# EFFECT OF BEACH NOURISHMENT ON SURFING – OBSERVATIONS FROM THE ST. JOHNS COUNTY SHORE PROTECTION PROJECT

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**Running title**: St. Johns County Beach Nourishment: Surfing Aspects

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## ABSTRACT

Oftentimes the surfing community, with concern for their local break, resists beach nourishment projects. However, the recent nourishment project in St. Augustine, FL, improved local surfing conditions. In 2003, the State of Florida teamed with the United States Army Corps of Engineers (USACE) to place approximately 4.5 mcy of sand on St. Augustine beaches. The USACE placed a further 2.8 mcy in 2005 as renourishment in response to severe erosion from the 2004 hurricane season. Consideration was given to a section of the project domain that historically experienced extraordinary erosion rates. The resulting nourishment design template applied additional sand at this erosional hotspot – and resulted in a protruding “elbow” in the planform design. This “elbow” of nourished sand inadvertently spawned a remarkable wave for local surfers, aptly named “The Dredge”. However, the quality of the surfing wave slowly deteriorated as the nourishment attained equilibrium in both planform and profile. This paper intends to document the evolution of the surfing wave with the nourishment equilibration.

Beach profile data (pre-, post-construction and yearly surveys) allow study of the beach nourishment performance. The surveys also document characteristics of the surfing wave – e.g. the more desirable steeper beach face immediately following construction, with gradual decrease in face gradient over time. A National Climatic Data Center (NCDC) buoy located 70 km offshore provides deepwater directional wave data. An independent surf report document a visual judgment of the surfing wave height quality upon breaking. Although subjective, the surf report data enables a comparison between offshore and inshore wave heights over the project’s history. Finally, wave modeling will verify the surfing wave quality evolution.

**ADDITIONAL INDEX WORDS**: *numerical models, wave transformation, beach nourishment, surfing waves.*

## INTRODUCTION

This paper documents improvement in surfing conditions as a direct consequence of beach nourishment – in this case, the St. Johns County Shore Protection Program. Surfing wave conditions are compared before and after project construction. The research shows beach nourishment, if so designed, can be considered as a public benefit to the surfing community.

The paper begins with a background of the project, with a focus on the surfing and nourishment history. A qualitative description of the project's bathymetric evolution (Pre-, Construction-, and Post-Fill surveys) with respect to the surfing wave follows. The numerical modeling exercise correlates the bathymetric evolution with simulated wave propagation. The analysis section compares model results with visual surf report data and describes surfing wave improvement from the project. Discussion and conclusion sections identify potential future work and summarize key findings.

## BACKGROUND

### Location

Located on the north east coast of Florida, the St. Johns County Shore Protection Project provides protection for a large portion of the St. Augustine Beach shoreline. Material for the project came from the St. Augustine Inlet ebb shoal, approximately 6 km north of St. Augustine Beach. Figure 1 shows the location of St. Augustine Beach and Inlet.

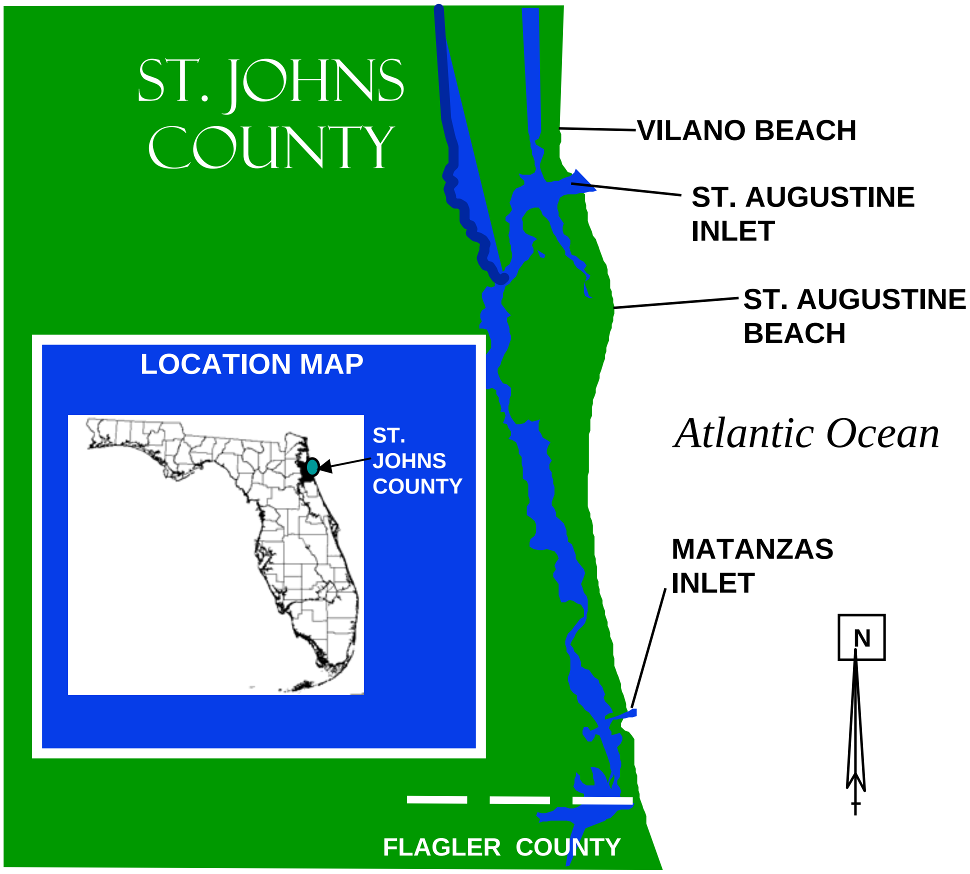

**Figure 1** Location Map

**Nourishment History**

The first nourishment (referred to as the 2003 project) of the St. Johns County Shore Protection Project, completed in January 2003, extended approximately 3.7 miles from south of St. Augustine Inlet to St. Augustine Beach in St. Johns County, Florida. The project was funded jointly by the USACE and the State of Florida. The severe 2004 hurricane season forced an expedited schedule of the renourishment project – backed with emergency remediation money appropriated from Congress. The first renourishment (referred to as the 2005 project) extended approximately 2.9 miles in St. Augustine Beach. Construction began in June and concluded in December 2005. For the initial nourishment and subsequent renourishment projects, the St. Augustine Inlet ebb shoal (approximately 4 km north) served as the borrow area. Nourishment sediment size (0.155 mm) approximated the native size of 0.14 mm. Aerial photographs (Figure 2) document the nourishment. Note the location and orientation of the pier for a reference of the camera’s perspective.

**Figure 2** Project Evolutions – Aerial Photographs

## Surfing History

St. Augustine Beach's thriving surf community initially opposed the beach nourishment project. The arguments centered on the potential loss of existing or historical surf breaks, three of which were directly affected by the nourishment project.

Figure 3 presents two historical surf break locations (First Access and the Pier) on a 1999 aerial photograph of St. Augustine Beach. The following paragraphs provide a qualitative description and history of the impacted surf breaks.

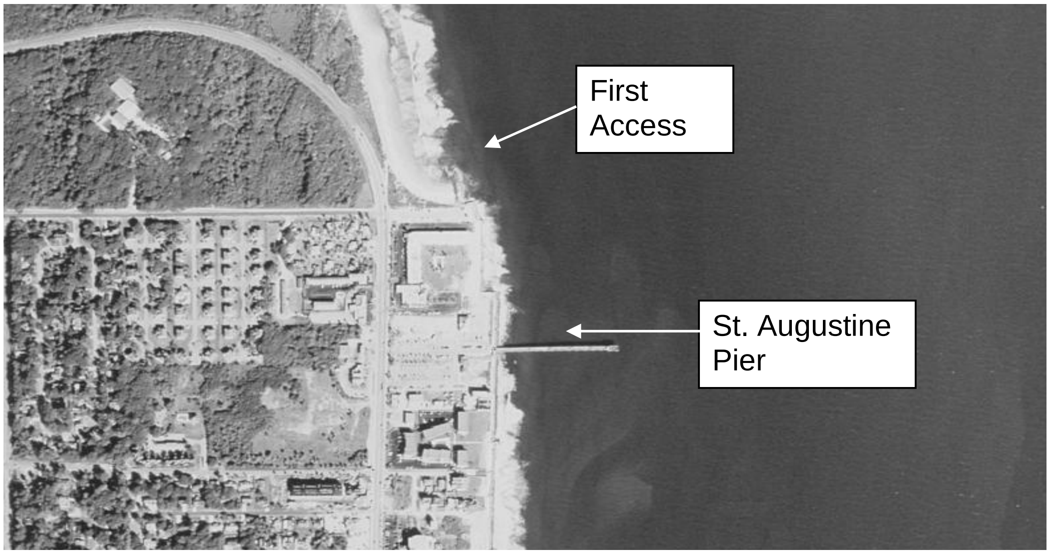

**Figure 3** Historical Surfing Locations

First Access (FAs), located immediately north of the St. Augustine Beach seawall/revetment, is the most pertinent consideration to this study as the right breaking wave produced by the nourishment project approximated the historical break's location. Preceding the nourishment project, localized erosion eroded the shoreline north of the seawall to approximately 50 m landward of the seawall. The surfing wave at FAs benefited from refraction of south east swells around the seawall to break on the eroded beach. The seawall acted as a headland to yield point-break type waves. As such, the potential loss of this break created the biggest uproar from the surfing community.

Prior to the 1980's, the Pier was recognized as one of Saint Augustine Beaches most popular surf breaks. Waves refracted around the pier structure and associated sand bar to produce quality surfing waves both north and south of the pier. The Pier began to degrade in the early 1980's as severe erosion adjacent to the seawall eroded the subaerial and subaqueous beach. Waves propagated over the eroded beach to break close to or on the armor stone. Wave interference from the increased wave propagation in front of the seawall coupled with reflection off the seawall reduced wave quality considerably.

Wave conditions at the various surf breaks in the St. Augustine area vary seasonally. Summer surf generally experiences minimal wave conditions. However, occasional hurricanes produce superlative surfing conditions that are highly dependent on the hurricane location, size, and wind speed. Fall is the most consistent season with swell events produced from both passing hurricanes and cold fronts. Winter and spring swell events are both dependent solely on passing cold fronts. Wave heights are most common around 1.5 m, but range from 0 to 2.5 m. Wave periods vary between 4 to 14 seconds. Swell direction varies from north east to south east.

## PROJECT EVOLUTION WITH RESPECT TO SURFING WAVE

The 2003 and 2005 projects improved the wave quality immediately following sand placement. Although the sand placement enhanced both a left and a right peeling wave, local observations suggest the left peeling wave developed at the dredge pipe discharge point with the breakpoint proceeding from north to south with the disposal location. The predominant right peeling wave frequently produced an identifiable surfing wave. This analysis focuses on the right produced by the 2005 project only.

A visual presentation of the bathymetric evolution of the nourishment cycle demonstrates the project's potential to temporarily enhance the surfing wave. Figure 4 show the 2005 project evolution from bathymetry collected before and after construction. The USACE sponsored beach profile survey data collection (via traditional methods) at approximately 300 m spacing for monitoring purposes since project inception. Notably, 2005 design templates formed the basis for the "construction" survey; the "construction" survey thus represents conditions immediately following sand placement. The nourishment's distinguishable perturbation at R-142 allows waves to refract and break at an oblique angle to the shore, thus improving surfing wave conditions.

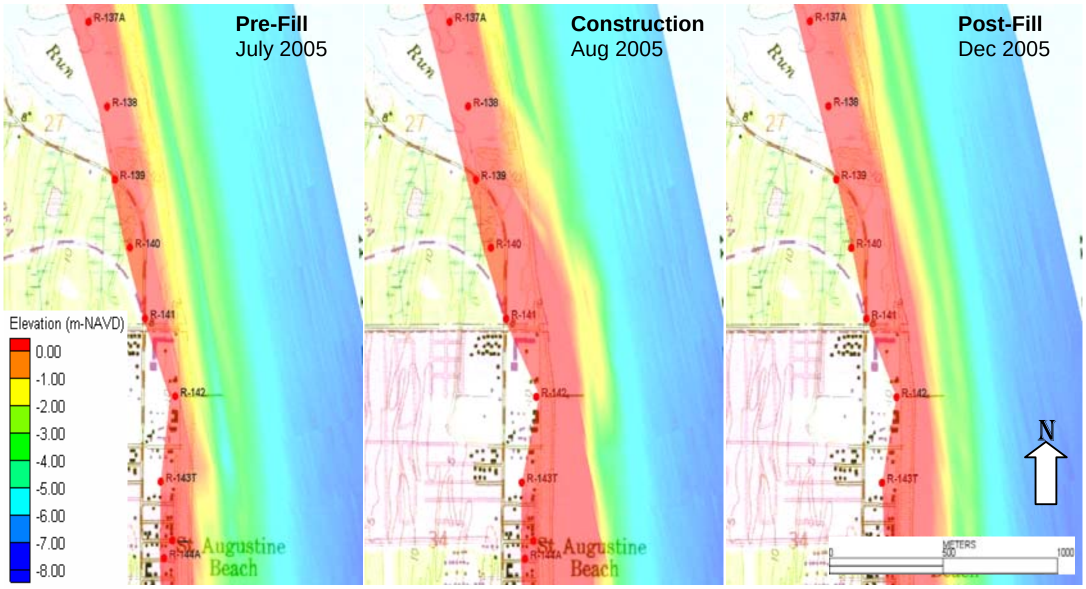

**Figure 4** Project Evolutions – Bathymetric Data

The Pre-Fill survey shows straight and parallel contours from offshore to onshore. The pronounced offshore bar located approximately 250 m from the shoreline is a product of offshore storm-induced transport from the active 2004 hurricane season. Of additional note, the shoreline protrudes seaward adjacent to R-142. In the 1970s, the USACE installed a riprap revetment and low-crested seawall as severe beach erosion threatened the adjacent hotel and state road at this protrusion.

The Construction survey extends the shoreline approximately 200 m seaward. Between R-138 to R-141, the nourished shoreline flanges to form an angle with the offshore contours. An aerial photograph in Figure 5 also demonstrates the protruded nourished shoreline.

**Figure 5** Aerial Photograph with Camera Pointing South showing Shoreline and Beach Fill Protrusion at R-142

Figure 6 shows the wave from an aerial perspective (taken by the USACE). The photograph clearly shows wave refraction around the nourished beach to produce a right-peeling breaking wave. The surf break is located on the nourishment project’s taper point that ties into the unnourished beach.

**Figure 6** Aerial Photograph showing waves breaking around the nourishment project's taper

The Post-Fill survey shows the shoreline has began to equilibrate back to straight and parallel contours. The pronounced angled shoreline in the construction survey has flattened as the nourished sand diffused laterally from the project area.

In the simplest sense, the profile surveys in Figure 7 show a potential improvement in the breaking wave type from the Pre-Fill period to the Construction period based upon the Surf Similarity Parameter, which suggests a steepened beach slope is more in favor plunging type breaking waves -- a more desirable shape for surfing. Surf similarity values for the selected swell conditions are presented in the following section.

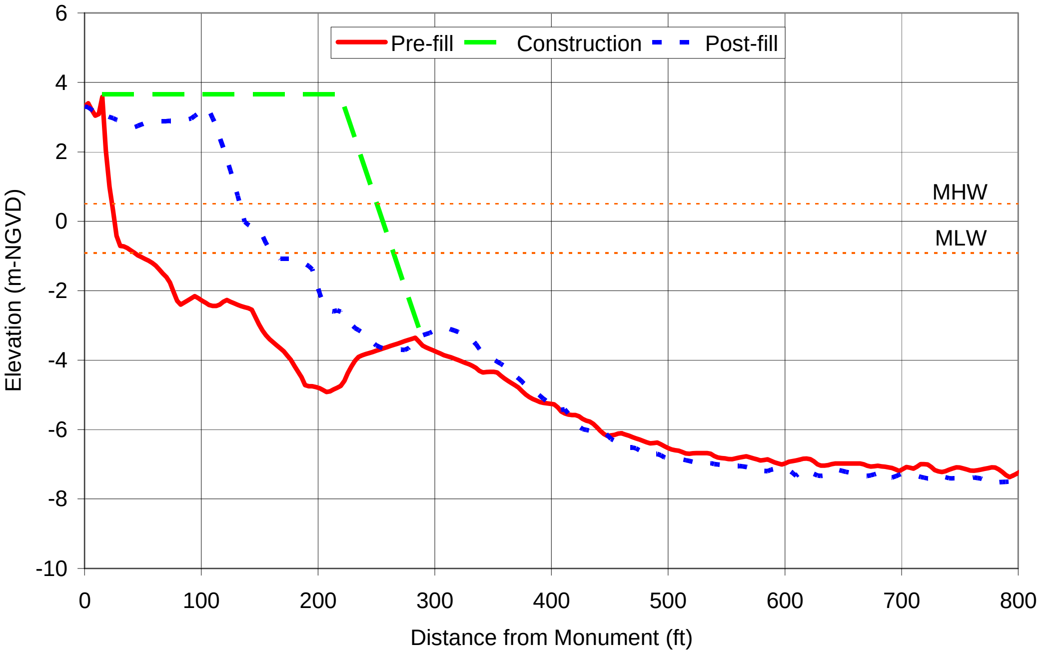

**Figure 7** Profile R-142

## WAVE MODELING

The modeling effort employed two wave transformation models to illustrate the surfing wave improvement. A coarse grid (100 m spacing) finite-difference wave action model transformed the waves to the nearshore region. A fine grid phase-resolving model (~2 m spacing) then examined wave transformation and breaking associated with the detailed nearshore bathymetry. Nearshore transformations included the Pre-Fill, Construction, and Post-Fill bathymetries. Two distinct swell events – one originating from the NE and one originating from the E, provided the incident wave conditions. Wind gages measured relatively calm winds during both swell events – ideal for surfing wave breaking as well as model output comparison with documented surf reports. Both events occurred following the 2005 construction period; however, for comparison, the exact same wave events were replicated for the Pre-Fill and Post-Fill bathymetries to illustrate differences in surfing characteristics. The events coincide with well-documented surf reports and photographs by a local surf shop, allowing a means to compare the numerical model output.

### Coarse Grid Wave Transformation Model

Danish Hydraulic Institute’s (DHI) finite difference Nearshore Spectral Wave (NSW) model propagated waves from the offshore boundary to the nearshore. The NSW model, a weakly nonlinear wave action model accurately reproduces wave transformation changes over arbitrary bathymetries. The finite difference model incorporates all the primary wave transformation mechanisms, including shoaling, refraction, local wind generation, and energy dissipation (due to wave breaking, bottom friction, and surface energy dissipation) (DHI, 2005).

### Wave Field Input

An offshore wave data buoy provided a time series of wave heights, periods, wind speed, direction, and other atmospheric observations from an offshore wave-rider data buoy for model input. The National Oceanic and Atmospheric Administration (NOAA) maintain wave data from a series of offshore buoys as part of the National Data Buoy Center (NDBC) program. Station 41012, located 70 km east of St. Augustine Beach (30° 02' 38" N 80° 33' 01" W), and represents the nearest buoy to the nourishment project. The location of the NOAA buoy thus directly established the offshore model boundary. Two representative swell conditions represented above average surfing days in St. Augustine Beach: August 12th-15th 2005 (E swell) and Oct 16th 2005 (NE swell). Table 1 lists the offshore boundary conditions applied to the NSW model.

**Table 1** NSW Model Offshore Boundary Conditions

| **Case** | **Date** | **Wave Height, $H_{mo}$ (m)** | **Mean Wave Period (sec)** | **Wave Direction (clockwise from North)** |
|---|---|---|---|---|
| E swell | Aug 12th-14th 2005 | 1.4 | 11 | 270° |
| NE swell | Oct 16th 2005 | 1.9 | 13.2 | 225° |

### Bathymetric Input

The NSW model domain contained 699 columns and 999 rows for a total of 698,301 grid elements (100 m square) with the grid axes rotated to align with the predominant shoreline orientation (Figure 8). The baseline grid bathymetry integrated NOAA nautical chart bathymetry (updated to 2006) for the St. Augustine, Florida region.

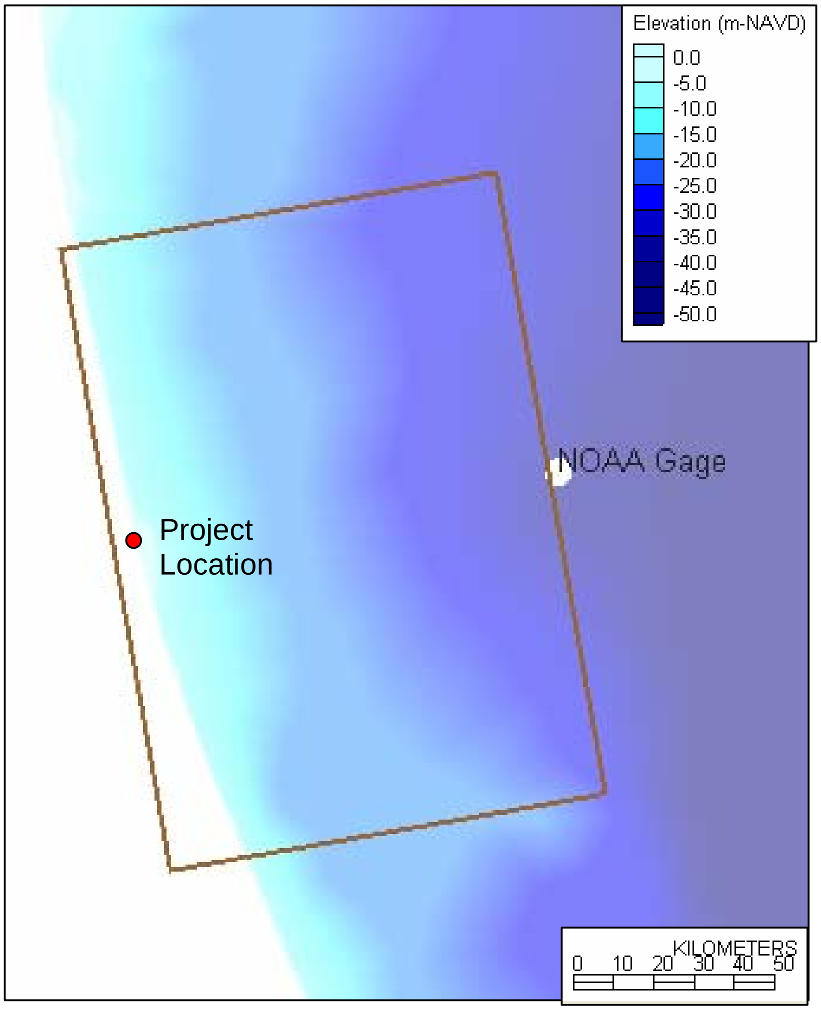

**Figure 8** NSW Model Boundaries

### Model Results Analysis

The NSW model propagated the incident wave conditions to the nearshore providing transformed wave height and direction value through the model domain. Simulation gages recorded wave climate conditions at the intersection of the fine model mesh offshore boundary. These wave conditions, presented in Table 2, served as input to the fine grid model.

**Table 2** Wave Climate from NSW Model at Intersection of Fine Model Mesh

| **Case** | **Date** | **Wave Height, $H_{mo}$ (m)** | **Mean Wave Period (sec)** | **Wave Direction (clockwise from North)** |
|---|---|---|---|---|
| E Swell | Aug 12th-14th 2005 | 1.2 | 11 | 263° |
| NE Swell | Oct 16th 2005 | 1.6 | 13.2 | 225° |

## Fine Grid Wave Transformation Model

CGWAVE, a phase-resolving elliptic model based upon the mild-slope equation, provided the detailed nearshore wave transformations. The model accurately resolves the combined effects of refraction, diffraction, reflection (by coastlines and structures), nonlinear dispersion, and dissipation due to friction and breaking (Demirbilek and Panchang, 1998). CGWAVE is well suited for this application given the objectives of the modeling exercise (i.e., to accurately capture nearshore wave transformations). Beach slopes are well within the computational range of the mild-slope criteria. Notably, a Boussinesq-based model would be most suited to analyze the nonlinear wave characteristics; however, this level of analysis was beyond the scope of the present study. Model setup requires a wave condition prescribed along the outer boundary and a finite-element mesh of the bathymetry. Calibration and verification of the wave model consisted of adjusting bottom friction until model results compared well with visual surf report observations and photographs.

### CGWAVE Model Setup

Model setup requires the boundary wave condition and bathymetry. The NSW wave model provided wave conditions at the model boundary (Table 2). The boundary wave conditions, in turn, dictate the appropriate model element size (approximately 10% of the wavelength). This effort limited the element spacing to 2m, well within model guidelines. The USACE bathymetry described earlier specified elevations throughout the grid. Figure 9 shows the CGWAVE model boundaries.

**Figure 9** CGWAVE Model Boundaries

## RESULTS

Figures 10 and 11 illustrate wave height and water surface elevations during the August (E swell) and October (NE swell) events for the Pre-Fill, Construction, and Post-Fill bathymetry. The breaker line is shown in red. Wave transformations are clearly driven by the bathymetric variations in the nourishment stage.

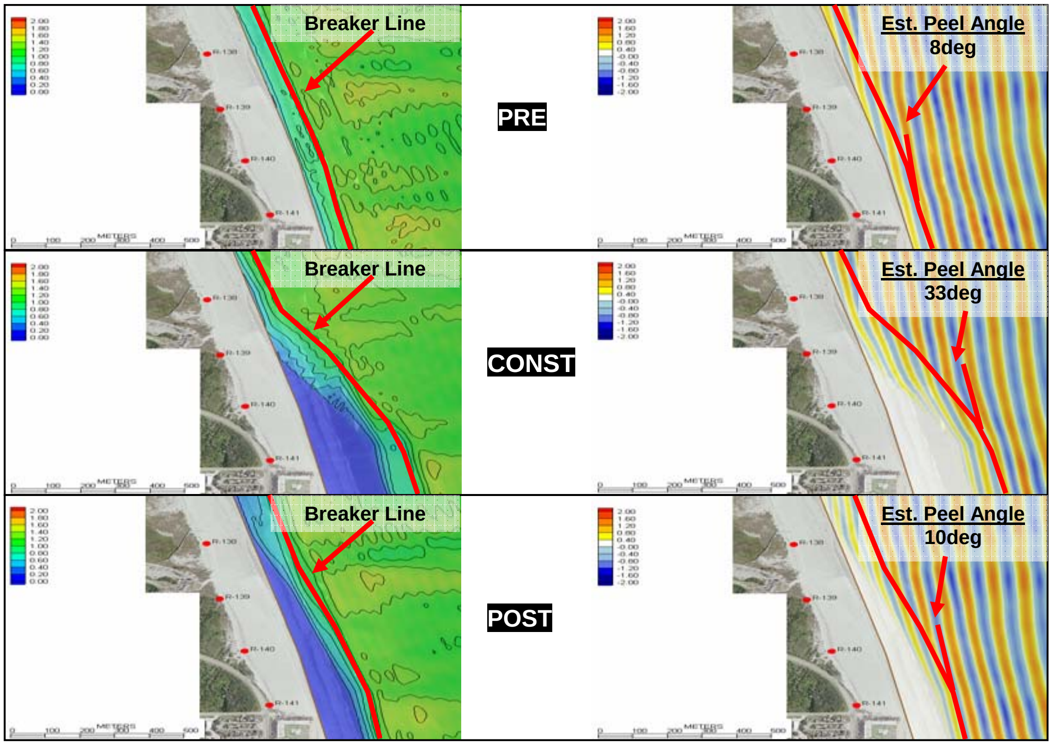

Figure 10 – Wave Height and Water Surface Elevations during August Swell for the Pre-Fill, Construction, and Post-Fill

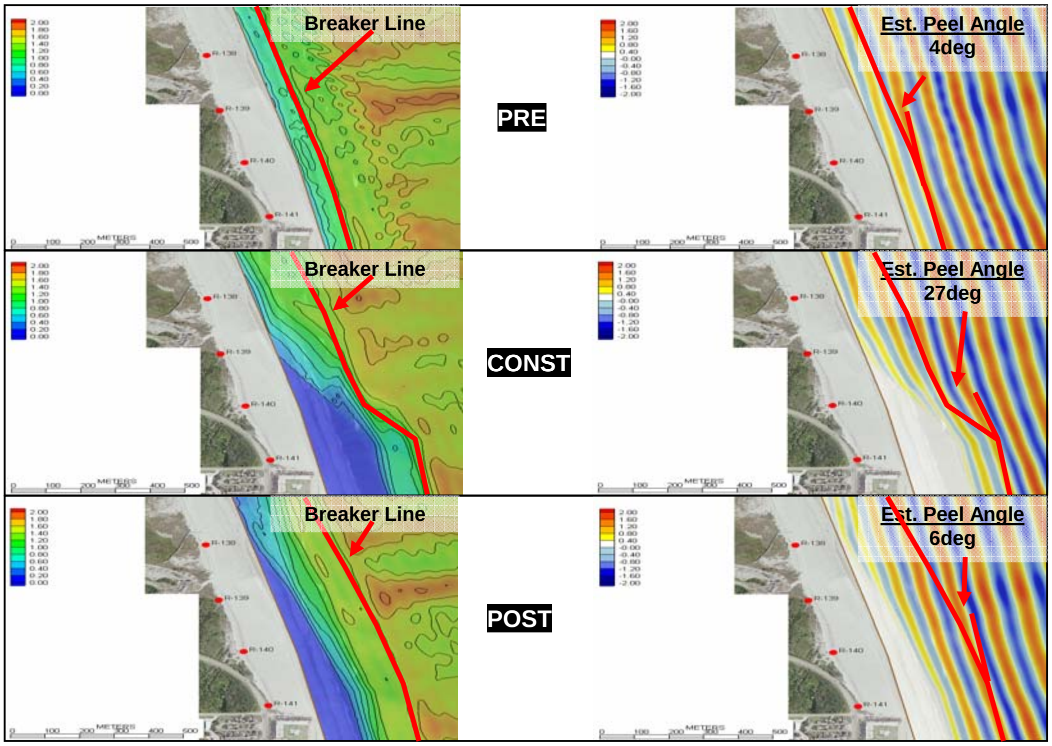

Figure 11 – Wave Height and Water Surface Elevations during October Swell for the Pre-Fill, Construction, and Post-Fill

Lack of any perturbation in the Pre-Fill nearshore bathymetry causes waves to propagate and break parallel to shore. The Construction bathymetry, characterized by the perturbation in the nearshore region, causes noticeable wave refraction around the ends of nourishment site. The refraction generates a substantial peel angle compared to the other nourishment stages. The perturbation is less pronounced in the Post-Fill bathymetry as sediment transport processes spread the nourishment laterally and reduce the offshore protrusion of the material. As such, wave refraction effects are lessened and the resulting peel angle approaches the Pre-Fill condition.

Comparison of peel angle and surf similarity parameter provides a means to quantify and assess the evolution of surfing conditions during the nourishment cycle. Table 3 lists the predicted surfing parameters for the three nourishment stages. Figure 12 illustrates the peel angle as a function of the nourishment stage. Although a peel angle of 30 deg is generally accepted as the minimum limit for surfable conditions (Walker, 1974), improvements to equipment and surfing standards may prove this value outdated. The model predicted peel angles of 33deg and 27deg during the August and October swell events for the Construction simulations. These values are nominally equal to Walker's prediction. Inspection of surfing photographs taken during these two events (Figure 13 and 14) suggest peel angles are low (~30deg) as the wave crest appears to break fast. Model predictions of peel angle for the same swell events during the Post-Fill bathymetry are lower as the nearshore perturbation has less affect on the refraction characteristics. The Pre-Fill condition, void of any perturbation, follows the same rationale and generates the smallest peel angles and close-out surfing conditions. The authors have personally experienced these predicted close-out conditions during conditions similar to the modelled Pre-Fill scenarios (i.e., calm winds, distinct uni-directional swell propagating towards a generally uniform coastline). However, these conditions are extremely rare. The additional effects (wind or secondary sea or swell components) generate variations in wave height and surf-zone currents, which in turn affect temporal and spatial breaking wave conditions to permit small sections of surfable conditions.

**Table 3 - Surfing Wave Parameters**

| **E SWELL (AUGUST)** | | | |
|---|---|---|---|
| **PARAMETER** | **NOURISHMENT STAGE** | | |
| | **PRE-FILL** | **CONSTRUCTION** | **POST-FILL** |
| **Nearshore Slope** | 40 | 10 | 27 |
| **Breaking Wave Height (m)** | 1.7 | 1.5 | 1.5 |
| **Surf Similarity Parameter** | 0.3 | 1.1 | 0.4 |
| **Est. Peel Angle (deg)** | 8 | 33 | 10 |
| | | | |
| **NE SWELL (OCTOBER)** | | | |
| **PARAMETER** | **NOURISHMENT STAGE** | | |
| | **PRE-FILL** | **CONSTRUCTION** | **POST-FILL** |
| **Nearshore Slope** | 40 | 10 | 27 |
| **Breaking Wave Height (m)** | 2 | 1.8 | 1.8 |
| **Surf Similarity Parameter** | 0.3 | 1.2 | 0.5 |
| **Est. Peel Angle (deg)** | 4 | 27 | 6 |

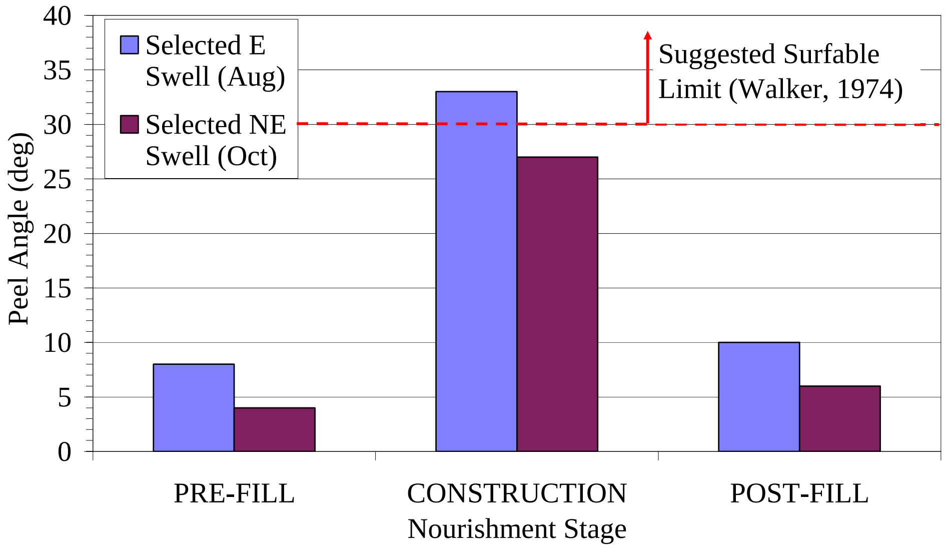

Figure 12 – Estimated Peel Angle during the Various Nourishment Stages

Courtesy of Dave Macri – Blue Sky Surf Shop

Figure 13 – Photograph of Surfing Conditions (August 2005)

Courtesy of Dave Macri – Blue Sky Surf Shop

Figure 14 – Photograph of Surfing Conditions (October 2005)

Breaking wave heights predicted by CGWAVE (Table 3) during the Construction simulations compare well with documented photographs (Figure 12 and 13). In the vicinity of R-141, the model predicts breaking wave heights of approximately 1.5 – 1.7m during the August swell and 1.8 – 2.0m during the October swell for the various nourishment stages. Assuming the surfer in the photographs is approximately 1.8m tall, the breaking wave height falls within similar range.

Figure 15 graphically illustrates the Surf Similarity Parameter for each nourishment stage. The limits for spilling, plunging, and surging/collapsing breaker type are labelled in the figure. The Construction simulations indicate plunging wave conditions, whereas the other nourishment stages generated more spilling conditions. For the modelled conditions, the breaker type is almost entirely a function of the beach slope (very little change in breaking wave height). Beach slopes were the steepest during the Construction stage (1 on 10 slopes) and flattened out as the profile equilibrated in cross-section. Plunging waves, illustrated in Figure 12 and 13, bode well for the use of the Surf Similarity Parameter as a means to assess breaker type.

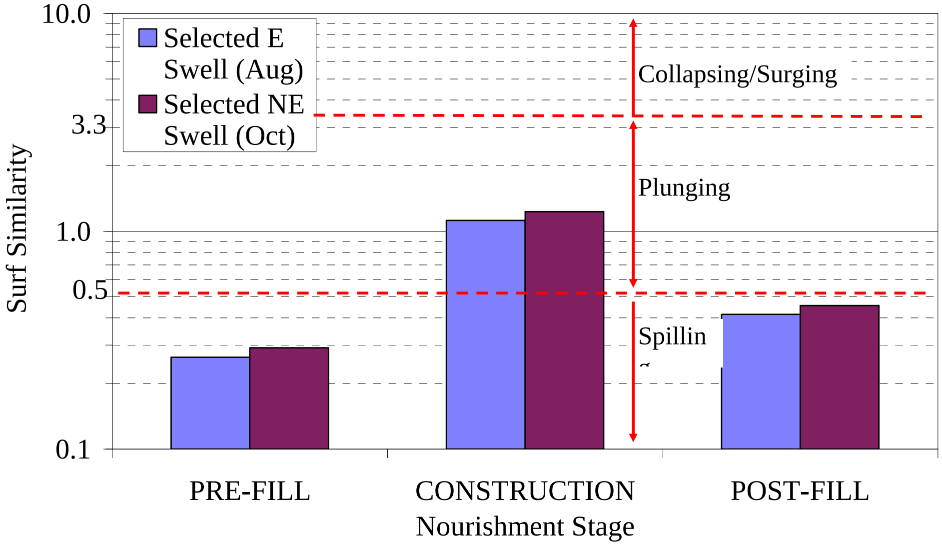

Figure 15 – Surf Similarity Parameter during the Various Nourishment Stages

## DISCUSSION

Although the model shows an acceptable comparison to the surfing events, the analysis would benefit from a more detailed survey exercise. The existing survey data, extracted from 300m profiles extending 1,000 m offshore do not capture subtle bars features that contribute to the surfing wave. Either a smaller grid spacing survey or LIDAR would better suit the desired study of the effect beach nourishment has on surfing waves.

The CGWAVE model adequately showed the surfing wave improvement. However the CGWAVE model is restricted to wave transformations and breaking wave heights within the mild slope criterion. A Boussinesq model would be required to assess the wave form (non-linear) characteristics.

Although St. Augustine Beach profited from the Shore Protection Project at the Dredge, the analysis does not address either additional surf locations generated or potential adverse impacts to existing surf breaks. For example, the nourishment project has allowed the region in front of the seawall to become surfable as waves break on the nourished sand instead of the armour stone. A future study would address this oversight.

As the 2005 Pre-Fill bathymetry included residual nourished sand from the 2003 project, the study did not consider the difference between the historical FAs wave (i.e. before the 2003 project) to the Post-Fill (the Dredge) wave. The mechanisms for the surfing wave generation differ. FAs broke from wave refraction around the seawall, while the Dredge broke from refraction around the nourished sand. A future study would analyse and compare the two waves.

As more interest is generated into consideration of surfing wave improvement from nourishment projects, a future study could include a proposal into project specific nourishment templates. Template suggestions include triangular or various trapezoidal planforms, or combination of nourishment with hardened structures. Of particular interest would be the performance of a saw-tooth design to allow for multiple break points. Shoreline change or morphodynamic modelling could demonstrate such project’s potential.

Regardless, the analysis clearly demonstrates the surfing wave improvement from the nourishment project. The results could be considered as a benefit in the USACE’s cost-benefit analysis of nourishment projects, especially for repeat projects such as that in St Johns County. Yearly surveys will further document the evolution of the wave generated. Monitoring of the surfing aspects in future nourishments provides a database of “full-scale” applications. This provides critical information on the science of surfing waves that is currently incomplete.

Although this effort concentrated on the St. Johns County project, surfing benefits are realised from almost all taper locations from beach nourishment projects. Figure 16 shows a picture, taken by the author on Jan 29th, 2007, of a right-breaking surfing wave produced by the Carolina Beach nourishment project in winter 2006/2007. Note the construction project is ongoing in the background of the picture. The picture shows that the wave produced by the St. Johns County project was not site-specific.

Figure 15 – Right-breaking wave produced by Carolina Beach Nourishment project

## CONCLUSIONS

Model results detail the improvement to the surfing wave from the nourishment project. For the two swell events monitored, average surf similarity increases from 0.3 (spilling wave) to 1.1 (pitching wave) – an increase of 280% - from pre-fill to construction surveys. Peel angles increase from 6º (closeout) to 30º (surfable) – an increase of 443%. However, after just 4 months of regular beach processes, the average surfing wave characteristics decrease to 47% (surf similarity) and 38% (peel angle) over Pre-Fill conditions. The remarkable success of the surfing wave improvement (albeit temporary) warrants further study that incorporates shore protection design with surfing wave consideration. With a design that achieves these two foci, surfing aspects can be included as a public recreational benefit to a beach project.

## ACKNOWLEDGEMENTS

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