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# Representative Beach Profile Generator

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**PURPOSE:** The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to introduce an Esri ArcGIS Pro ArcPy Toolbox entitled "Representative Beach Profile Generator (RBPG)" that generates a single representative profile for a given study area based on elevation profiles. The toolbox aligns and averages input elevation profiles into a single profile based upon a chosen alignment feature. Furthermore, the toolbox allows the user to create maximum and minimum trapezoidal profile approximations for use within numerical models such as **S**torm-Induced **BEA**ch **CH**ange (SBEACH) and Beach-fx. This CHETN presents a brief description of the toolbox methods and includes a short demonstration of the toolbox's application to help familiarize the user with inputs, outputs, and possible uses. The RBPG toolbox is available for public download at the link where this paper is hosted with the US Army Engineer Research and Development Center library services (*http://dx.doi.org/10.21079/11681/46916*).

**INTRODUCTION:** Numerical modeling is a critical tool that informs United States Army Corps of Engineers (USACE) mission of protecting and maintaining US coastlines (Rosati et al. 2015). Elevation cross sections are typically used in numerical models by coastal researchers. Beach-fx, the USACE model of choice for economic analysis of Coastal Storm Risk Management (CSRM) project (Rogers et al. 2009), requires elevation profiles that represent, on average, either the CSRM project as a whole or distinct reaches within a project. The 2D elevation cross section, or representative profile, displays the elevations at a shore perpendicular regular interval along a coastline. Geomorphic features (i.e., sand dunes and bluffs) represented in the cross-shore profile are often of interest to engineers and scientists and provide a framework for understanding coastal change.

The numerical model for simulating SBEACH requires a large number of iterative elevation profiles representing the beach at different time-steps throughout a simulation (especially when run in conjunction with Beach-fx) (Larson and Kraus 1989). While a single representative profile may not be the only profile that is used in a model such as SBEACH, the iterative profiles that are generated in the SBEACH data generator do require a single maximum profile and a single minimum profile to serve as the basis for iterating profile shapes developed throughout a simulation. In SBEACH, the representative profile has historically been developed through the beach morphology analysis package (BMAP), a software within the Coastal Engineering Design and Analysis System (Sommerfeld et al. 1994). The RBPG is able to generate this representative profile using a similar methodology as the BMAP system with the added benefit of seamlessly integrating with modern Geographic Information Systems (GIS) platforms such as Esri ArcGIS Pro. The RBPG generates these representative profiles as well as the minimum and maximum profiles for the purposes of SBEACH model inputs based on spatially georeferenced raster data.

**BACKGROUND:** Modern methods for capturing coastal topography and bathymetry vary depending upon extent, resolution requirements, and budget considerations. Coastal engineering applications that require high-resolution, high-accuracy elevation data often rely on lidar as a cost-effective way to acquire data at regional scale. The USACE Joint Airborne LiDAR Bathymetry

Technical Center for Expertise (JALBTCX) specializes in regional topographic and bathymetric lidar data collection and provides these data with accompanying imagery data for USACE district engineers and scientists through the National Coastal Mapping Program (NCMP) (Wozencraft and Lillycrop 2006). JALBTCX recently developed a geomorphology feature extraction toolbox to support transect-based feature extraction from lidar-derived Digital Elevation Models (DEMs). This toolbox is the foundation for the Coastal Engineering Resilience Index (CERI), a metric that allows coastal scientists to quantitatively define engineering resilience of the coastline based on coastal morphology and wave climate (Dong et al. 2018; Spurgeon 2022). This toolbox has been applied to regional lidar datasets to support shoreline analysis (Dunkin et al. 2020; McGill et al. 2021; Elkins 2022), CERI analysis (Spurgeon 2022), and geomorphic feature extraction and monitoring (Robertson et al. 2018). While feature extraction within Esri products is not a novel idea, the applications of the geomorphology feature output derived via this toolbox to support USACE engineering activities are still being discovered.

Models such as Beach-fx (which typically uses SBEACH inputs) continually update simulated elevation profiles using a trapezoidal approximation (Figure 1[*]). Regardless of application, the ability to extract elevation profile data from regional, geospatial data increases efficiency and standardization of developing representative beach profiles, especially when using airborne lidar as compared to terrestrial lidar as airborne lidar allows for much larger regional areas to be analyzed as a part of the profile approximating process.

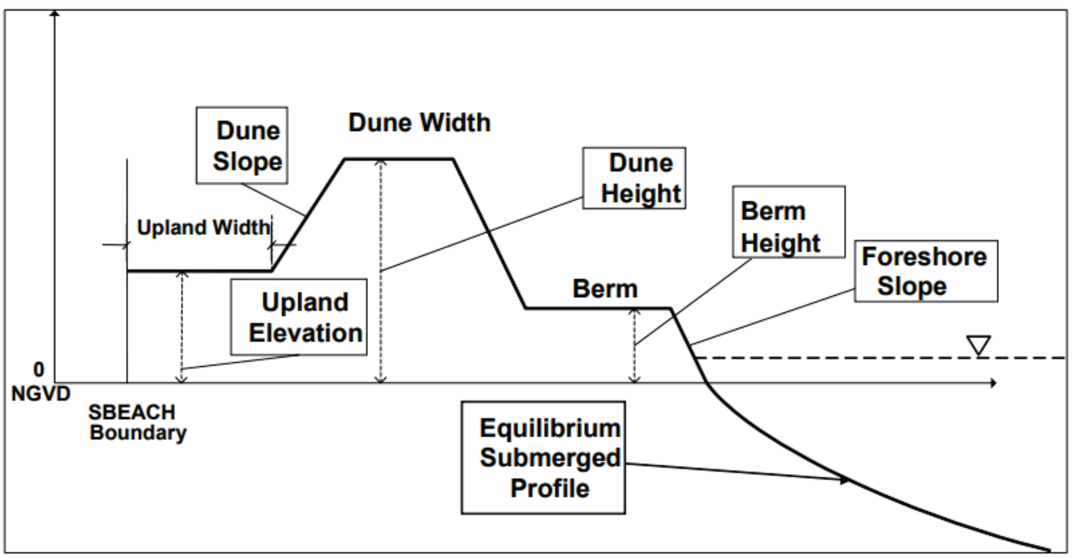


Figure 1. Beach-fx trapezoidal schematic of a beach profile adapted from Rogers et al. (2009).

The extraction process that is completed by the dune feature extraction toolbox is documented in Spurgeon (2022) and Robertson et al.[†] Dune feature extraction toolbox steps that must occur to support the RBPG toolbox include the following:

1. Generate Shoreline (to generate a baseline)

[*] NGVD = National Geodetic Vertical Datum

[†] Robertson, Quin, Zhifei Dong, and Jennifer Wozencraft. In Review. "Incorporating Wave and Storm Data to Apply the Coastal Engineering Resilience Index at Regional Scales." *Coastal Engineering*.

2. Generate Transects
3. Grid Data to Transects (Step 1 of Dune Feature Extraction Toolbox)
4. Extract Profile and Plot (Step 2a of Dune Feature Extraction Toolbox)

If needed, steps to smooth the shoreline or extend the transects may also be used to refine transects to ensure complete coverage of the shoreline and bathymetric area of interest. These steps build on one another, and the output from one step serves as an input to the next step. Depictions of DEM data, baseline, transects, and extracted features are shown in Figure 2 from a section of Duck, North Carolina. The extracted features include the back toe of the dune (BT), the extracted bar crests (BarC#) and toes (BarT#), the dune toe (TO), extra dunes (ED#), the frontal dune (FD) feature, the highest dune (HD) feature, and the landward limit (LL). The feature set is exported to a feature class in which each feature (point geometry) is attributed with the cross-shore position (relative to the baseline, known as the range) and DEM elevation at each of these points. Points identified as extracted features are shown in Figure 2; these extracted features along with all points sampled from the DEM at 1 m[‡] are required inputs for the RBPG toolbox. Note that the *spacing interval* within the gridding step of the dune feature extraction toolbox is important to specify (in feet or meters, depending on what horizontal unit the raster and transects are in) as it will appear again in the RBPG toolbox.

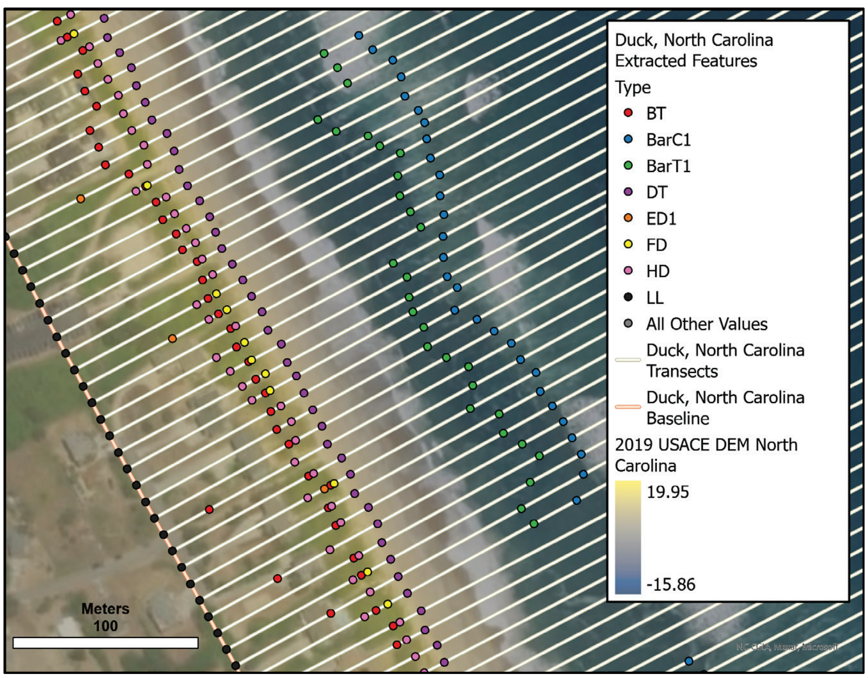


Figure 2. Duck, North Carolina, Digital Elevation Model (DEM), baseline, transects, and extracted geomorphology feature points.

**REPRESENTATIVE BEACH PROFILE GENERATOR (RBPG) TOOL DESCRIPTION:** The RBPG requires specific inputs that are generated from the dune feature extraction toolbox. The

[‡] For a full list of the spelled-out forms of the units of measure and unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248–52 and 345–7, respectively. [https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf](https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf).

workflow presented here will use dune feature extraction toolbox outputs generated for an area in Duck, North Carolina. The specific outputs include the baseline, a set of transects, the elevation points along the transects, and the extracted geomorphology feature point file. The DEM used as an input to the dune feature extraction toolbox is the USACE (2019) NCMP North Carolina topobathy lidar dataset available on the National Oceanic and Atmospheric Administration Digital Coast website. The transects were created along a smoothed baseline at 10 m spacing for a total of 228 transects. Best practice for application of the RBPG toolbox uses raster datasets that have similar morphology at a local or neighborhood scale and can therefore be easily represented by a single profile without overgeneralizing the entire region. For example, attempting to use an area where the raster dataset includes engineered dunes, nondune areas, and nonengineered beach might be an overgeneralization and can instead be considered as various reaches instead of one large reach.

After the dune feature extraction toolbox is executed, a user imports the RBPG toolbox into Esri ArcGIS Pro via the Toolbox > Add Toolbox drop-down menu on the Insert tab. Directing ArcGIS Pro to the latest version of the RBPG toolbox will place it under the Toolboxes menu within the ArcGIS Pro project's catalog. The RBPG toolbox is used in a very similar fashion to that of the dune feature extraction toolbox: each step is run in succession.

**Step 1: Plot and Align Profiles.** The first step in the RBPG toolbox is to plot and align the dune feature extraction toolbox output. The imports for this step are shown in Figure 3 and include the CERI factor table, extracted point file, a user-specified seaward limit, and the spacing interval from the Step 1 of the Dune Feature Extraction toolbox, and alignment choices. Note that while the extracted dune feature point shapefile is not a required input for this toolbox, the CERI factor table is required. The last input is an output folder so that a comma separated values (CSV) file can be saved for later use in the toolbox.

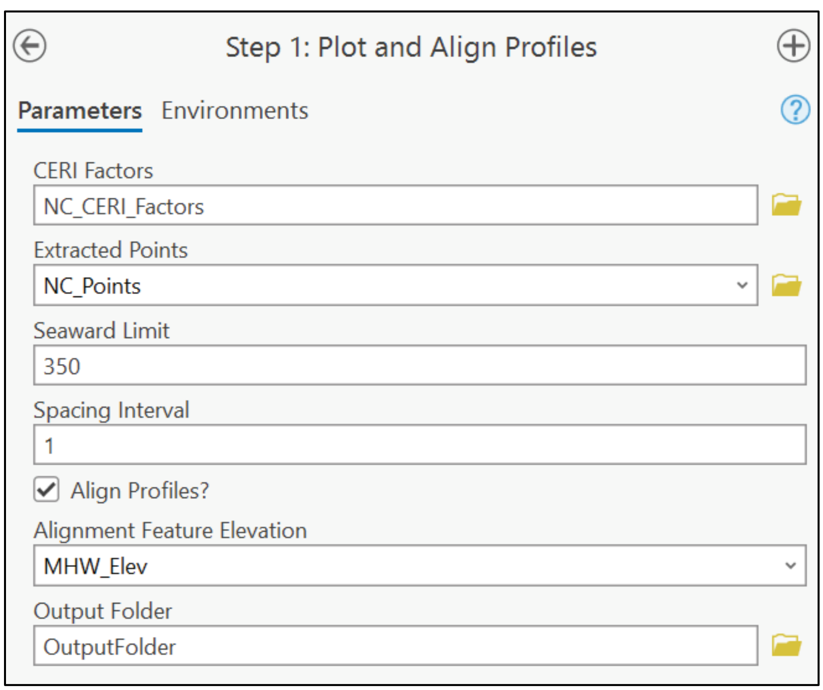


Figure 3. Representative Beach Profile Generator (RBPG) Step 1 inputs with included values from the Duck, North Carolina, example case.

The CERI factors and extracted points inputs are direct outputs from the dune feature extraction toolbox and can be selected and used seamlessly without user alteration of the data. The user may want to specify a smaller distance to better visualize the nearshore region, especially if offshore data are not a priority for the project. The spacing interval needs to be the same spacing interval that was used in the first step of the Dune Feature Extraction toolbox to ensure the alignment process works correctly. For example, if the spacing interval of the points is 10 m, the toolbox will adjust to plot accordingly. Both the seaward limit and spacing interval have units of feet or meters depending on the horizontal unit of the raster data and transects used in previous steps. Figure 3 contains values with units of meters as the data used in the Duck, North Carolina, data are in a Universal Transverse Mercator (meters)–projected coordinate system.

The alignment choices listed are two-fold: first, a checkbox for the user to turn alignment on or off. Alignment occurs through the use of an alignment feature elevation from the dune feature extraction toolbox such as the mean high water (MHW), dune toe, frontal dune, high dune, or landward limit. Alignment happens by shifting each profile to ensure that the specified elevation (such as the MHW elevation) occurs at the same range along a transect. For example, if the average extracted MHW point occurred at a range of 100 m and the MHW elevation is 0.5 m, each profile is then shifted left or right so that the profile elevation crosses the 0.5 m elevation mark at 100 m of range. An example of this alignment is seen in Figure 4; the *blue profile* would be shifted left until the *red mark* on the *blue profile* aligns with the *red* MHW average position. The alignment of each profile is to account for any curvature in the shoreline that may have caused the landward limit to not be the same cross-shore distance from the shoreline for every transect due to skewing from angled transects. For example, if the location of the frontal dune for one transect is at 100 m and for another it is 95 m and the profiles were to be averaged, there is likely to be a blending of the two peaks resulting in an averaged profile that is not representative of either of the two example profiles. Instead, each profile is shifted so that their shoreline elevations line up; their frontal dune points are likely to line up assuming they have a similar morphologic shape. The user can also select the frontal dune as the feature to align to, meaning that wherever each profile crosses that average frontal dune elevation would be shifted to align with the averaged cross-shore position for that elevation. The process is the same regardless of the feature chosen for alignment. In certain cases where the transects are very straight and there may be multiple features that may confuse the alignment process, alignment may not be turned off with better results than an incorrect alignment.

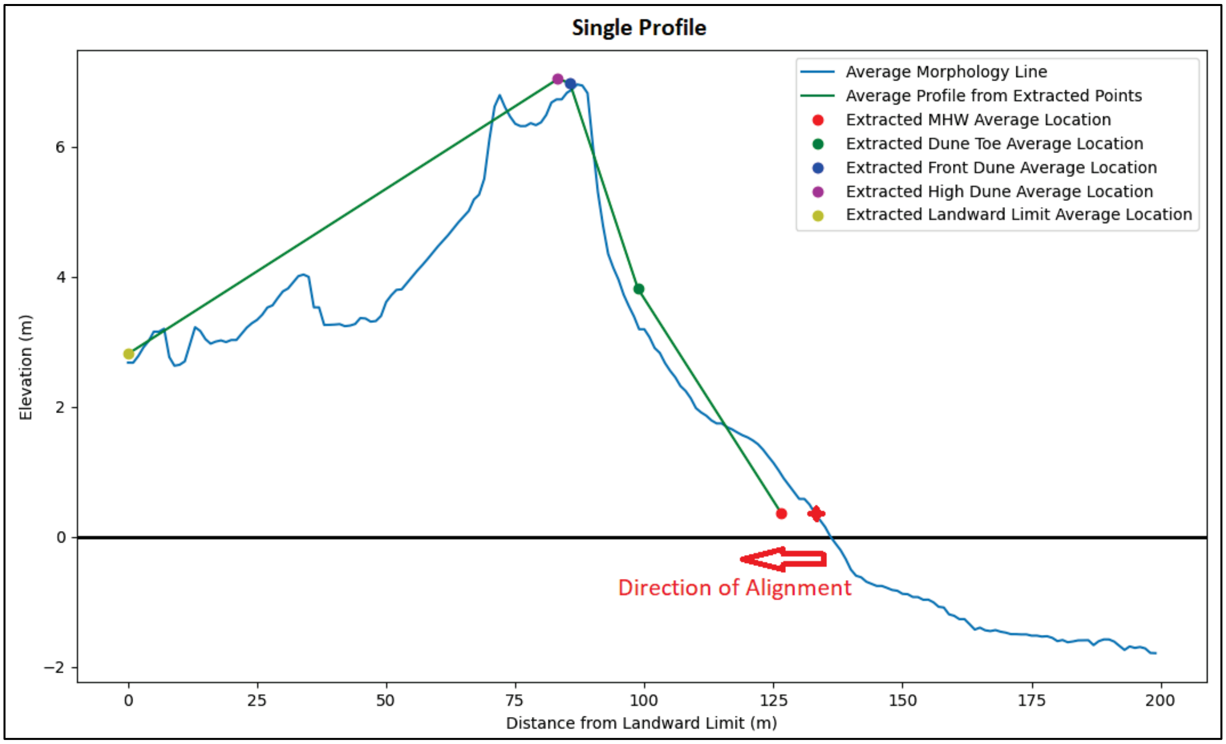


Figure 4. A single profile showing the direction of alignment when aligned to mean high water (MHW).

The profile points from the Duck, North Carolina, dataset were put through the RBPG toolbox's Step 1 to generate the results in Figure 5. The top plots (*A* and *B*) are the aligned data with the MHW being used as the alignment feature, and the bottom plots (*C* and *D*) are the unaligned plots. The data on the left are all of the profiles overlayed, and the data on the right are the averaged profile from that data (in *blue*) and the averaged profile based on extracted dune feature points (in *green*). The aligned data include only minor shifts since there is no major curvature in the baseline, but the aligned data are closer to the average profile from extracted points line. Note that the *green line* ("average profile from extracted points") in plots *B* and *D* are an average of extracted geomorphic feature elevations and are therefore constant regardless of alignment choice by the user. As such, the *green line* in the average profile plot provides a point of reference when comparing the *blue* average morphology line. For example, the average profile that has data aligned to the FD (plot *B*) places the average peak of the profile at approximately 80 m away from the landward limit while the same line in the non-aligned average profile (plot *D*) shows the peak of the profile at approximately 85 m from the landward limit. Thus, the not-aligned profile in plot *D* has a frontal slope that is closer to the average profile based on extracted points, although that shift in turn pulls the morphology line away from the back dune *green* profile line. As the *green* profile line approximates the morphology based on only a few points, it is advised that the user make their own judgement call which profile they feel is more accurate to reality.

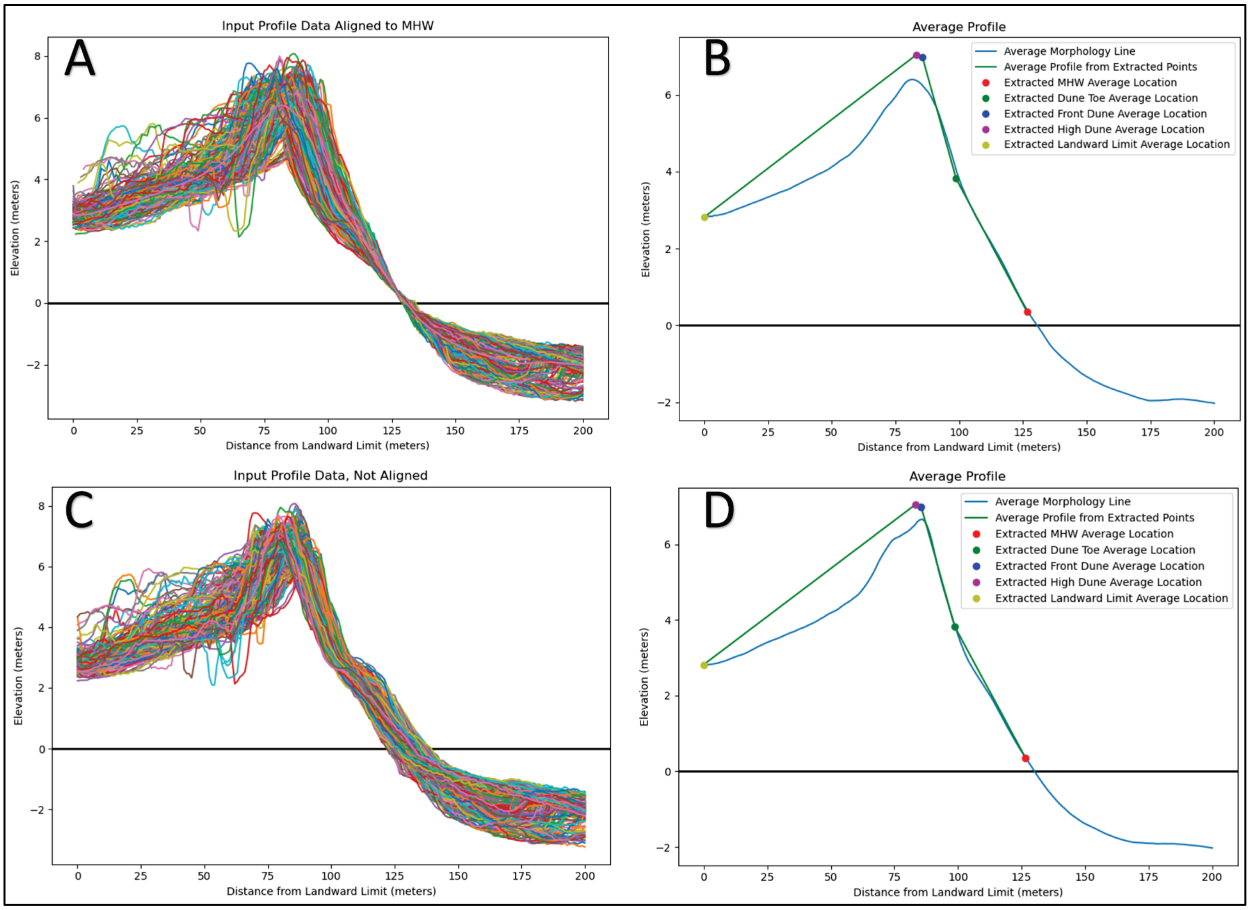


Figure 5. Aligned (subplots *A* and *B*) and unaligned (subplots *C* and *D*) comparisons for all profiles from Duck, North Carolina, dataset.

Figures 6 and 7 display the aligned plot outputs for all 228 transects for the Duck, North Carolina, stretch of coastline (plots *A* and *B* in Figure 5). While in an active ArcGIS Pro session with the ArcPy script running, these plots can be zoomed into, enlarged, and panned in the interactive chart viewer window. The chart viewer window will generate plots exactly like the ones seen throughout this publication. Closing the plot window(s) writes the CSV output file to the specified output folder. In this example, the MHW was used as the alignment feature. Alignment feature is user defined and should consider the feature that provides the best overall alignment and averaged morphology line. Alternatively, the user may decide to run Step 1 iteratively to achieve more accurate morphology information for each feature and make a patchwork of the profile information for use in Step 2; the alignment feature for each iterative run of Step 1 would create slightly different profiles that would then be pieced together to create Step 2 input. In comparison to Figure 5 above, Figures 6 and 7 were generated with a seaward limit of 400 m compared to 200 m to show the offshore alignment and averaging.

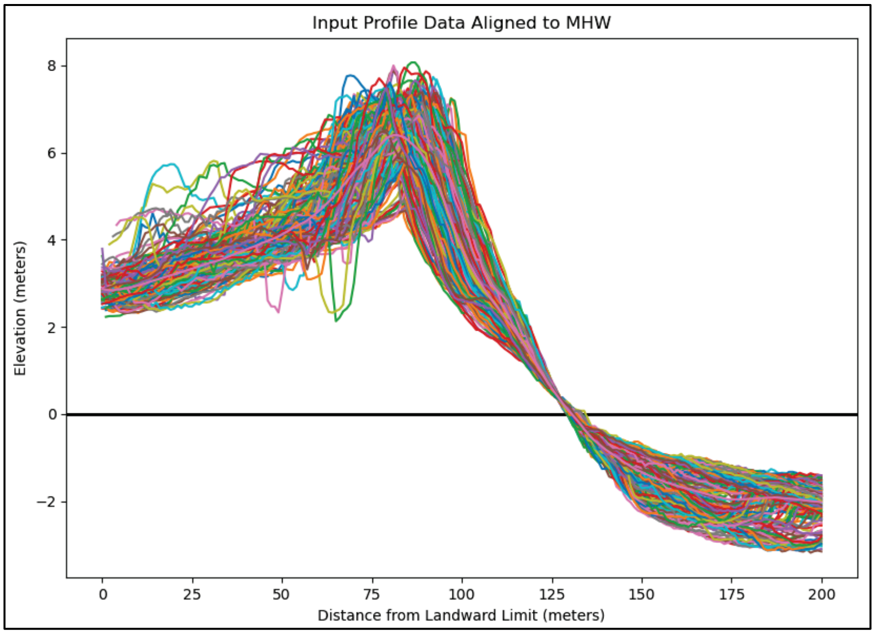


Figure 6. All Duck, North Carolina, transects plotted as aligned to the MHW point.

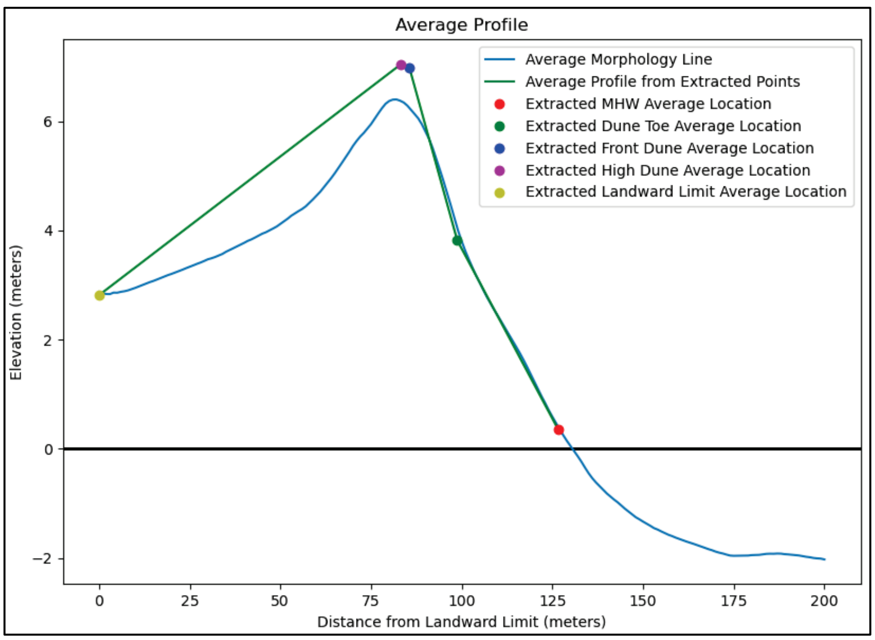


Figure 7. The average and aligned (to MHW) profile generated for all transects at Duck, North Carolina.

Averaging the elevation profiles does inherently result in loss of detail. For example, in Figure 6 the bathymetric profile at 175 m ranges from 0.5 m depth to as deep as a 3 m depth, and the average profile (Figure 7) shows a 2 m depth. Based on visual inspection of the Duck, North Carolina, profiles, this is due to offshore bar features existing in some areas offshore and not in others. To retain alongshore detail, users may decide to run the toolbox for profiles with and without offshore bar features by using the selection tools within ArcGIS Pro.

The step of averaging the profiles (Step 1) is generally an iterative process. Once the user is satisfied with the averaging, they should save the figures using the built-in save capability of the chart viewer interface. Saving the average profile plot from the first step of the toolbox as an image is recommended so that the user can reference the figure during Step 2 of the RBPG toolbox.

**Step 2: Create User-Generated Trapezoidal Approximation.** The second step in the RBPG toolbox creates maximum and minimum approximations for the averaged profile output from Step 1. User inputs are shown in Figure 8. The first input is the exported file from Step 1, which includes the averaged profile data and extracted feature positions. The remaining input values are all user supplied based on the figure generated (Figure 7) in Step 1. Future research will likely include automation of these inputs to reduce the final differences between the trapezoidal approximation and the representative profile.

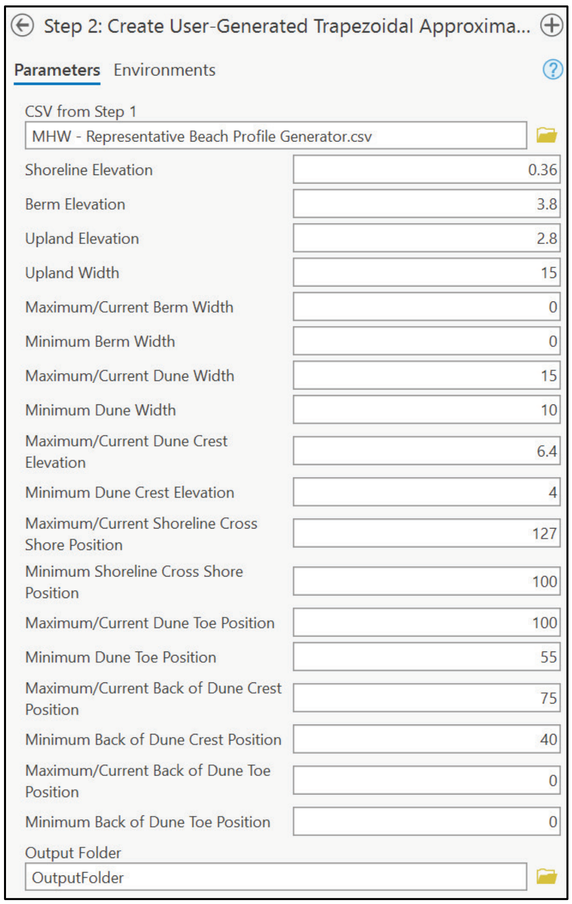


Figure 8. RBPG toolbox Step 2 inputs with values for the Duck, North Carolina, example.

Note that the tool input refers to *width* as the value of the cross-shore width of that feature and represents the nonsloping portion of that feature. For example, the dune width is only the width of the top portion of the dune (or the distance between the front and back dune crests). Similarly, the distinction of the cross-shore position of a feature references a single value for a zero-width feature such as the dune toe position. The values that are required in the second step of the RBPG toolbox are the same values that are required to generate reaches in the SBEACH data generator except for the various step values that are required to build all of the profiles. The trapezoidal approximations for both the maximum and minimum profiles are plotted in Figure 9 for the Duck, North Carolina, profiles.

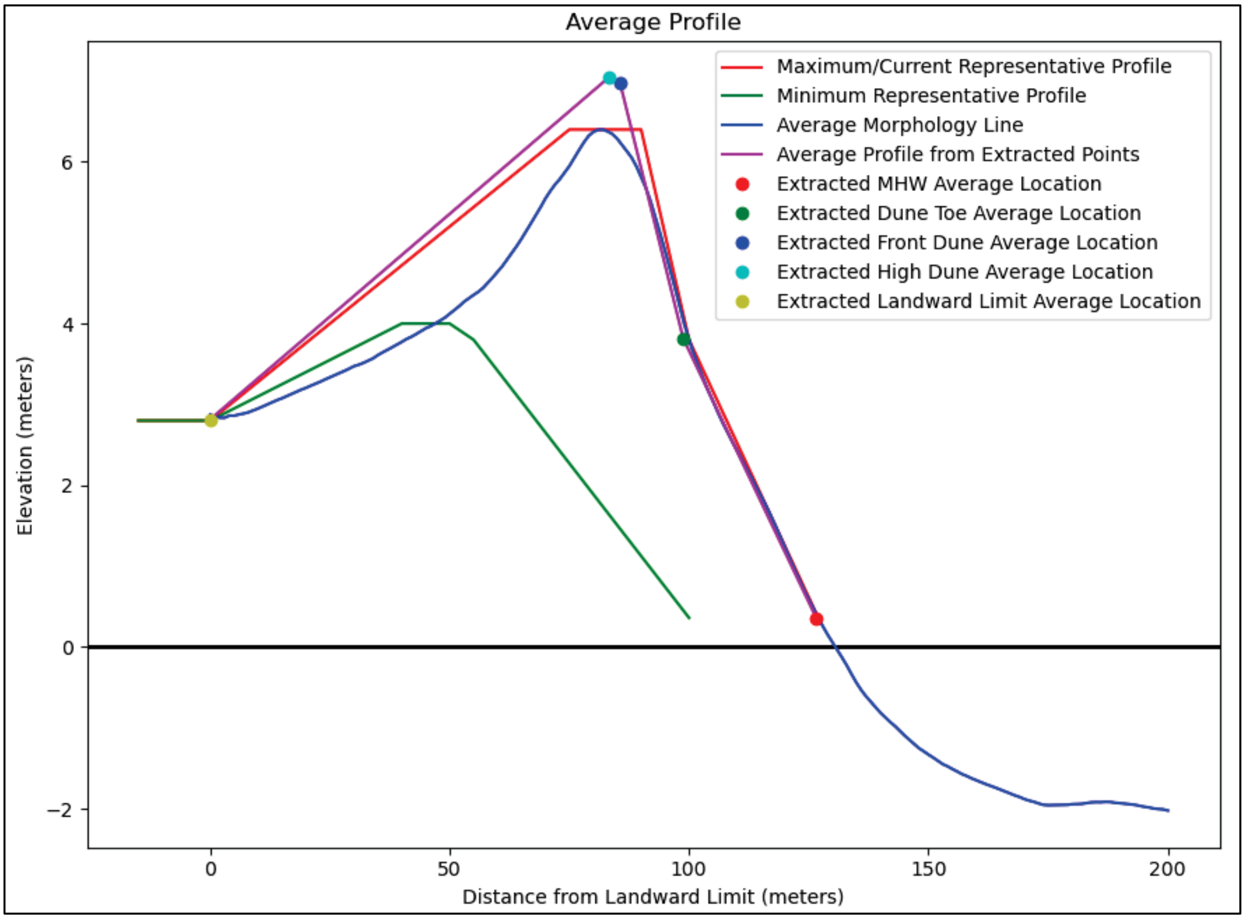


Figure 9. Step 2 RBPG toolbox output plot including maximum and minimum profiles generated for the Duck, North Carolina, example.

Saving the plot as an image is recommended. Once the plot is closed, the output for Step 2 is output to a file and saved in the output folder specified in Step 1. The output files include the distance from the landward limit (range) and elevation for each point along the averaged profile. Furthermore, it outputs the *X* and *Y* coordinates for the average extracted points as well as labels for each that define the average range and average elevation for each point. Last, it includes the user input values for future reference and a root mean squared difference (RMSD). The RMSD is the root mean squared difference between the extracted average profile (the *blue line* in Figure 9) and the user-generated maximum/current approximation (the *red line* in Figure 9). The RMSD is also printed to the geoprocessing window and can be accessed under the geoprocessing details for the run. This allows the user to compare runs quickly with adjustments in between to systematically lower the difference. The RMSD for Step 2 of the toolbox when using the Duck, North Carolina, inputs seen in Figure 8 is 2.23 m.

**SUMMARY:** The first version of the RBPG toolbox is an Esri ArcGIS Pro toolbox built using ArcPy (Python version 3.9.11) and provides a quick and straightforward methodology for users to create a representative beach profile for a study area. The RBPG toolbox leverages the transect-based elevations (points) and features extraction using the JALBTCX Dune Feature Extraction toolbox. Once the dune feature extraction toolbox has been run, the first step of the RBPG toolbox allows the user to align and average the selected data into a single representative profile. The ability to limit which points are aligned through selection allows for users to use their own discretion in the case that there are multiple representative morphologies that need to be differentiated. Plots are generated to allow the user to visualize the aligned profiles as well as the averaged profile with average extracted points. The alignment process includes shifting profiles in the cross-shore direction to align them according to a selected alignment feature. Step 1 of the RBPG toolbox generates a CSV output file that can be used as an input for Step 2 and can also be used for general profile information. Step 2 allows the user to generate trapezoidal approximations for the minimum and maximum condition of the beach and create additional plots to visualize these additional conditions. These minimum and maximum trapezoidal approximations are for input into the SBEACH data generator for eventual use within SBEACH. Once SBEACH runs are completed, Beach-fx reaches can also be defined with these approximations and use the SBEACH data as direct input data. The script exports the values used and calculates an RMSD between the trapezoidal approximation and the averaged profile.

Future work on the RBPG toolbox could extend its utility towards generating model specific representative profiles as numerical model inputs for other models. Currently, the second step in the toolbox is focused on creating inputs for the SBEACH model for the eventual use in a Beach-fx study.

**ADDITIONAL INFORMATION:** This CHETN was prepared as part of the USACE NCMP by Scott Spurgeon (US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Coastal Engineering Branch, at JALBTCX, Kiln, Mississippi). Questions pertaining to this CHETN may be directed to Scott Spurgeon (*scott.l.spurgeon@usace.army.mil*).

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## REFERENCES

Dong, Zhifei, Nicole Elko, Quin Robertson, and Julie Rosati. 2018. "Quantifying Beach and Dune Resilience Using the Coastal Resilience Index." *Coastal Engineering Proceedings* 1 (36): 30. *https://doi.org/10.9753/icce.v36.papers.30*.

Dunkin, Lauren, Eve Eisemann, Michael Hartman, and Jennifer Wozencraft. 2020. *Seamless Integration of Lidar-Derived Volumes and Geomorphic Features into the Sediment Budget Analysis System*. ERDC/TN RSM-20-4. Vicksburg, MS: US Army Engineer Research and Development Center. *https://doi.org/10.21079/11681/36296*.

Elkins, Ashley. 2022. *LiDAR Data Analysis Strategies to Determine Features Indicative of At-Risk Coastal Sites.* Mobile, AL: University of South Alabama.

Larson, M., and N. C. Kraus. 1989. *SBEACH: Numerical Model for Simulating Storm-Induced Beach Change. Report 1. Empirical Foundation and Model Development.* CERC SR-89-9. Vicksburg, MS: Coastal Engineering Research Center.

McGill, Sean, C. Sylvester, Lauren Dunkin, Eve Eisemann, and Jennifer Wozencraft. 2021. "2020 Hurricane Impact Assessment for the Northern Gulf of Mexico: Hurricane Sally and Hurricane Zeta." *Shore & Beach* 89 (2): 56–64. https://doi.org/10.34237/1008927.

Robertson, Quin, Lauren Dunkin, Zhifei Dong, Jennifer Wozencraft, and Keqi Zhang. 2018. "Florida and US East Coast Beach Change Metrics Derived from LiDAR Data Utilizing ArcGIS Python Based Tools." In *Beach Management Tools—Concepts, Methodologies and Case Studies*, edited by Camilo M. Botero, Omar Cervantes, and Charles W. Finkl, 239–58. Coastal Research Library, vol. 24. Springer, Cham. https://doi.org/10.1007/978-3-319-58304-4_12.

Rogers, Cory M., Kristine A. Jacobson, and Mark Gravens. 2009. *Beach-Fx User's Manual: Version 1.0*. ERDC/CHL SR-09-6. Vicksburg, MS: US Army Engineer Research and Development Center.

Rosati, Julie Dean, Katherine Flynn Touzinsky, and W. Jeff Lillycrop. 2015. "Quantifying Coastal System Resilience for the US Army Corps of Engineers." *Environment Systems and Decisions* 35 (2): 196–208. https://doi.org/10.1007/s10669-015-9548-3.

Sommerfeld, B. G., J. M. Mason, N. C. Kraus, and M. Larson. 1994. *BFM: Beach Fill Module. Report 1. Beach Morphology Analysis Package (BMAP), User's Guide*. Fort Belvoir, VA: Defense Technical Information Center.

Spurgeon, Scott. 2022. *Resilience Metrics at Panama City Beach, Florida*. M.S.C.E., University of South Alabama. https://www.proquest.com/docview/2656180558/abstract/988A157EF1294EBAPQ/1.

Wozencraft, Jennifer M., and W. Jeff Lillycrop. 2006. "JALBTCX Coastal Mapping for the USACE." *International Hydrographic Review* 7:20–37.