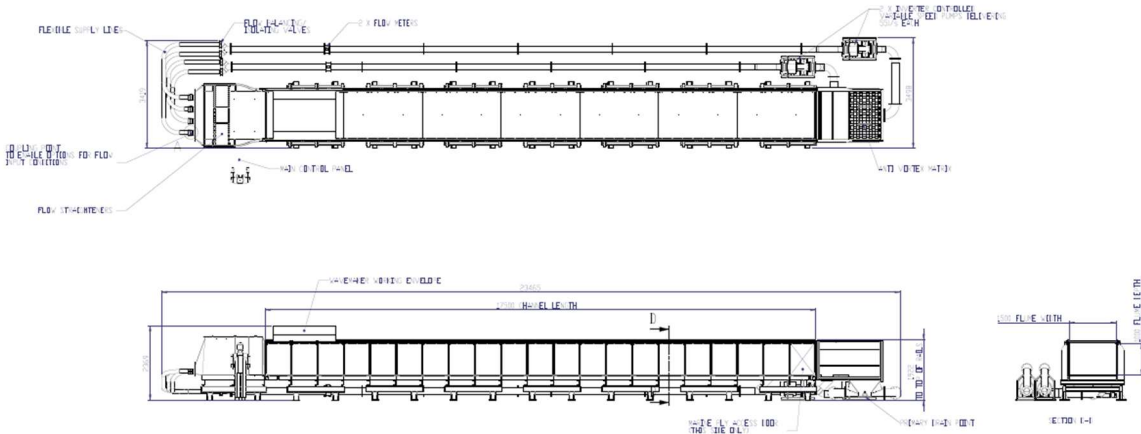


Figure 3: USA Large Wave Flume Details

Table 2: USA Flume Details

width	= 1.5	<i>meters</i>
length	= 22.7	<i>meters</i>
test length	= 17.5	<i>meters</i>
depth	= 1	<i>meters</i>
tank capacity	= 9000	<i>gallons</i>
wave height capacity	= 0.4	<i>meters (greater than)</i>
wave period	= 0.5	<i>(0.5 to 5) seconds</i>
flow rate capacity	= 110	<i>(up to) liters/sec</i>
d50 (well-sorted coarse sediment)	= 0.3	<i>millimeters</i>

3.2 Methodology & Parameters

Most testing setups included experiments with five different water depths and up to seven distinct wave conditions. With one exception, all wave conditions were monochromatic. Each experiment was conducted in triplicate, labeled a, b, and c. A total of 309 tests were completed: 96 tests each for the 24x80 and Defender™ models, 105 tests for the 21x60 model with a cap, and only 12 tests for the 21x60 model without a cap. Test durations were generally 60 seconds, except for irregular wave scenarios, which lasted more than 180 seconds.

The selection of water levels and wave conditions were chosen to represent a range of typical tidal, meteorological, and vessel wake scenarios. The testing did not focus on extreme events, although some combinations of higher water levels and wave heights may resemble mild storm conditions at certain locations.

Water levels were selected relative to the crest of each structure to reflect typical tidal datums in North Carolina. For the 24x80 and Defender™ models, tests were conducted at two water levels below the crest, one level at the crest, and two levels above the crest. Due to its smaller vertical profile, the 21x60 model was tested with only one water level above the crest, one at the crest, and three below the crest.

3.3 Product Scaling (Flume)

Final model scale ratios were determined based on a combination of model geometry, tank dimensions, and Froude scaling principles. The 24x80 structure was scaled down to 60% of its original size, giving a model-to-prototype ratio of 1:1.67. The Defender™ model was reduced to 33%, resulting in a 1:3.03 scale, while the 21x60 model was scaled by 50%, corresponding to a 1:2 ratio. This 1:2 scale was applied to both the capped and uncapped versions of the 21x60 model.

Figure 5

Froude scaling was used to convert real-world (prototype) tidal levels, wave heights, and wave periods to appropriate model values for testing in the Large Wave Flume (LWF). As a result, the simulated water levels and wave conditions reflect typical and minor storm events commonly encountered in actual deployments. **Figure 4** shows the scaled STL renderings of the Defender product tested. Please reference Appendix A for all drawings.

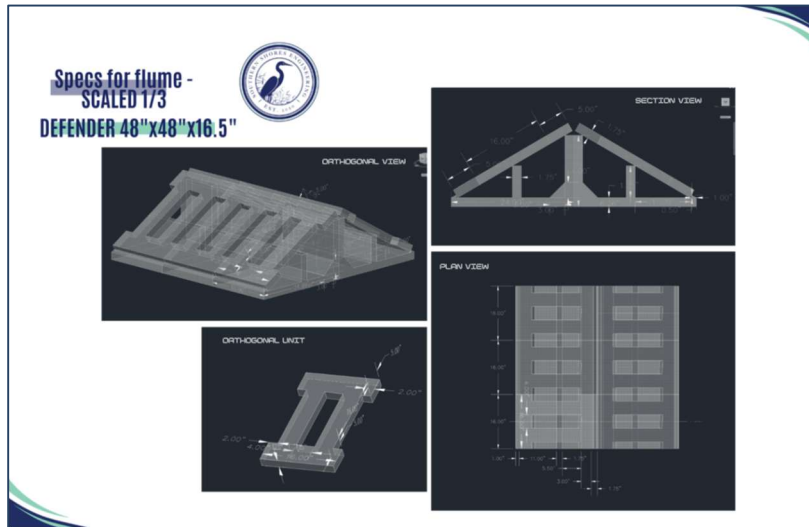


Figure 4: Defender Specs for Flume

3.4 Results Summary

The wave-reducing performance of the 24x80 and Defender™ structures is closely tied to their relative freeboard—the ratio of freeboard to wave height. For these models, wave transmission coefficients could be predicted reasonably well using simple exponential equations, with prediction errors averaging about 15% of actual measured values. In contrast, the capped 21x60 structure behaved differently: while its wave transmission still correlated with freeboard, transmission actually increased as freeboard increased. This unexpected trend may have been caused by wave leakage around the structure ends or overtopping due to runup amplified by the cap on the model.

For all QuickReef® products, wave reflection coefficients were generally comparable to—or lower than—those typical of rubble mound structures. Reflection tended to be higher when the water level was below the crest of the structure and lower when it was above. Reflections were influenced by both the water depth (i.e., freeboard) and the wave steepness, which aligns with expected behavior for low-crested structures, although this relationship needed to be quantified.

Although some QuickReef® panels were fitted with accelerometers to monitor motion, very little movement was detected during testing. The small amounts of acceleration and rotation observed were likely due to minor instabilities in the physical model setup, such as protruding aggregate pieces that allowed the panel to rock slightly.

4.0 COMPUTATIONAL FLUID DYNAMICS (CFD) MODELING

FLOW-3D HYDRO is a commercial CFD software tailored for simulating fluid flows in various engineered and natural environments. CFD is the process of mathematically predicting physical fluid flows by simultaneously solving empirical equations using computational power. Based on recent industry studies, CFD is considered to be a fast and reliable alternative to physical modeling when evaluating complex hydrodynamics at varying scales (Carter et. Al – Biloxi Marsh). For this study, a CFD based approach was utilized for estimating wave transmission through QR's Defender products for a variety of wave and water level scenarios. Essentially, FLOW-3D was recommended due to its ability to function as a numerical laboratory, which will allow Native Shorelines flexibility in adjusting future product designs without conducting more physical modeling.

4.1 Study Background

FLOW-3D simulations were developed to mimic the physical setup of the USA wave flume. Therefore, the simulations consisted of scaled QR products and wave/water-level scenarios. A total of two (2) FLOW-3D models were developed for each QuickReef® Defender design variation (48" & 36"). Each of these models contained 8 (eight) simulations with varying hydraulic conditions for a total of 16 simulations. Please note that all modeling dimensions will be presented in meters as opposed to SI units. Both model structures were drawn three dimensionally in AutoCAD by SSE personnel based on sketches provided by Native Shorelines and inserted into each FLOW-3D model as a .STL file. Model configuration, calibration, and parameter selection included insight from the physical modeling study, in an effort to match the initial conditions to the extent possible.

4.2 Study Goals

The overall study intent was to develop a model capable of replicating similar waves, currents, and water levels observed during the desktop study (and scaled for the flume study) for evaluating wave transmission through the QR products. Wave transmissivity is typically characterized by the transmission coefficient (Kt), which can be defined as the ratio of the transmitted and incident wave

heights. It is typical for the transmission coefficient of low crested structures to decrease with increasing water levels, and this was a prevailing trend observed during the USA physical study as well.

4.3 Product Scaling

A total of two (2) FLOW-3D models were developed for each QuickReef® Defender design variation (48" & 36"). Each of these products were reduced at a 1/3 scale to facilitate placement into the flume-like domain. See **Figure 4** and **Figure 5** below for the model and prototype Defender renderings.

4.4 Model Set-Up

The model domain was developed using the USA flume specifications displayed in **Table 2** referenced in Section 3. The domain was constructed to be 22.7 meters in length, 1.5 meters in width, and 1.0 meter in height. The model was scaled and set up to emulate the target structure installation depth for the Bogue Sound sites (approximately 2 ft at MTL). The Defenders were arranged in the model in such a way as to ensure at least one complete QuickReef® unit was within the domain limits. The flume bottom was constructed of well-graded coarse sediment (d50 value set to 0.3 millimeters – medium sand) with a mildly increasing slope in the wave propagation direction. A back-barrier berm made up of the same sediment was also constructed to emulate wave dissipation and reflection observed in the flume. The model domain was developed to include these sand features as well. Additionally, the wave source was created by adding an object (block) with prescribed motion in the wave propagation direction. The block was situated in a way that protruded the lateral extents of the flume to ensure a water seal at all points of contact.

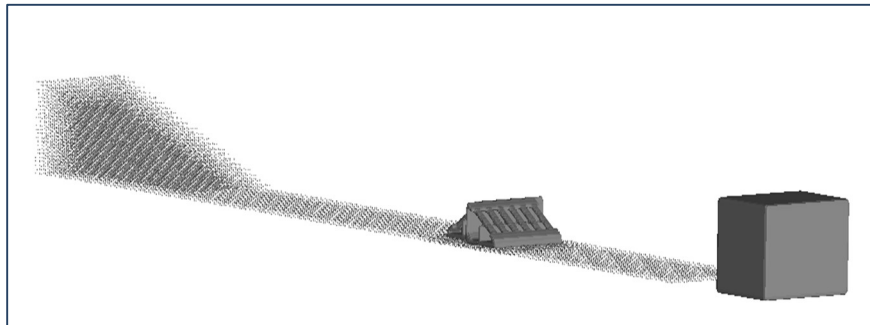


Figure 5: Defender Model Setup

There were a total of three grids developed that encompassed the model setup. The largest of the grids extended the entire model domain and consisted of a coarser mesh than that of the other two. A second grid was developed at the face of the oscillating block with a somewhat finer mesh to further resolve the fluid structure interaction at wave generation. The final grid also consisted of a considerably finer mesh due to the complexities of the fluid- wave attenuation structure interaction at this location.

Figure 6 below displays the model grids and their respective mesh sizes and locations. Meshes are shown in blue, and labeled S for the fine mesh at the structure and W for larger meshes further from the modeled structure.

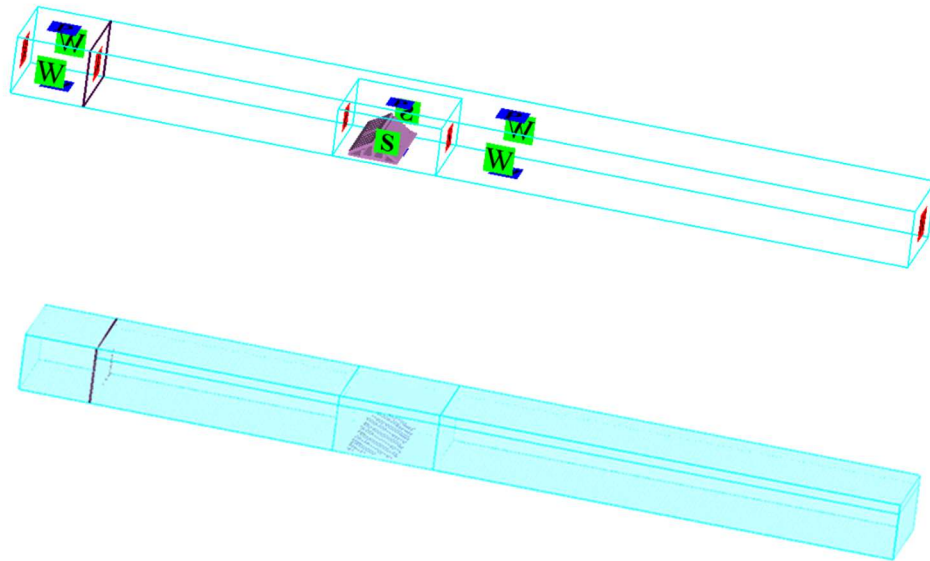


Figure 6: View of Grid Block Development

Figure 7 shows the eight (8) probes inserted in the domain at strategic locations along the center of the flume just above the sandy bed; four (4) probes in front of the structure and four (4) probes at the leeward side of the structure. These probes were set to record water levels throughout the duration of the simulation. This setup reflected the physical model probe configuration.

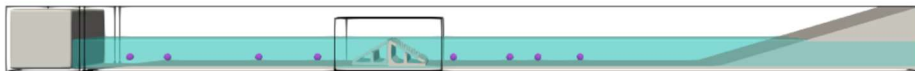


Figure 7: Probe Setup and Locations

4.5 Water Level & Wave Cases

Table 3 shows water level and wave cases from the physical modeling study that were selected for numerical modeling. Water and wave cases were selected to mimic conditions that were selected for testing during the physical model. Due to variations in the modeled oscillating block and the wave maker at the physical model, wave and water level cases did not match exactly but are representative of the cases observed during physical modeling.

Table 3: Water Level and Wave Cases – Model vs. Prototype

Defender™ Case Name	MODEL SCALE			PROTOTYPE SCALE		
	Tank Depth (mm)	T0 (s)	H0 (mm)	Tank Depth (mm)	T0 (s)	H0 (mm)
A1	280	1.49	88.00	848	2.59	266.67
A2	280	0.90	28.00	848	1.57	84.85
A3	280	1.12	34.00	848	1.95	103.03
A7	280	2.01	38.00	848	3.50	115.15
B1	375	0.89	50.00	1136	1.55	151.52
B2	375	2.01	50.00	1136	3.50	151.52
B3	375	0.90	66.00	1136	1.57	200.00
B4	375	1.11	66.00	1136	1.93	200.00
B5	375	1.41	88.00	1136	2.45	266.67
B6	375	1.73	88.00	1136	3.01	266.67
B7	375	2.01	112.00	1136	3.50	339.39
D1	480	0.89	112.00	1455	1.55	339.39
D2	480	1.42	112.00	1455	2.47	339.39
D3	480	1.12	122.00	1455	1.95	369.70
D4	480	1.42	122.00	1455	2.47	369.70
D5	480	1.12	134.00	1455	1.95	406.06
D6	480	1.42	134.00	1455	2.47	406.06
D7	480	2.01	134.00	1455	3.50	406.06
E1	585	1.12	138.00	1773	1.95	418.18
E2	585	1.42	138.00	1773	2.47	418.18
E3	585	1.12	134.00	1773	1.95	406.06
E4	585	1.42	134.00	1773	2.47	406.06
E5	585	1.12	122.00	1773	1.95	369.70
E6	585	1.42	112.00	1773	2.47	339.39
E7	585	2.01	112.00	1773	3.50	339.39
F1	682	1.12	138.00	2067	1.95	418.18
F2	682	1.42	138.00	2067	2.47	418.18
F3	682	1.12	134.00	2067	1.95	406.06
F4	682	1.42	134.00	2067	2.47	406.06
F5	682	1.12	122.00	2067	1.95	369.70
F6	682	1.42	112.00	2067	2.47	339.39
F7	682	2.01	112.00	2067	3.50	339.39

4.6 Summary of Results

Wave energy reduction was calculated as the ratio of the transmitted wave height squared to the incident wave height squared. FLOW-3D model runs yielded similar results to that of the flume study. All designs tested performed well maintaining 50% or less wave energy transmission under design conditions. Figure 8 shows an example model run of free surface elevation in front of the structure and behind the structure. This data was utilized to calculate transmitted and incident wave heights.

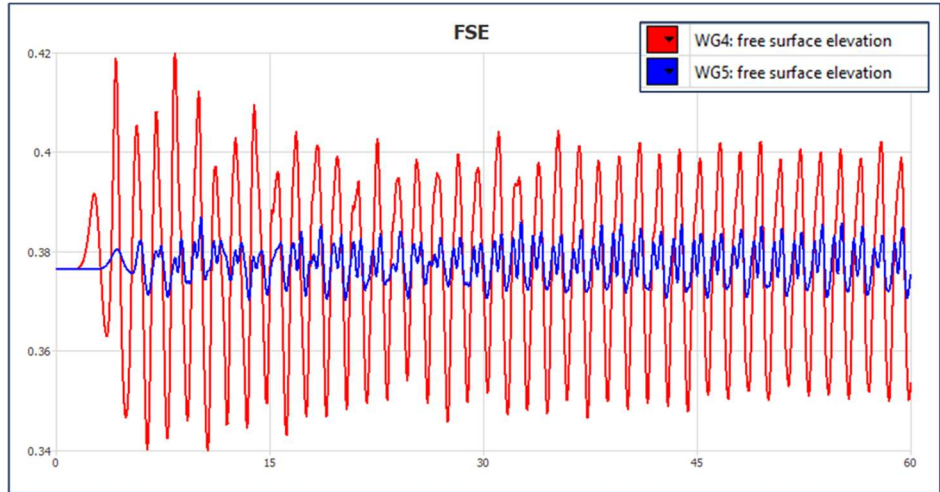


Figure 8: Sample Plot of Free Surface Elevations for Defender Simulation.

Based on the correlation of results between the FLOW-3D model and the physical study, it can be reasonably assumed that the model domain is capable of evaluating QuickReef products of a relatively similar scale with high confidence. An example of this correlation is shown in **Figure 9**, which compares the wave transmission observed in the physical model and the FLOW-3D model. Future uses for the model may include verifying unique wave cases (varying angles of incidence), hydraulic forces on individual members, and fluid-structure interaction at a much finer scale (turbulence). This may allow for predications of scour. The goal of this study was to build a functional numerical laboratory to test future design variations or design conditions, without the need for another flume experiment. Utilizing the flume experiment as a calibration/validation tool will ultimately save Native Shorelines product development costs in the future.

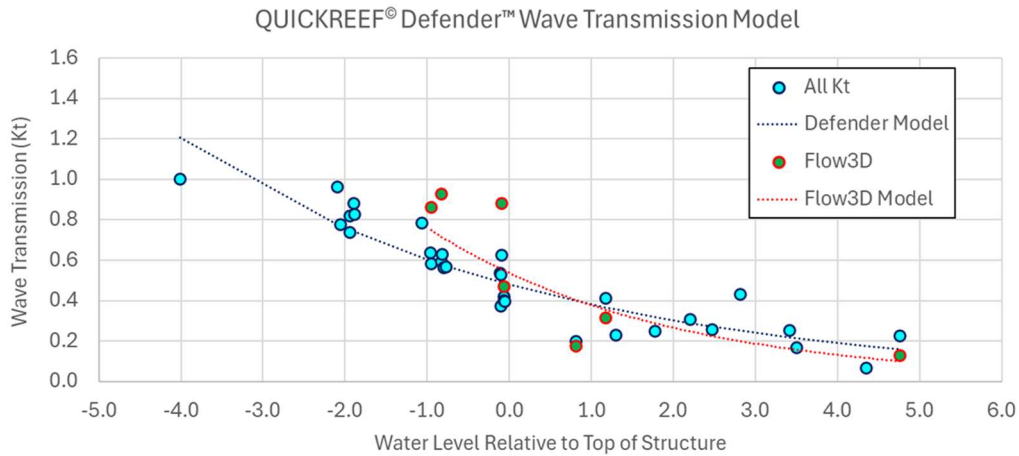


Figure 9: Wave Transmission Results – FLOW-3D vs Flume

5.0 FIELD MONITORING

There is no shortage of living shoreline technologies as new designs are being developed at a rapid pace. However, limited field data has been collected to determine the efficacy of these living shoreline technologies at dissipating wave energy. The North Carolina Coastal Federation (NCCF) contracted SSE in 2024 to perform a field monitoring study of various living shoreline technologies deployed throughout North Carolina. The scope included the construction of twenty-eight (28) total wave gauges and deploying these gauges at thirteen (13) living shoreline installations in the vicinity of Bogue Sound; QuickReef® was among the four (4) technologies monitored. This report will give a brief summary of QuickReef® results only. The reader is recommended to reference the full NCCF report. Additionally, monitoring of shoreline erosion via drone is ongoing and will assist in corroborating the transmission values observed in all three (3) studies.

5.1 Regional Characterization

The Bogue Sound and White Oak River sites are influenced by semidiurnal tides. Both areas are shielded from offshore wave influences, and waves in the area are primarily fetch driven and/or generated via boat wake. Wind speeds and directions were evaluated for potential deployment times based on four (4) years of meteorological data collected by the Beaufort Duke Marine Lab Meteorological Station (No. 8656483). **Table 4** shows the average wind speed and direction per month. Based on the recent meteorological data analyzed, it was determined that the highest wind speeds (and therefore largest potential wave climate) have occurred in recent years between the months of November and December. SSE personnel conducted field deployments from November 5, 2024, to November 7, 2025. The following section describes deployment procedures and operations.

Table 4: Wind Field Characterization

Month	Wind		
	Wind Speed Avg		Direction (deg)
	Kn	Mph	
September	6.89	7.93	137.86
October	6.81	7.83	156.07
November	7.40	8.52	157.86
December	6.54	7.53	176.41
Average	6.91	7.95	157.05

5.2 Methods

Two (2) instruments were deployed at each site for a total of twenty-eight (28) instruments deployed. The instruments were installed on the landward and seaward sides of the living shoreline structures in an effort to characterize wave attenuation capabilities by evaluating the transmissivity at each structure. Transmissivity is typically quantified through the transmission coefficient (Kt) defined as the ratio between transmitted and incident wave height. In general, transmissivity is a function of both the structure’s geometric characteristics and wave parameters (Carter et. Al 2015). Upon retrieval of the data from the gauges, SSE was tasked with evaluating each living shoreline structure’s ability to dissipate wave energy.



5.3 QuickReef® Sites



Gauge No.: NCCF-03
Installation Date: 11/5/2024
Programming Time: ---
Bucket Time: 15:31 CST
Installation Time: 16:58 EST
Position: Seaward of Quick Reef
Coordinates: Lat: 34.727168
 Long: -76.867686



Gauge No.: NCCF-04
Installation Date: 11/5/2024
Programming Time: ---
Bucket Time: 15:31 CST
Installation Time: 17:01 EST
Position: Landward of Quick Reef
Coordinates: Lat: 34.72718333
 Long: -76.86769167



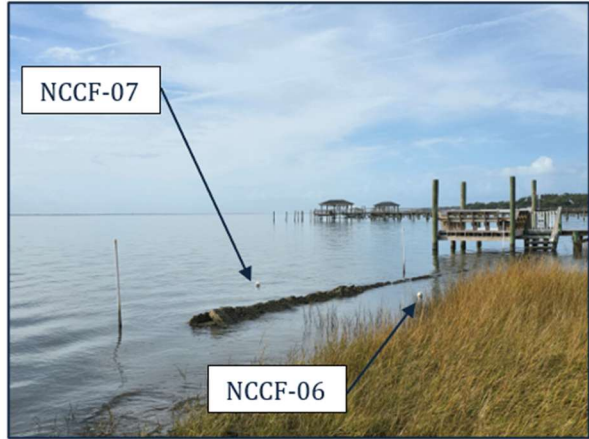
Gauge No.: NCCF-10
Installation Date: 11/6/2024
Programming Time: ---
Bucket Time: 13:54 CST
Installation Time: 15:31 EST
Position: Landward of Quick Reef
Coordinates: Lat: 34.69865278
 Long: -76.98417669



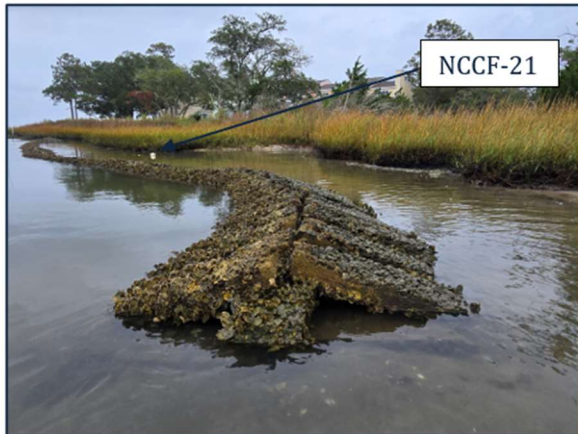
Gauge No.: NCCF-12
Installation Date: 11/6/2024
Programming Time: ---
Bucket Time: 13:54 CST
Installation Time: 15:29 EST
Position: Seaward of Quick Reef
Coordinates: Lat: 34.69863611
 Long: -76.99196944



Gauge No.: NCCF-06
Installation Date: 11/6/2024
Programming Time: ---
Bucket Time: 9:13 CST
Installation Time: 10:28 EST
Position: Landward of Quick Reef
Coordinates: Lat: 34.72664444
Long: -76.87886667



Gauge No.: NCCF-07
Installation Date: 11/6/2024
Programming Time: ---
Bucket Time: 9:13 CST
Installation Time: 10:24 EST
Position: Seaward of Quick Reef
Coordinates: Lat: 34.72660833
Long: -76.87887222



Gauge No.: NCCF-21
Installation Date: 11/7/2024
Programming Time: 8:14 CST
Bucket Time: 8:57 CST
Installation Time: 10:02 EST
Position: Landward of Quick Reef
Coordinates: Lat: 34.704482
Long: -76.822796



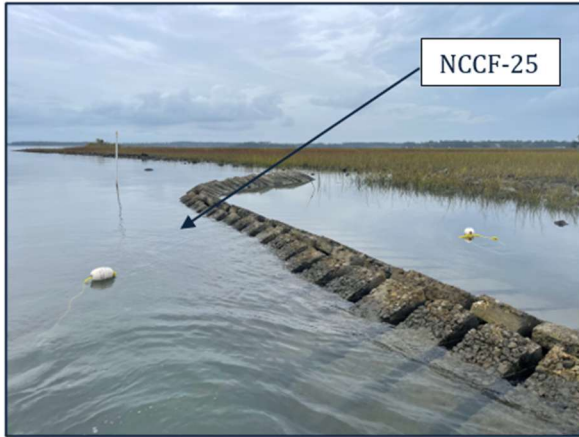
Gauge No.: NCCF-22
Installation Date: 11/7/2024
Programming Time: 8:19 CST
Bucket Time: 8:57 CST
Installation Time: 10:06 EST
Position: Seaward of Quick Reef
Coordinates: Lat: 34.704439
Long: -76.822762



Gauge No.: NCCF-27
Installation Date: 11/7/2024
Programming Time: 10:58 CST
Bucket Time: 12:08 CST
Installation Time: 13:12 EST
Position: Seaward of Quick Reef
Coordinates: Lat: 34.67921111
Long: -77.10908333



Gauge No.: NCCF-28
Installation Date: 11/7/2024
Programming Time: 11:22 CST
Bucket Time: 12:08 CST
Installation Time: 13:16 EST
Position: Landward of Quick Reef
Coordinates: Lat: 34.67924167
Long: -77.10988333



Gauge No.: NCCF-25
Installation Date: 11/7/2024
Programming Time: 10:50 CST
Bucket Time: 11:35 CST
Installation Time: 12:47 EST
Position: Seaward of Quick Reef
Coordinates: Lat: 34.68256111
Long: -77.11194444



Gauge No.: NCCF-26
Installation Date: 11/7/2024
Programming Time: 10:54 CST
Bucket Time: 11:35 CST
Installation Time: 12:44 EST
Position: Landward of Quick Reef
Coordinates: Lat: 34.68253889
Long: -77.11193056

5.4 Analyses & Results

Once the data from each gauge was filtered, the gauges were grouped into their respective pairs for wave height comparisons. This also provided insight to whether the initial post-processing operations were sufficient in rooting out bad data. Each wave gauge pairing and their recorded significant wave heights are displayed in the following sections along with a brief qualitative description. Additionally, wave transmission statistics for each pairing are presented along with overall technology type statistics. Sample filter data plots are shown below in **Figure 10**.

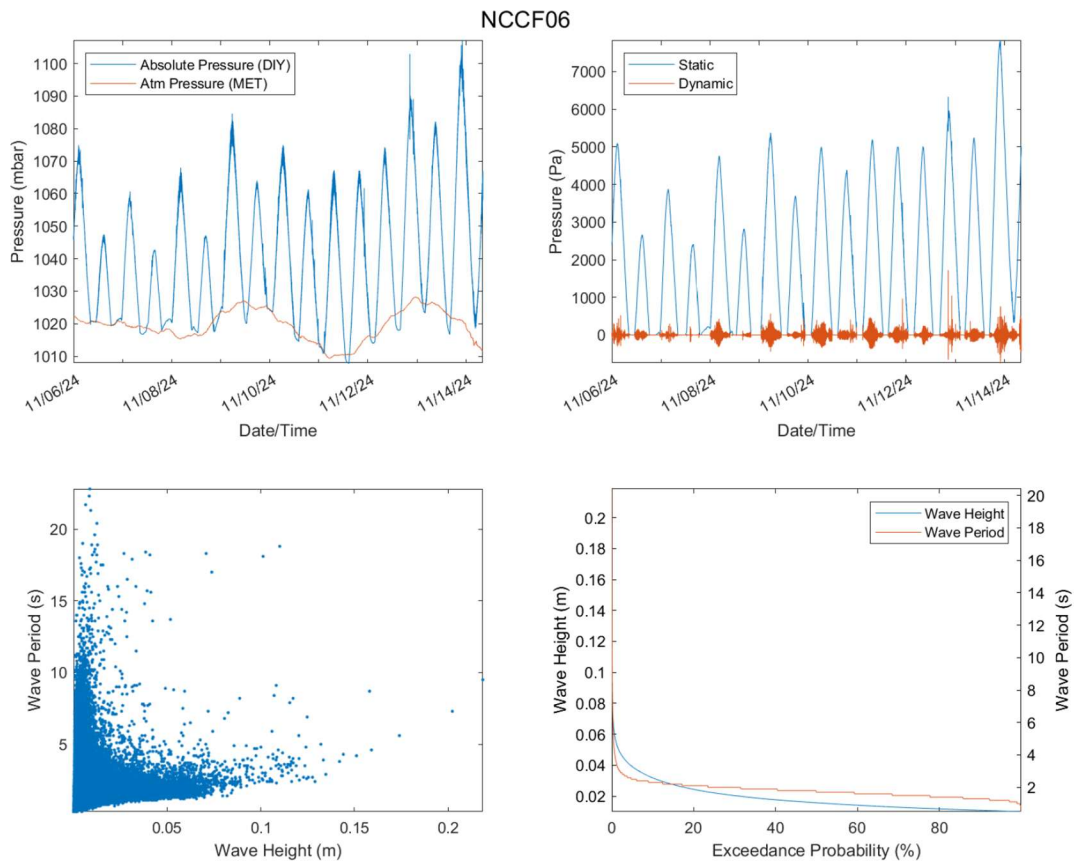


Figure 10: Post-Filtering Sample Plots from NCCF06

Wave transmissivity is typically characterized by the transmission coefficient (K_t), which can be defined as the ratio of the transmitted and incident (incoming) wave height relative to a coastal structure. Various researchers have shown that it is typical for wave transmissivity of low crested structures to increase with increasing water levels (Van der Meer et. al, 1994). For engineering analyses, the transmission coefficient (K_t) was compared to the relative freeboard (H_{ci}) for each structure. Variables K_t and H_{ci} were calculated as follows:

$$K_t = h_2 / h_1$$

Where, h_2 = significant wave height recorded at shoreward gauge
 h_1 = significant wave height recorded at seaward gauge

$$H_{ci} = H_{crest} - W_d$$

Where, H_{crest} = Crest height of the structure above existing ground
 W_d = Water Depth recorded at each gauge

Higher values of K_t indicate that the wave transmissivity is higher while lower values indicate that less of the incoming wave height passes through the structure. Positive H_{ci} values indicate that the crest of the structure is emergent or above the water level while negative values indicate that the structure is submerged. H_{ci} values of zero indicate that the water level is at the crest elevation of the structure. As previously discussed, low crested structures generally have increasing transmission coefficients as water levels increase.

Each wave gauge pairing and its recorded significant wave heights are displayed in the following sections along with a brief qualitative description. Additionally, wave transmission statistics for each pairing are presented along with overall technology type statistics. Wave transmission was compared to relative freeboard for each structure. Crest height relative to existing ground was estimated.

NCCF-07 vs. NCCF-06

Gauges 06 and 07 were deployed at the landward and seaward sides, respectively, of a 21x60 QuickReef® technology in northern Bogue Sound. Gauges 06 and 07 recorded approximately 300 and 200 hours of data, respectively, yielding approximately 200 hours of overlapping data for transmission calculations. During post-processing, wave gauge readings were converted to significant wave heights (top 1/3 of wave heights recorded) for six (6) minute intervals. On average, the significant wave height realized at the shoreward gauge appeared to be consistently less than that of the seaward gauge. It should be noted that the gauges appeared to capture a relatively mild wave climate considering the largest significant wave height recorded was approximately 15 cm (~ 6 in). **Figure 11** shows the significant wave heights recorded at both gauges.

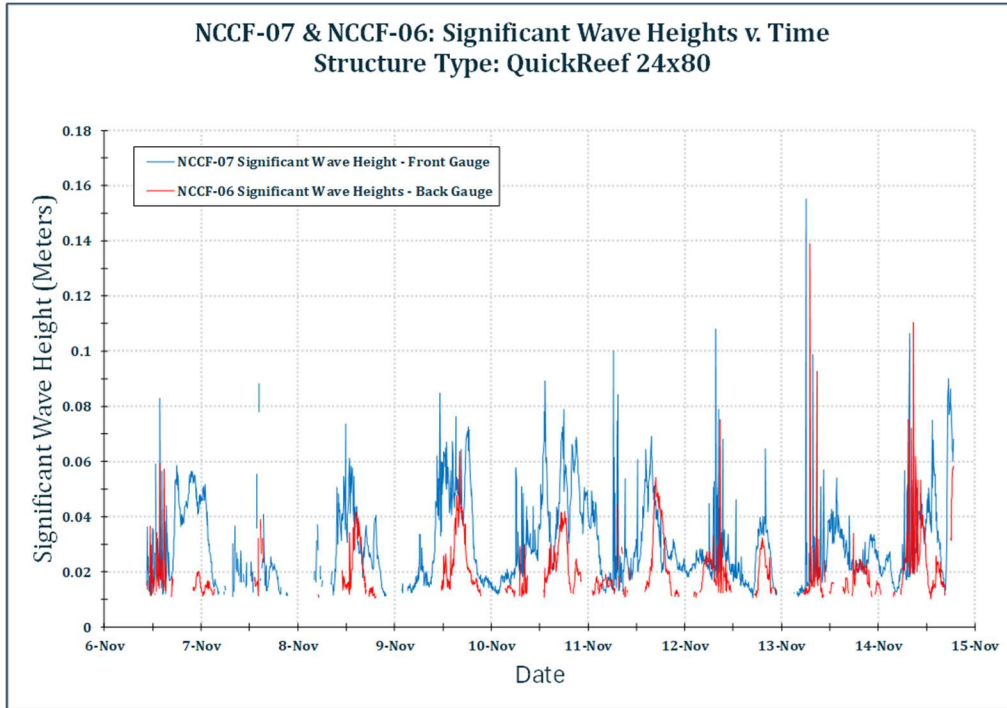


Figure 11: NCCF 07 & NCCF 06 Measured Significant Wave Heights vs. Time

In general, the wave transmission model results for NCCF-07 and NCCF-06 were as anticipated. As relative freeboard increases, wave transmissivity decreases. It should be noted that several data points were higher and lower than expected when the relative freeboard was less than 0.0 (at crest elevation or greater). Overall, the structure performed well during the observation period with a majority of data points showing 60% or less wave transmission through the structure. The average wave transmission for this QuickReef® structure during the observation period was approximately 48% ($K_t = 0.48$). **Figure 12** shows the transmission coefficients versus relative freeboard for the structure.

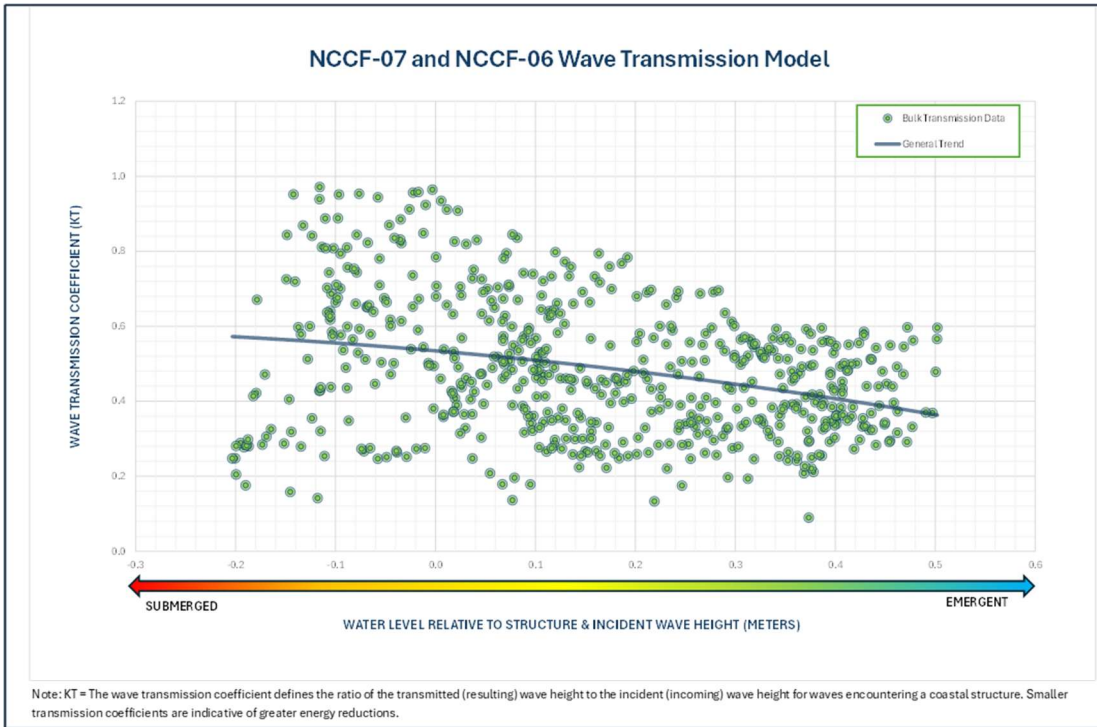


Figure 12: NCCF 07 & NCCF 06 Wave Transmission Plot

NCCF-12 vs. NCCF-10

Gauges 12 and 10 were deployed at the landward and seaward sides of a 21x60 QuickReef® technology in northwest Bogue Sound. Gauges 12 and 10 recorded approximately 247 and 164 hours of data, respectively, yielding approximately 164 hours of overlapping data for transmission calculations. On average, the significant wave height realized at the shoreward gauge appeared to be significantly less than that of the seaward gauge. It should be noted that the gauges appeared to capture a relatively mild wave climate considering the largest significant wave height recorded was approximately 18 cm (~ 7 in). **Figure 13** shows the significant wave heights recorded at both gauges.



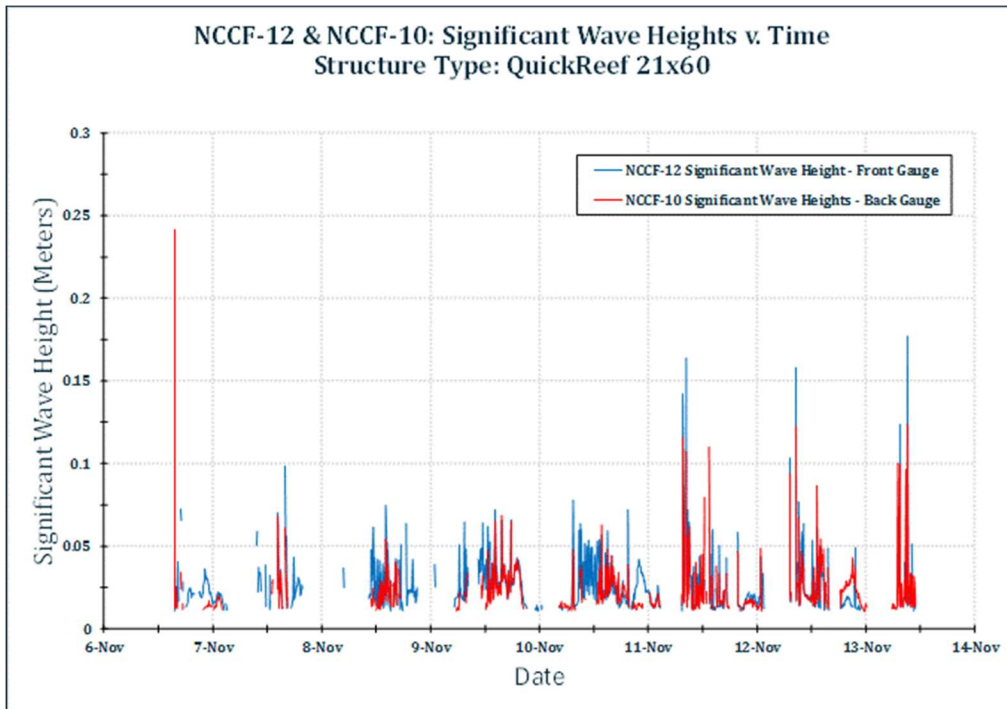


Figure 13: NCCF 12 & NCCF 10 Measured Significant Wave Heights vs. Time

In general, the wave transmission model results for NCCF-12 and NCCF-10 were as anticipated. As relative freeboard increases, wave transmissivity decreases. It should be noted that several data points were higher than expected when the relative freeboard was between 0.0 and 0.1m (at crest elevation or greater). Overall, the structure performed well during the observation period with a majority of data points showing 60% or less wave transmission through the structure. The average wave transmission for this QuickReef® structure during the observation period was approximately 45% ($K_t = 0.45$). **Figure 14** shows the transmission coefficients versus relative freeboard for the structure.

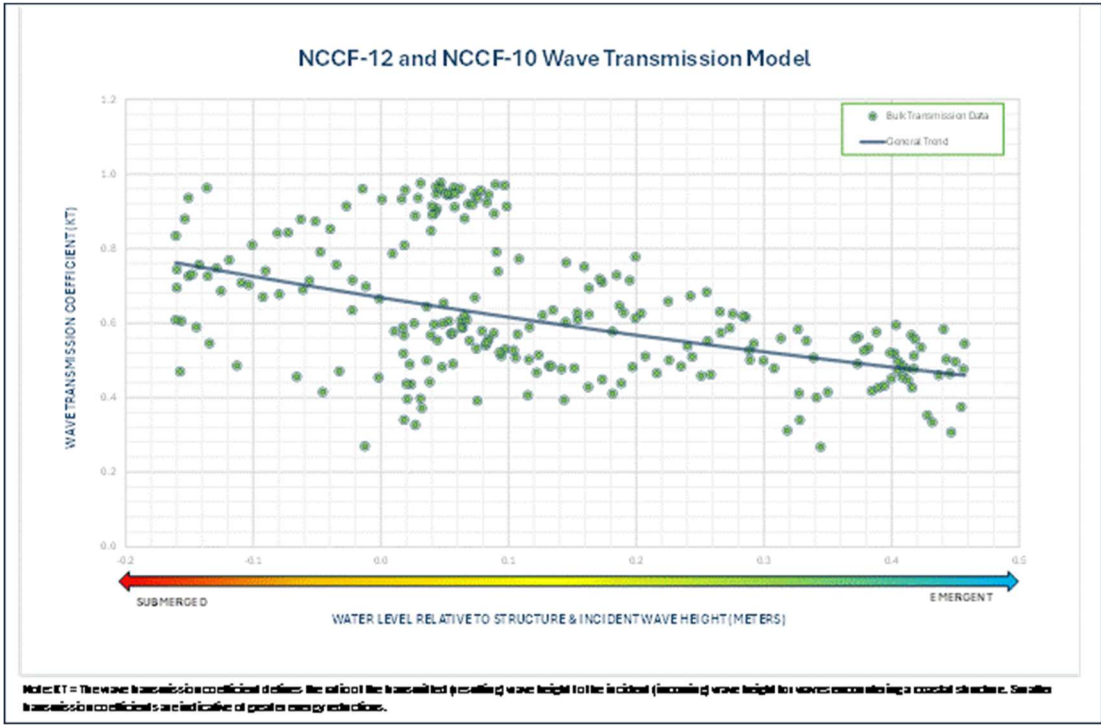


Figure 14: NCCF 12 & NCCF 10 Wave Transmission Plot

NCCF-22 vs. NCCF-21

Gauges 21 and 22 were deployed at the landward and seaward sides of a 21x60 QuickReef® technology in Bogue Sound, east of the Pine Knoll Aquarium, adjacent to gauges NCCF-19 and NCCF-20. Gauges 21 and 22 recorded approximately 116 and 192 hours of data, respectively, yielding approximately 116 hours of overlapping data for transmission calculations. On average, the significant wave height realized at the shoreward gauge appeared to be significantly less than that of the seaward gauge. It should be noted that the gauges appeared to capture a relatively mild wave climate considering the largest significant wave height recorded was approximately 13 cm (~ 5 in). **Figure 15** shows the significant wave heights recorded at both gauges.



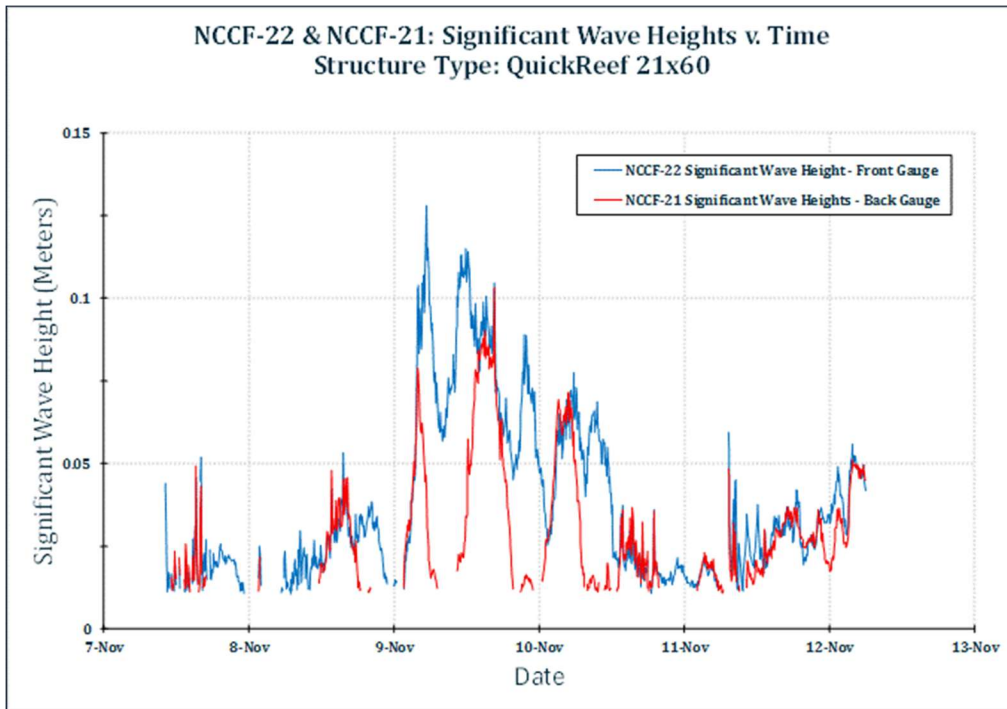


Figure 15: NCCF 22 & NCCF 21 Measured Significant Wave Heights vs. Time

In general, the wave transmission model results for NCCF-22 and NCCF-23 were as anticipated. As relative freeboard increases, wave transmissivity decreases. It should be noted that several data points were higher than expected across a range of relative freeboards. These higher recordings may have been due to wind direction or deployment position of the gauges. It should be noted that these readings are very similar to what was observed at the adjacent Oyster Bag site (NCCF-19 and NCCF-20). With these points excluded, the structure performed well during the observation period with a majority of data points showing 75% or less wave transmission through the structure. The average wave transmission for the QuickReef® structure during the observation period was approximately 60% ($K_t = 0.60$). It should be noted that this average was heavily influenced by the above-mentioned elevated K_t values. **Figure 16** shows the transmission coefficients versus relative freeboard for the structure.

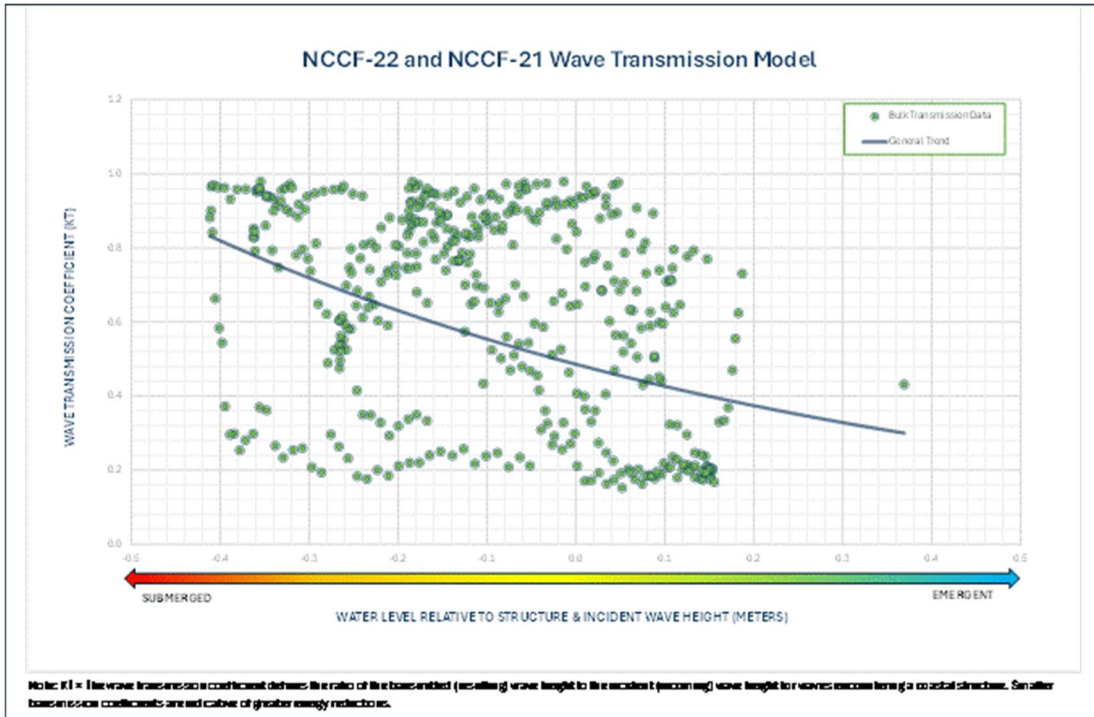


Figure 16: NCCF 22 & NCCF 21 Wave Transmission Plot

The study data suggest that on average across site conditions the QuickReef® structures allowed for less wave transmission during the observation period than other comparable living shoreline structures with an average transmission coefficient of 0.54. It should be noted other technologies monitored have a different functionality with wave attenuation being a secondary benefit (i.e. Oyster Catcher's – first priority is to recruit oysters). Therefore, a direct wave attenuation comparison is not necessarily appropriate in this case.

6.0 CONCLUSIONS & RECOMMENDATIONS

QuickReef technologies were modeled at the University of South Alabama wave flume. Wave and water level conditions modeled were based on coastal engineering analyses conducted for the Bogue Sound, North Carolina area. The physical model evaluated structure stability and wave attenuation. All technologies tested showed strong ability for wave attenuation and were stable within the physical modeling environment.

FLOW-3D models were set up to evaluate wave attenuation under similar conditions to the physical modeling. FLOW-3D model results were in good agreement with the physical modeling which suggest that a working numerical laboratory could be utilized to evaluate different wave cases or conditions, or even new products in the future.

Field analyses were also conducted on QuickReef products throughout Bogue Sound. Data collected shows strong wave attenuation for QuickReef projects, comparable to rubblemound structures. In addition, vast ecological benefits were observed at the QuickReef deployment sites including oyster spat development.

In all three of the studies conducted, QuickReef technologies showed strong wave attenuation capabilities. Physical modeling also showed that the structures were stable under a variety of conditions. Comparable results were observed both in numerical modeling and field data measured at deployment sites. Ecological benefits of the QuickReef Deployments are still being quantified, but qualitative observations suggest that erosion rates have been reduced behind the structures and significant oyster spat recruitment has occurred at many of the deployment sites.

Ongoing work includes 3D scans of oyster growth over time and topo/bathy surveys showing shoreline response over time. Continuing studies of this nature will help coastal communities and coastal engineers to make more informed decisions on living shoreline technologies to deploy for ecological benefits, shoreline response, and wave attenuation.

7.0 REFERENCES

1. Computational techniques for tidal datums handbook; NOAA Special Publication; September 2003
2. ACES 24-003 QuickReef Testing Report; University of South Alabama; Center for Applied Coastal Engineering and Science.
3. National Oceanic and Atmospheric Administration; Tides & Currents;
<https://tidesandcurrents.noaa.gov/map/index.html?region=North%20Carolina>
4. Carter, J., Fenical, S., Harter, C., and Todd, J. (2015). "CFD modeling for the analysis of living shoreline structure performance." Coastal Structures and Solutions to Coastal Disasters, 442–450.

APPENDIX A – STL FILES/RENDERINGS

APPENDIX B – USA FLUME STUDY REPORT