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## Coastal Resilience Metrics from Beach-fx

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**PURPOSE:** In this Coastal and Hydraulics Engineering Technical Note (CHETN), a preliminary approach is presented to quantify the resilience of dune and beach nourishment projects using metrics from Beach-fx (Rogers et al. 2008). The objectives of this CHETN are to describe how dune and beach nourishment projects fit into the definition of resilience and to identify Beach-fx output data that can be used as metrics to quantify resilience. The U.S. Army Corps of Engineers (USACE) has implemented dune and beach nourishment projects across the country for coastal storm risk management (CSRM) purposes. Quantifying resilience will support the planning and design of resilient CSRM projects.

**BACKGROUND:** A key finding of the North Atlantic Coast Comprehensive Study (USACE 2015) is that resilience can be improved within the CSRM framework. A technical report was published, as a part of the NACCS effort, entitled *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience* (Bridges et al. 2015). This report presents a framework for analyzing the contributions of NNBF, such as dune and beach nourishment, to coastal system resilience and states “Models, tools and techniques to assess coastal systems, such as Beach-FX... can be applied to quantify performance...” Beach-fx is the only USACE-approved planning model for dune and beach nourishment projects nationwide. The NACCS study identified Beach-fx as a potential research opportunity to understand the performance of dune and beach nourishment projects, and this technical note attempts to provide a preliminary methodology to develop metrics to quantify the resilience provided to communities by dune and beach projects using output data from Beach-fx.

**DEFINING RESILIENCE:** There are many definitions of resilience that have been used for different applications. For natural coastal features, the NACCS lists several of these definitions and notes that organizations advocating for resilience emphasize four key words in the definition of resilience: prepare, resist, recover, and adapt. For this CHETN, resilience is defined as the ability of a system to prepare, resist, recover, and adapt to achieve functional performance under the stress of disturbances through time (Rosati et al. 2015). Resiliency is increased when there is less loss in desired functionality and faster recovery following disturbances over time. In general, there are different types of disturbances that impact coastlines and different types of management measures that can be implemented to increase resilience of coastal communities. One possible solution to maximizing the resilience of coastal communities is to better engineer coastal storm risk management projects to be resilient. This CHETN will focus on the management strategies associated with increasing the resilience of dune and beach nourishment projects to coastal storms.

Typical dune and beach nourishment projects require periodic renourishment as the dune and beach erode naturally. As the project is monitored throughout its lifetime, designs can be adapted to improve resilience so that the next disturbance results in less impact to the ability of a project

to reduce risk. Figure 1 displays this timeline concept and the four key resilience stages as they apply to dune and beach nourishment projects. Table 1 describes how these stages specifically apply to dune and beach nourishment projects and specifies the data that represent these terms in the context of Beach-fx.

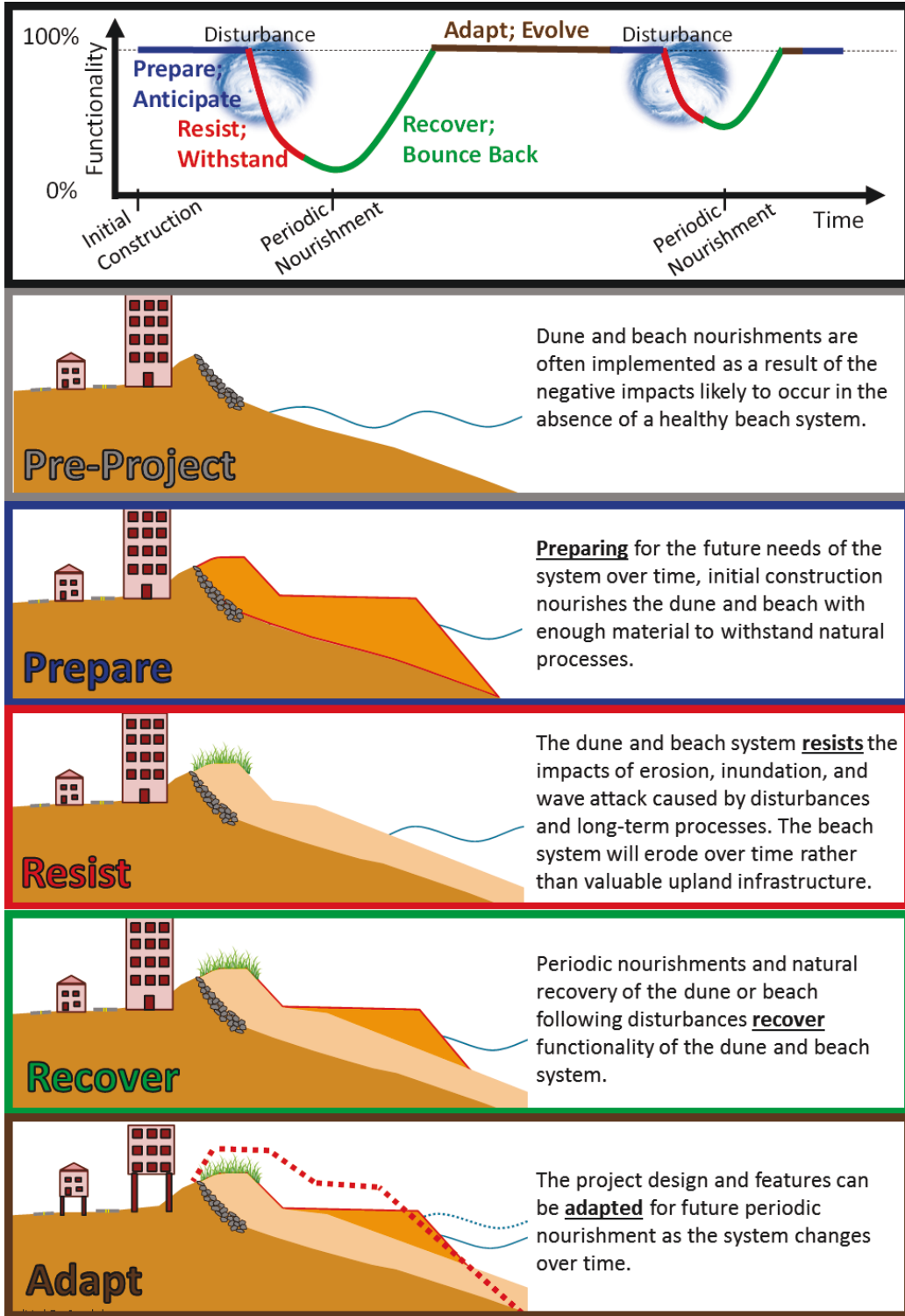


Figure 1. Resilience for dune and beach nourishment projects.

<b>Table 1. Breakdown of resilience definition for dune and beach nourishment projects.</b>		
<b>Resilience:</b> The ability of a <b>system</b> to <b>prepare, resist, recover,</b> and <b>adapt</b> to achieve <b>functional performance</b> under the <b>stress of disturbances</b> through <b>time</b> .		
<b>Term</b>	<b>Applicability to Dune and Beach Nourishment Projects</b>	<b>Representation in Beach-fx</b>
System	The entire beach system, including dunes, dry beach berm, submerged profiles, and sand bars. The nourishment alternative. Community infrastructure.	Representative profiles and the Shore Response Database. Coastal morphology output files. Damage element inventory.
Prepare	Predicting the long-term and storm-induced forces that will cause damage to infrastructure in the future. Design phase of a project.	Plausible Storm Database. Calibration to long-term erosion with factored in sea level rise. Planned Alternatives.
Resist	The dune and beach system eroding in response to coastal storms. The dune and beach system reducing damages from erosion, inundation, and wave attack.	Shore Response Database. Economic damages prevented.
Recover	Nourishment events and natural recovery.	Planned nourishment alternatives. Berm recovery factor.
Adapt	Adjusting re-nourishment needs by monitoring performance.	Initially defined minimum mobilization volume and nourishment triggers that do not change throughout a lifecycle.
Project Performance	Reduced damages to infrastructure. CSR National Economic Development benefits	Damage output files. Coastal morphology output files. Lifecycle costs. FWOP* vs. FWP* scenario model runs.
Disturbance Impact	Damage to infrastructure caused by erosion, flooding, and wave attack induced by coastal storms and long-term coastal processes. Degradation of the beach's protective capacity.	Plausible Storm Database. Shore Response Database. Damage functions relating physical processes to economic damages to infrastructure. Beach morphology output files.
Time	50-year period of Federal Participation	Time-step processes. Lifecycle results. 50-year model simulations.

\*Notes

FWOP = Future Without Project Condition

FWP = Future With Project Condition

**COASTAL MORPHOLOGY IN BEACH-FX:** Beach-fx is a model for evaluating the physical performance and economic benefits of CSR projects. Beach-fx calculates morphology evolution and the associated damages caused by storm events. Beach-fx is an economic-engineering model that utilizes detailed information from coastal process models. These process models use a simplified beach profile with key morphologic features that include upland width, upland elevation, dune width, dune height, dune slope, berm width, berm height, foreshore slope, and a static representation of the submerged profile (Figure 5). The model assumes a single dune, static dune slope, single berm at a constant elevation, static foreshore slope, and static representative submerged profile.

Once profiles are established, a suite of plausible storms is developed for the project area based on historic events or an analysis of a probabilistic storm database. The Storm-induced Beach Change (SBEACH) model is run for each representative profile to define the profile response to storms contained in the plausible storm suite (Larson and Kraus 1989). The SBEACH results include morphology change along with wave, water level, and erosion profiles. These SBEACH results are then made accessible after being uploaded to the Shore Response Database (SRD), a housing location for SBEACH results. As Beach-fx is running, the model looks up profiles from the SRD to simulate profile change over time as plausible storms occur. Beach-fx is calibrated so that cross-shore erosion is consistent with the historic shoreline change rates measured in the area being modeled.

Natural recovery is handled by Beach-fx using a berm width recovery factor, which is a user-defined percentage of storm-induced, berm-width erosion that is restored due to post-storm recovery processes over a given time period. For example, specifying a recovery factor of 90% and recovery period of 21 days would restore a 40-foot (ft)-wide berm that erodes to 20 ft during a storm, back to a 38 ft wide berm 21 days after the storm. Outside of this recovery factor and period, no additional long-term dune accretion (aeolian sand transport) is considered. Figure 2 shows a screen capture of a Beach-fx animation displaying the modeled profile change associated with a storm event and berm recovery.

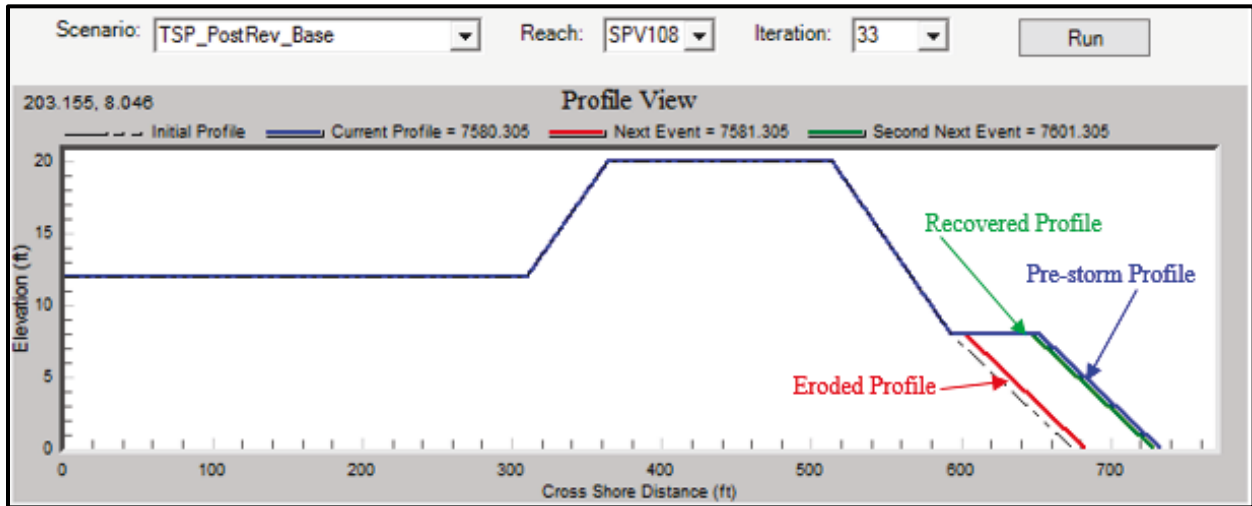


Figure 2. Modeled profile change associated with a storm event and berm recovery.

Planned dune and beach nourishment activities restore the beach profile to the alternative design template throughout the simulated project life cycle when user-defined erosion and mobilization thresholds are met to trigger a nourishment. Figure 3 shows a screen capture of the Beach-fx animation showing the modeled profile change associated with the construction of a planned nourishment event.

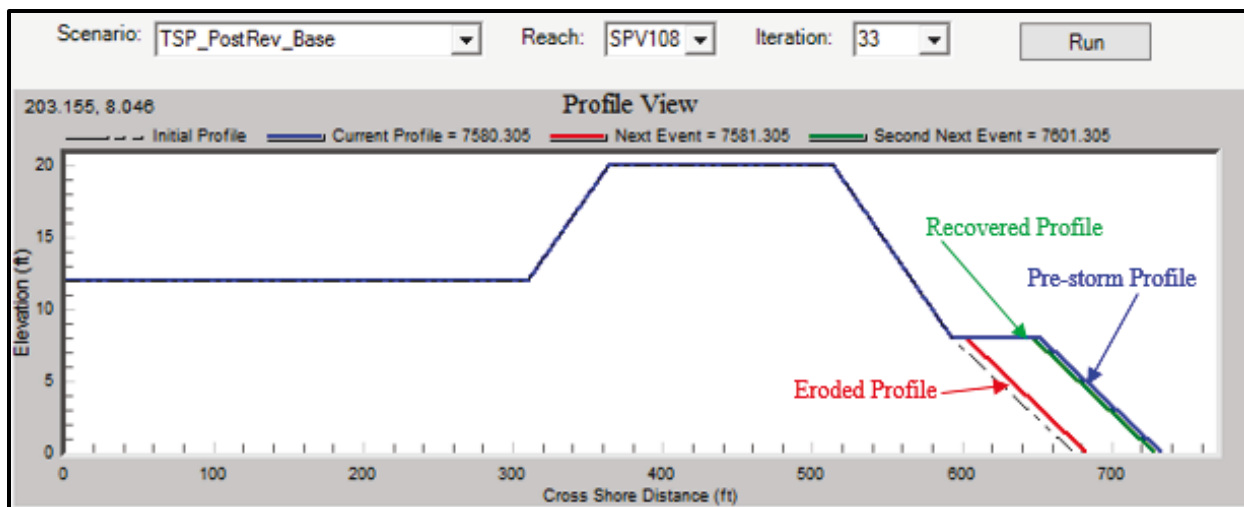


Figure 3. Modeled profile change associated with a nourishment event.

Beach-fx tabulates the upland width, dune height, dune width, and berm width for a modeled storm event occurrence in the MorphologyTimeline.csv output file. A screenshot capture of this output is pictured in Figure 4.

	A	B	C	D	E	F	G	H	I
1	Iteration	Time	Reach	UplandWidth	DuneHeight	DuneWidth	BermWidth	EventType	
24179	51	9809	SPV100	310	20	112.851	28.226	PreStorm	SFE_19931201
24180	51	9810	SPV100	310	20	112.851	16.07	PostStorm	SFE_19931201
24181	51	9830	SPV100	310	20	112.851	27.18	REC	SFE_19931201
24182	51	9931	SPV100	310	20	112.851	27.97	PreStorm	SFE_19990131
24183	51	9932	SPV100	310	20	112.851	19.878	PostStorm	SFE_19990131
24184	51	9952	SPV100	310	20	112.851	27.33	REC	SFE_19990131

Figure 4. Screen capture of MorphologyTimeline.csv Output File where time unit is in days; event types include “PreStorm,” “PostStorm,” and “REC” (or recovery) nourishments. Storm identifier numbers are listed in column “I.”

Beach-fx makes several other simplifications to comply with USACE planning policies that must be considering when applying its output data for resilience metrics. These simplifications include the inability to increase structural inventory, inflation, or demand, and the static nature of coastal armoring and a single planned alternative through the project life cycle. The Beach-fx structure inventory represents the existing community infrastructure and cannot grow throughout the project life cycles. However, community infrastructure likely will change over time. Coastal armoring features in Beach-fx do not influence the coastal morphology but reduce erosion damages to zero when armor is in place and has not failed based on user-defined thresholds. Finally, planned nourishment alternatives cannot be changed over the course of a simulated life cycle. A single template with specified dune and berm dimensions is used for all nourishments throughout the life cycle simulated.

**METHOD TO QUANTIFY RESILIENCE:** The term *resilience metric* refers to a standard measurement by which resilience can be assessed. Within this CHETN, Beach-fx output data from

a completed study were used to identify potential resilience metrics and quantify the resilience afforded by several planned alternatives. It is assumed that there is a correlation between the function of dune and beach nourishment projects to reduce damages to infrastructure and the overall community resilience. In this way, if dune and beach nourishment features are managed to be better prepared for storm events and effectively manage coastal storm risk over time, then the resilience of the coastal community where this measure is implemented is also increased.

**IDENTIFYING BEACH-FX OUTPUT DATA AS RESILIENCE METRICS:** The predictive life-cycle modeling approach of Beach-fx simulates the outcome of multiple sequences of storm events that characterize the potential future storm climatology. This type of approach is well suited for coastal systems because of how dynamic they are as a function of storm frequency and severity. Although assumptions and idealizations in profile dimensions are made, a Beach-fx model simulation is an efficient, robust, and cost-effective means to evaluate beach nourishment alternatives.

Due to the simplification of complex coastal processes and nourishment design described in the above sections, it is concluded that resilience metrics for the “recover” and “adapt” stages cannot be appropriately quantified using output data from Beach-fx. This analysis will focus on quantifying the resilience metrics for the ability of the coastal communities to better “prepare” for and “resist” storm disruption based on the dimensions of an adjacent dune and berm. Since both the dune and berm portions of the active beach profile evolve as the shoreline responds to storm events, a single measurement entitled “buffer width” (BW) is proposed to represent the portion of the beach profile that serves to prevent damages to upland infrastructure.

The U.S. Geological Survey identified a beach change envelope (BCE) that represents a storm wave impact zone on the upper portion of the beach profile. The measurement of the BCE width was used as a metric to analyze natural beach recovery and geomorphic resiliency following Hurricane Sandy along Fire Island, New York. (Hapke et al. 2015).

BW is similar to the BCE and will be used as a resilience metric based on the simplified profiles used in the Beach-fx model. The BW metric reflects the functionality of a dune and beach nourishment project because it includes the portion of the profile that can be nourished to buffer community infrastructure from storm-induced damages. It is the combined horizontal distance of the dune width, seaward dune slope, and berm width. Figure 5 illustrates the BW for a typical Beach-fx profile. The BW can be measured for a given point in time from the MorphologyTimeline.csv output file using the following equation, where the berm height and dune slope are constants.

$$\text{Buffer Width (BW)} = \text{dune width} + \frac{(\text{dune height} - \text{berm height})}{\text{dune slope}} + \text{berm width} \quad (1)$$

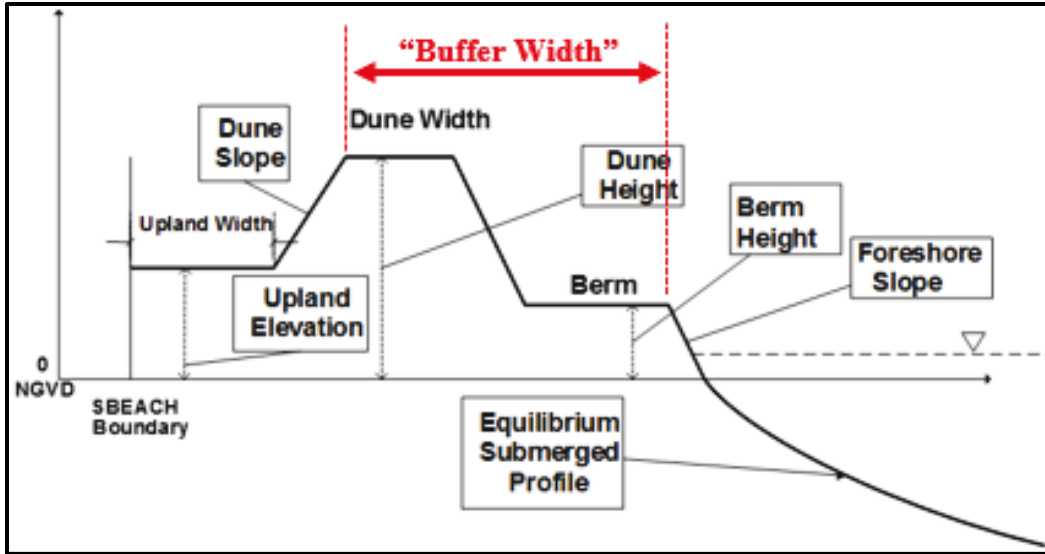


Figure 5. BW on the Beach-fx representative profile.

The BW is a relevant metric where erosion is the primary driver of without project damages, but for other coastal dune and beach systems where inundation or wave attack is the primary damage drivers, other metrics such as dune height or dune width may be more appropriate.

**ANALYSIS OF BEACH-FX RESILIENCE METRIC:** The Beach-fx output data used for this analysis are a result of the St. Johns County, Florida, Coastal Storm Risk Management Feasibility Study. The BW was compared for the project reach across three different project alternatives and a future without project condition (FWOP) over a specific Beach-fx simulated life cycle. The three alternatives include “0D\_60B” for a 60 ft seaward extension of the berm, “10D\_40B” for a 10 ft seaward extension of the dune and 40 ft seaward extension of the berm, and “20D\_20B” for a 20 ft seaward extension of the dune and 20 ft seaward extension of the berm. The morphology constants for this profile include an upland elevation of 12 ft (North American Vertical Datum 1988 [NAVD 88]), a dune slope of 0.15, a berm elevation of 8 ft (NAVD 88), and a foreshore slope of 0.1. The starting dimensions of this profile include a dune width of 150 ft, dune height of 20 ft (NAVD 88), and a berm width of 0 ft. Figure 6 shows the initial profile for the model reach along with the three alternative templates to be compared.

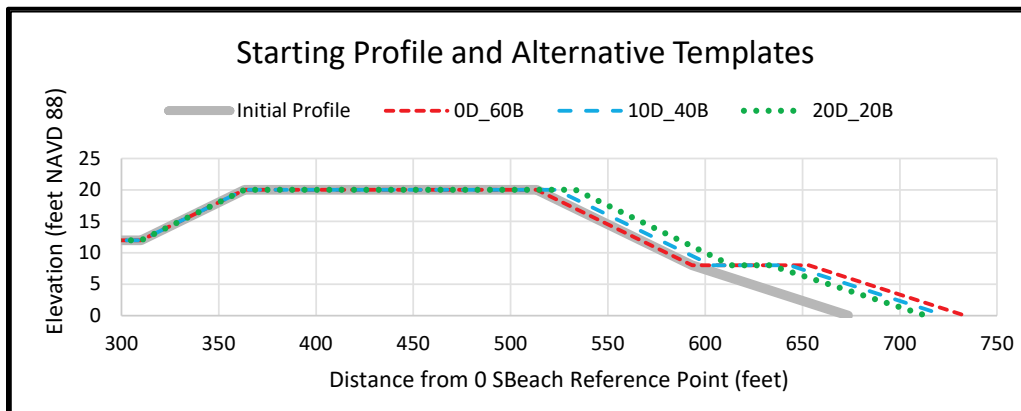


Figure 6. BW over 50-year period of analysis.

The BW value is taken here to represent the functional performance of an alternative over time. Figure 7 shows a comparison plot of the BW over time for the three alternatives and FWOP condition for a single simulated project life cycle. Multiple life cycles were simulated for the feasibility study, but the single life cycle used for this analysis was selected because it had the average number of storms for the life cycles modeled. For decision documents, all life cycles could be considered for assessing resilience and comparing alternatives. Within Figure 7, the downward spikes indicate erosion of the BW associated with a storm event. This example utilized a 90% berm width recovery factor over 21 days. Even with 90% recovery, the BW of the FWOP profile decreases over time. For the project alternatives, upward spikes indicate periodic nourishment events that restore the BW to the original alternative design throughout the simulation. The upward spikes following a storm represent the simplified berm recovery modeled by Beach-fx. Figure 8 shows the BW plot associated with a single storm event that occurs approximately 11 years after initial construction.

The “prepare” stage of resilience is represented by the pre-storm BW. Although the dune and beach profile changes over time due to natural erosion, it is built back out to the planned nourishment template based on renourishment triggers defined by the Beach-fx user.

The “resist” stage of resilience is represented by the rapid reduction in BW associated with storm driven erosion of a specific event. This storm response is based on the SBEACH simulations used to build the shore response database.

The “recover” stage of resilience is represented by the increase in BW associated with a nourishment event or natural post-storm recovery. The natural berm recovery is applied uniformly following all storm events in the simulation based on the user-defined berm width recovery factor and recovery time period.

The “adapt” stage of resilience is not represented on the BW profile because Beach-fx is limited by planning policy to only implement one planned nourishment alternative throughout a life cycle. However, monitoring project performance and adaptive management throughout the project life cycle can increase resilience.

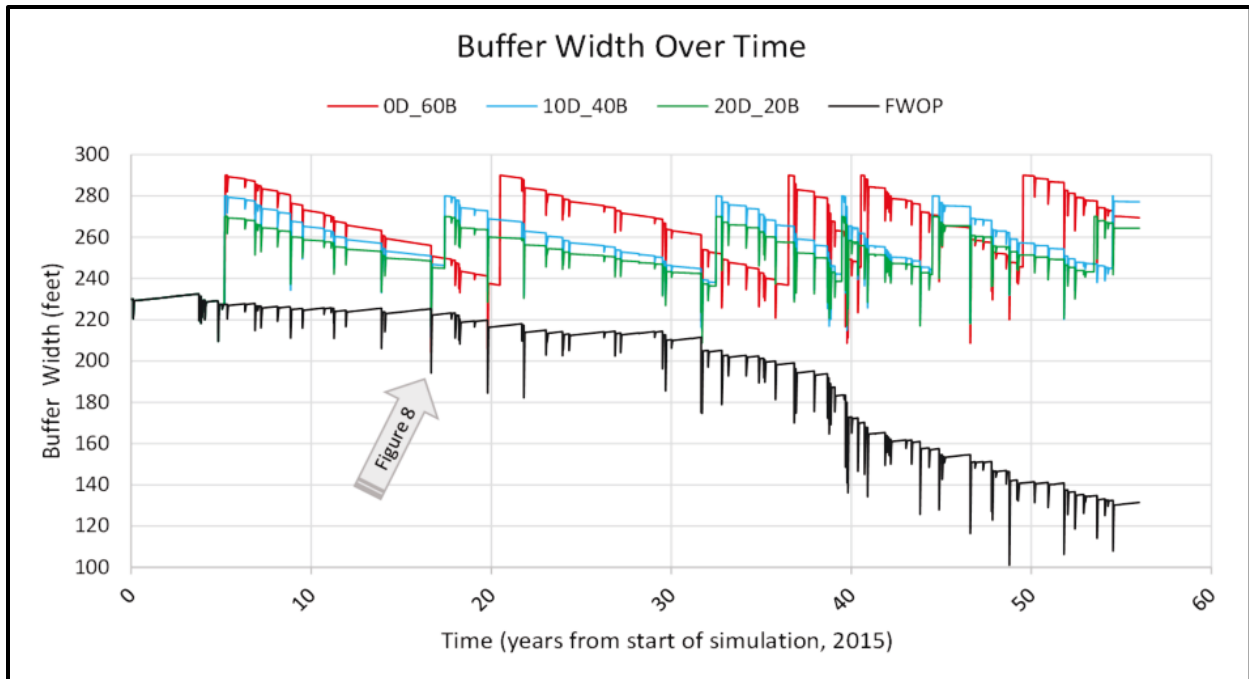


Figure 7. BW over the project life cycle. Grey arrow indicates the location on the timeline that Figure 8 occurs.

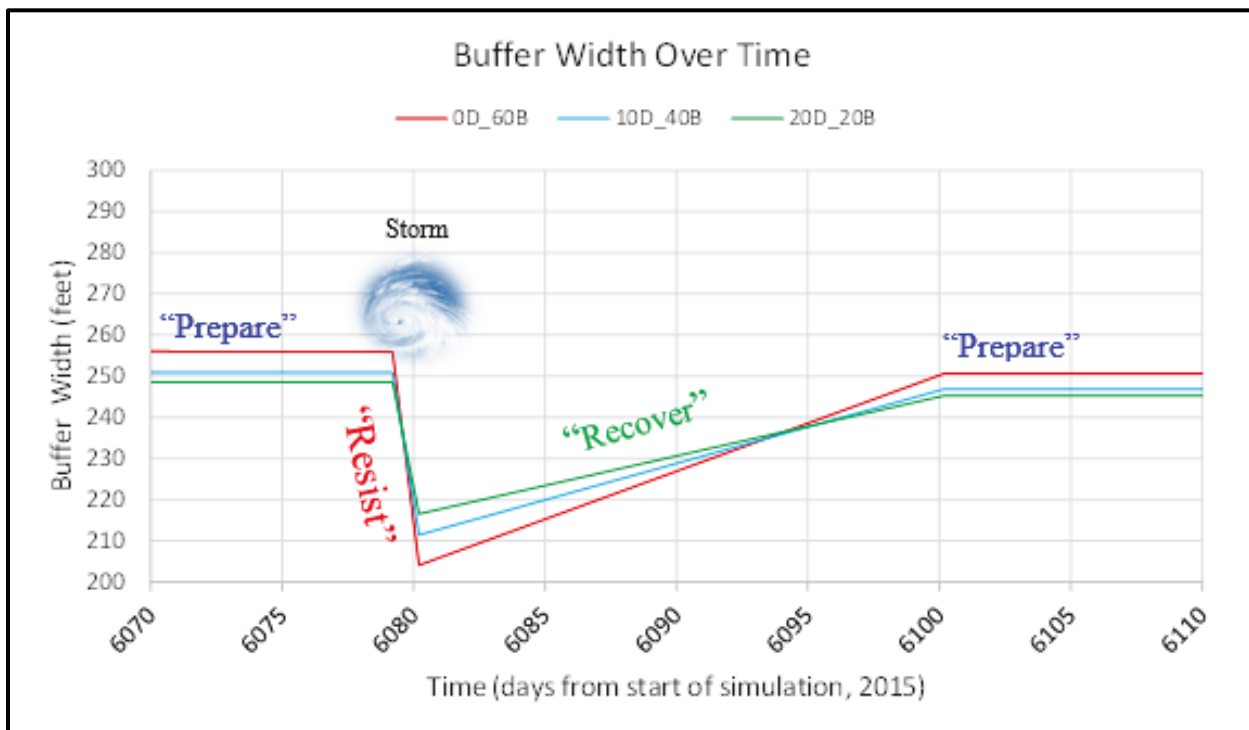


Figure 8. BW for a single storm.

Similarities can be seen between the BW plot in Figure 8 and the typical resilience timeline at the top of Figure 1 showing resilience functionality over time.

For quantifying resilience, the “resist” stage of the BW plot is the most telling, since the “prepare,” “recover,” and “adapt” stages are constant over a simulated life cycle. Looking at the storm event in Figure 8, it can be seen that the 20D\_20B alternative undergoes the least amount of pre- to post-storm BW change, indicating that it does a better job of resisting the erosion of the storm than the other two alternatives. To gauge resilience in terms of how well each alternative resists storm impacts, the “resist” portion of the BW plot was reviewed over the entire life cycle. This was accomplished by isolating the pre-storm and post-storm BW values and calculating the pre- to post-storm BW change associated with each storm event in the life cycle. The cumulative pre- to post-storm BW change is plotted for the project life cycle starting at the time of initial construction in Figure 9. Cumulatively, the 20D\_20B alternative is the most resilient alternative based on how it resists losses to its BW over the 50-year period of analysis. This indicates that having an alternative with a larger dune width increases resilience.

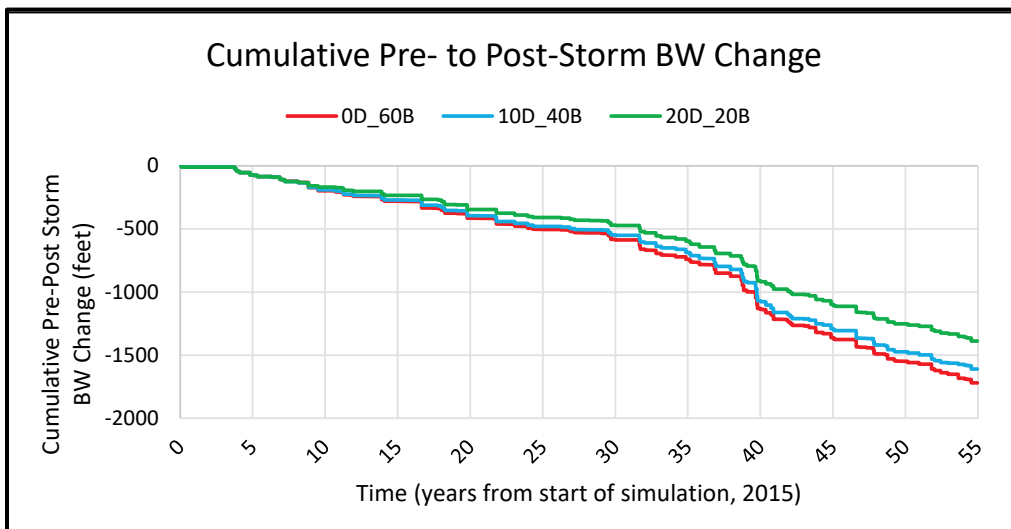


Figure 9. Cumulative pre- to post-storm BW change.

This analysis only considers a single beach profile for a single project life cycle. It is possible that results might vary for profiles located at the ends of the beach fill as compared to the middle. It is also possible that results might vary depending on the nature and timing of storm events over modeled life cycles. Comparing the distribution of the cumulative pre- to post-storm BW change across multiple life cycles for different alternative would be a good way to compare the resilience of those alternatives since Beach-fx models multiple life cycles.

Note that the dune and beach system examined in this case study has unique morphology, and storm damages for this morphology type are primarily driven by erosion. The BW is a relevant metric for this morphology, but for other coastal dune and beach systems, other metrics may be more appropriate. For example, for projects that are designed to primarily prevent flood or wave damage, a different metric such as dune height might be more appropriate. This approach can be used to quantify resilience using different metrics with time-series data from the MorphologyTimeline.csv output file.

**Potential Applications for Beach-fx Resilience Metrics.** Beach-fx is used to plan CSRM dune and beach nourishment projects across the nation, and the model outputs for these studies

can be used to quantify resilience. USACE Engineering Regulation 1105-2-101, *Risk Assessment for Flood Risk Management Studies* (USACE 2017), requires a risk assessment for all principal decision documents that “will quantify the performance, resilience and risk of all scales of all alternatives considered in formulating the recommendation.” This approach could be used to quantify resilience. Metrics for resilience can be used in the planning process to determine if certain alternatives will be more resilient than others over time and to better design and manage projects to increase resilience. This approach to quantifying resilience can also be used for other types of flood risk management projects using life-cycle planning models that provide time-series output data describing the project’s physical performance.

**SUMMARY:** This CHETN presents an approach to quantify the resilience that dune and beach nourishment projects can afford to coastal communities using the metrics from Beach-fx data. The definition of resilience has been broken down to show how the stages of resilience specifically apply to dune and beach nourishment projects and the data that have been identified to represent these stages in the Beach-fx model. The BW is defined as a metric that can be used to quantify the resilience of dune and beach nourishment projects using output data from Beach-fx model runs. Specifically, the change in BW from pre- to post-storm can be used to quantify the “resist” stage of the resilience. The goal of quantifying resilience aligns with several of the resilience-related strategies described in the Resilience Initiative Roadmap (USACE 2016), and data-based approaches like these can greatly improve the understanding of what being resilient means for dune and beach nourishment projects.

**POINTS OF CONTACT:** This Coastal and Hydraulics Engineering Technical Note (CHETN) was prepared as part of the USACE Flood and Coastal Systems (FCS) Program by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Vicksburg, MS. Additional information pertaining to the FCS Program may be obtained from the FCS Program Manager, Mary Cialone ([Mary.A.Cialone@usace.army.mil](mailto:Mary.A.Cialone@usace.army.mil)). Questions regarding this CHETN can be addressed to Martin Durkin (904-232-2190; [Martin.T.Durkin@usace.army.mil](mailto:Martin.T.Durkin@usace.army.mil)) at USACE Jacksonville District (SAJ). This document can be referenced as follows:

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