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LiDAR Data Analysis Strategies to Determine Features Indicative of At-Risk Coastal Sites

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THE UNIVERSITY OF SOUTH ALABAMA
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LiDAR Data Analysis Strategies to Determine Features Indicative of At-Risk Coastal Sites

BY

Ashley Jordan Elkins

A Thesis

Submitted to the Graduate Faculty of the
University of South Alabama
in partial fulfillment of the
requirements for the degree of

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in
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LIST OF ABBREVIATIONS

LiDAR	=	Light detection and ranging
BEC	=	Beach erosion control
CSRM	=	Coastal storm risk management
CSPI	=	Coastal Systems Portfolio Initiative
USACE	=	U.S. Army Corps of Engineers
JALBTCX	=	Joint Airborne LiDAR and Bathymetry Center for Expertise
DEM	=	Digital elevation model
NCMP	=	National Coastal Mapping Program
GPS	=	Global positioning system
IMU	=	Inertial measurement unit
CRS	=	Congressional Research Service
ICZM	=	Integrated coastal zone management
RSM	=	Regional sediment management
CSRM	=	Costal storm risk management
ERDC	=	Engineering Research and Development Center
NOAA	=	National Oceanic and Atmospheric Administration
USGS	=	U.S. Geological Survey
MHW	=	Mean high water level
SBAS	=	Sediment budget analysis system
DTM	=	Digital terrain model
ECL	=	Erosion control line
dVol	=	Volume change
dDenstiy	=	Density rate of change
DW	=	Design width
GLRI	=	Great Lakes Restoration Initiative

ABSTRACT

Elkins, Ashley, Jordan, M. S., University of South Alabama, May 2022 LiDAR Data Analysis Strategies to Determine Features Indicative of At-Risk Coastal Sites. Chair of Committee: Stephanie, Patch, Ph.D.

Light detection and ranging (LiDAR) derived volume changes provide both visual and statistical information for how project shorelines change over time. For beach erosion control (BEC) and coastal storm risk management (CSRM) projects, changes across storm events are fundamental to understanding a project's progress. The Coastal Systems Portfolio Initiative (CSPI) aims to document and track U.S. Army Corps of Engineers (USACE) projects in a holistic systems-based manner. This web based geographic information system currently lacks numerical metrics beyond fill volumes to represent a project's progress or reliability. This study aims to identify potential reliability metrics using the Joint Airborne LiDAR and Bathymetry Center for Expertise (JALBTCX) Volume Change Toolbox within ESRI's ArcGIS software. The toolbox was run on the Haulover and Bal Harbour sections of the BEC project to analyze volume change and identify erosional hotspots. Volume change analysis was done between LiDAR derived digital elevation models (DEMs) for before and after Hurricane Matthew as well as DEMs from project design plans. Single transect profiles were also compared between the post-Matthew LiDAR and the designs to use in determining potential metrics. From these comparisons total volume change, shoreline change, beach width difference, change rates, and composite metrics were discussed to potentially include within the CSPI reliability ratings.

CHAPTER I

INTRODUCTION

This research focuses on using the ArcGIS suite to analyze Light Detection and Ranging (LiDAR) data at specific coastal site locations to find shoreline features indicative of "at risk" sites. These sites are defined as "at risk" based on how threatened the ecosystem or infrastructure is by coastal storms, long term erosion, and sea level rise. The site locations of interest will be based on information from the United States Army Corps of Engineers (USACE) Coastal Systems Portfolio Initiative (CSPI) database. This initiative was set forth to compile information on coastal projects focused on storm risk management, ecosystem restoration, and navigation projects to allow decision makers to see the "big picture" for current and future needs within the United States Army Corps of Engineers (USACE, 2022). The process for examining and defining project reliability and risk is to be refined over time, and this research aims to provide a data analysis process which can be used to indicate project risk status on a quantitative basis. It should be noted that within CSPI, risk is a separate project marker associated with endangered structures or ecosystems and "at-risk sites" for this project relates to the project reliability. Reliability for a project defines the site's progress within its life cycle. This is an indicator for how the project is progressing towards the intended result.

The National Coastal Mapping Program (NCMP) has collected spatial datasets which provide high-resolution, multi-year, regional elevation data that can be used in conjunction with ArcGIS. ArcGIS allows for LiDAR shoreline data from various collection dates to be compared visually or through ArcPy toolboxes which analyze changes in the shoreline. One of these toolboxes, the JALBTCX Volume Change Toolbox, was developed as a tool to standardize elevation, volume, and shoreline change products nations wide but has shifted to a quick response tool to determine shoreline changes and sediment volume lost or gained after a storm event. The toolbox produces volume and shoreline change metrics from two spatially overlapping digital elevation models (DEMs), which are derived from LiDAR data (Dunkin et al. 2020). The NCMP LiDAR datasets are available at sandy shorelines at the contiguous United States and includes locations with active sediment transport and storm activity. The availability of data across most U.S. coastlines allows for sites that are "at risk" to be compared to those that are indicated to be less threatened or affected by morphologic changes.

Coastal protection involves actions intended to reduce damage to land and assets along the coast from hazards such as inundation and erosion. Battling "coastal squeeze" has become an ongoing process for many governments and municipalities. Coastal squeeze describes the process of rising sea levels and storm surge effects pushing coastal habitats landward towards infrastructure like structures or recreational areas (Doody, 2013). After the impacts of the 2004 Hurricane Season, which included landfall of five major hurricanes, USACE was tasked with implementing a systems approach to coastal risk reduction. The CSPI is a system of interconnected shore protection, navigation, and coastal ecosystem projects. It is a "system of systems" that seeks to optimize how project benefits and funding intertwine across entire regions (Cresitello, 2011). A regional agency or municipality decides on a needed project and progress is tracked through the CSPI. Each project is added to a database and visualized on a map. The CSPI database holds details, on a project level, for USACE Districts who are asked to regularly update content. This content can be found by clicking a project point on the interactive map and viewing details. The project's reliability history, dredging windows, nourishment volumes, risk details, and reliability history can be found. The risk level of a project ranges from unconstructed/study to good, with unstructured/study being projects that have not begun yet and good indicating the project is on schedule and or performing better than expected. Table 1 below breaks down the descriptions for each level.

Table 1. CSPI Reliability Descriptions from https://navigation.usace.army.mil/CSPI

Rating	Rating Descriptions
Good	Project is early in the renourishment cycle, or the project is performing better than expected, or both
Intermediate	Project is midway through the renourishment cycle, or the project is performing worse than expected, or both
Poor	Project is late in the renourishment cycle or below the design profile.
Unconstructed	These projects have significant coastal storm risk management and aquatic ecosystem restoration problems identified but no action has been taken
Study	This site may have significant coastal storm risk management and aquatic ecosystem restoration problems, but no specifics have been identified

The CSPI Reliability Ratings approach the ratings based on how a project is progressing in a general sense. Some projects include details to further explore a project's reliability status, but this process relies on tracking reactive fill or dredge volumes or a visual inspection of the site. Quantifying the environmental or coastal damages at various sites should allow agencies to better understand needs and asset allocations. Outputs from the volume change toolbox like total volume change, bin volume change, and shoreline change will be obtained and discussed in this study as potential metrics to track project reliability after storm events in an objective manner. This goes beyond single transect surveys to look at results across entire sites. The goal is to quantify changes across projects through a repeatable, objective, metric-based processes.

1.1 Background

Rising sea levels, storm impacts, and human developments have combined to greatly impact the world's coastal habitats. As coasts erode, shorelines retreat near hard structures and developments that have been constructed. This narrowing of coastal environments is known as "coastal squeeze" (Pontee, 2013). This phenomenon can be attributed to the prevention of landward shoreline migration, which occurs naturally in response to changes in tidal currents, wave conditions, and sediment supply, by land use practices, such as the construction of infrastructure or property management plans, on the back border of those habitats.

There are also severe morphological changes associated with hurricane impacts. Typically, sandy sediments, beaches, and dunes offer natural coastal protection, but inundation and energetic waves can lead to dune erosion and wave-driven currents can shift sediment on beaches, leading to morphological change (Marmoush & Mulligan, 2020). Shoreline erosion and dune loss due to the in-tandem expansion of urban development and rise of sea levels are cause for concern. Unfortunately, the scale of the threat to the dunes and sandy beaches is difficult to determine due to the sediment and erosion pathways being difficult to predict (Hanley et al., 2017). LiDAR data allows for an analysis of the erosion caused by storm events through shoreline and dune digitization. Previous shoreline data can provide observations of how sites have changed for various storm events and those observations can be used to predict future shoreline behavior.

LiDAR uses a laser, a global positioning system (GPS), and an inertial measurement unit (IMU) to calculate the heights of objects on the ground. An emitter sends a laser pulse that travels from one point and is then reflected off the Earth's surface and returned to a receiver. The round-trip travel time that laser pulse takes to between the emitter and the receiver is used to create a topographic or bathymetric elevation. This process is limited by the clarity of the water column and requires factoring in the movement of the LiDAR system, temperature, and humidity. Regardless, LiDAR surveys enable a rapid acquisition of high-resolution elevation data (Schmid, et al., 2011). The ability to mount a LiDAR sensor in an aircraft (Airborne Laser Scanning or ALS) allows for surveys to be conducted over large lengths of coast that may be inaccessible by other sensor types. An analysis of unprecedented regional-scale morphological response was conducted in New South Wales, Australia using LiDAR data to measure beach volume. Harley and others (Harley, et al., 2017) examined the impacts from an extratropical cyclone on a regional scale. This larger survey size meant that local behavior was linked to regional trends and then compared to historical data with a more holistic approach. Understanding how previous storms have impacted coasts aids in the prediction of future impacts to predicting future impacts. One study done by Le Mauff, on the Vendée coast of France proposed monitoring solutions based on the geomorphological response of a shoreline (Le Mauff, et al., 2018). Three LiDAR datasets obtained over five years were taken at three beach and dune systems which spanned a variety of morphological beach types for that region. Using the dune crest and dune base, the 'Geomorphic Change Detection' was computed using DEMs of difference, which show a high variability in beach responses between and even within the three study sites.

While LiDAR allows for monitoring of coastal morphology, solutions must be developed to address threatened infrastructure and ecological systems. Coastal communities must decide to take one or more various forms of action in both the short and long term; accommodation of the infrastructure to allow the natural trajectory of the shoreline, retreat to remove humans from the natural system, or through engineered solutions (Elko, et al., 2021). While managed retreat and sacrifice areas are becoming more common, beach nourishment is the most common protection implementation against erosion. Nourishment, specifically beach widening, also provides flood risk reduction through storm surge management (Dean, 2005). This strategy is not without its setbacks considering the studies highlighting the impacts on organisms surrounding the borrow and fill sites (Adriaanse & Coosen, 1991). At borrow areas, suspended sediments, and turbidity increases, may cause benthic fauna disappearance and animal displacement. At the replenishment areas, benthic communities are covered by sand and the organisms could die or be disrupted by the chemical or physical properties of the new material.

Despite this, the storm damage reduction benefits, recreational boons, and increase in habitat make beach nourishment and widening common and advantageous along the coast.

A total state beach nourishment volume over the last century of 1.2 billion cubic meters was normalized by total length of a state's ocean coastline by the Congressional Research Service (CRS) in 2006 (Elko et al., 2021). It is shown that California and Florida utilized the highest volume of material, but New Jersey and Delaware have the highest average unit volume change along their coastlines. Across decadal data shows that U.S. beach nourishment volume requirements have been increasing with no signs of a slow-down, as shown in Figure 1 (Elko, et al., 2021).

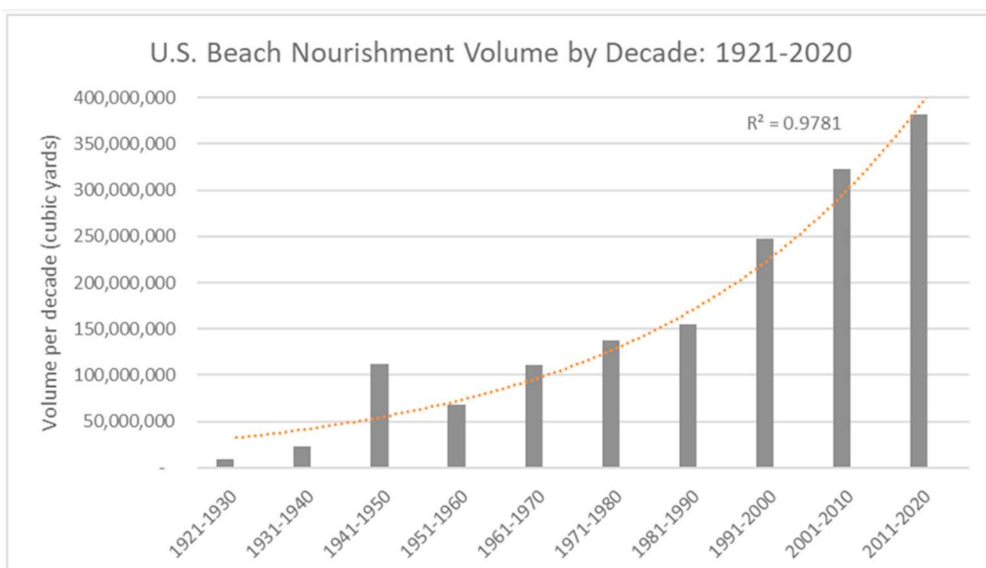

Figure 1. U.S. Beach Nourishment Volume by Decade, Fit To an Exponential Trend Line with an R-squared Value of 0.98 (Elko, et al., 2021)

Coastal management in the past has involved receiving funding based on three factors: nature of the proposed project, governance and delivery of coastal protection, and the characteristics of the beneficiary. The overall goal is sustainable development backed by collective decision making for coastal projects. A study by Ware and Banhalmi-Zakar breaks down the three established coastal protection funding approaches into private investment, government investment, or intergovernmental grants (Ware & Banhalmi-Zakar, 2020). This report was focused on providing strategies for governments to close the gap on coastal adaptation funding using four projects as a basis. The design and construction aspects that contributed to success are outside of the scope of this project. However, the use of non-fiscal policy and non-traditional funding with action and oversite by a central government agency is something this research aims to streamline into a more quantitative process.

The European Union has implemented a program for the Integrated Coastal Zone Management (ICZM) to synchronize a range of policies and decision-making structures in order to achieve sustainability goals. Natural pressures also affect the coastal system, including storm surges and rising sea levels. A study focusing on the Catalan coast of Spain acknowledged how flooding and storm surge risks are exacerbated by sea level rise and climate change (Roca, et al., 2018). Monitoring of the coastal risk(s) must be considered holistically while being balanced with management strategies and stakeholder needs.

Many organizations have tracked and reported on erosion and beach nourishment in the United States. The Water Resources and Development Act of 1986 provided authorization for USACE projects across the Nation while also incentivizing a more efficient use of tax dollars through cost-sharing (USACE, 2006). This, in conjunction with previous legislation, requires USACE to monitor projects while also leading Regional Sediment Management (RSM) works across federal flood and navigation authorities on a national scale. After the hurricane season of 2004, Congress charged USACE to assess damages prevented across various projects as an interconnected system. This led to the creation of the Coastal Systems Portfolio with the intent to better study, plan, construct, and re-nourish coastal risk reduction projects. Examining the "big picture" of federal projects as a system allows local and federal decision makers to better inform judgements for funding and project needs. The map interface, which can be found at the USACE CSPI ArcHub, shows color coded projects that fall within three major project types: Coastal Storm Risk Management (CSRM), Aquatic Ecosystem Restoration, and Navigation Projects (USACE, 2022). CSRM projects focus on reducing the risks of coastal storm damages to coastal areas. These CSRM projects aim to reduce flood risk and damages from storm surges. Aquatic ecosystem restoration is intended to partially or fully reestablish the function, structure, and dynamic processes within wetlands and other floodplains. Navigation projects work to maintain safe vessel travel through ports, channels, and harbors. This research is focused on the CSRM project reliability ratings at the Miami Count Beach Erosion Control (BEC) project.

The Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX), an interagency partnership among USACE South Atlantic Division, US Army Engineer Research and Development Center (ERDC), Naval Oceanographic Office, National Oceanic and Atmospheric Administration (NOAA), and US Geological Survey (USGS), performs operations, research, and development in airborne lidar bathymetry. Their survey operations support the Corps National Coastal Mapping Program (NCMP), NAVOCEANO Airborne Coastal Surveys, and post-storm surveys for USACE and Federal Emergency Management Agency as well as LiDAR research within ERDC, NOAA, and USGS. Most ERDC research relevant to this study focuses on regional sediment budgets created under the RSM process. The JALBTCX Volume Change Toolbox provides a straightforward way to quantify coastal change while supporting bin creation for littoral cell analysis. A Regional Sediment Management tech note on the workflow for computing LiDAR-derived volume changes stated that "specific metrics produced using the JALBTCX Volume Change Toolbox include shoreline change, total volume change, as well as above and below mean high water (MHW) volume change" (Dunkin et al, 2020). The ERDC team took those metrics and implemented them with the Sediment Budget Analysis System (SBAS) for RSM strategies, but adjacent studies focus on the application of the toolbox as a post-storm quick response tool. The JALBTCX was deployed as quickly as possible to the affected areas along the US East and Gulf Coasts after Hurricanes Matthew, Irma, Maria, Florence, and Michael during 2016, 2017, and 2018 to obtain post-storm datasets to allow for direct pre-storm to post-storm comparisons within the ArcPy toolbox. The surveys comprised 3,850 square miles of coast (Eismann, et al., October 2019). The regional nature of that study conducted in 2019 created opportunities to assess large-scale patterns between storm and fair-weather erosion and deposition.

1.2 Area of Focus

In partnership with USACE, the project area for this study is a BEC project at Miami Beach in Miami-Dade County, Florida as shown in Figure 2. The Master Plan for this project outlines the Corps plan to place beach fill along the 10.5-mile length of the whole project. This included protective dunes against storm surge at key locations.

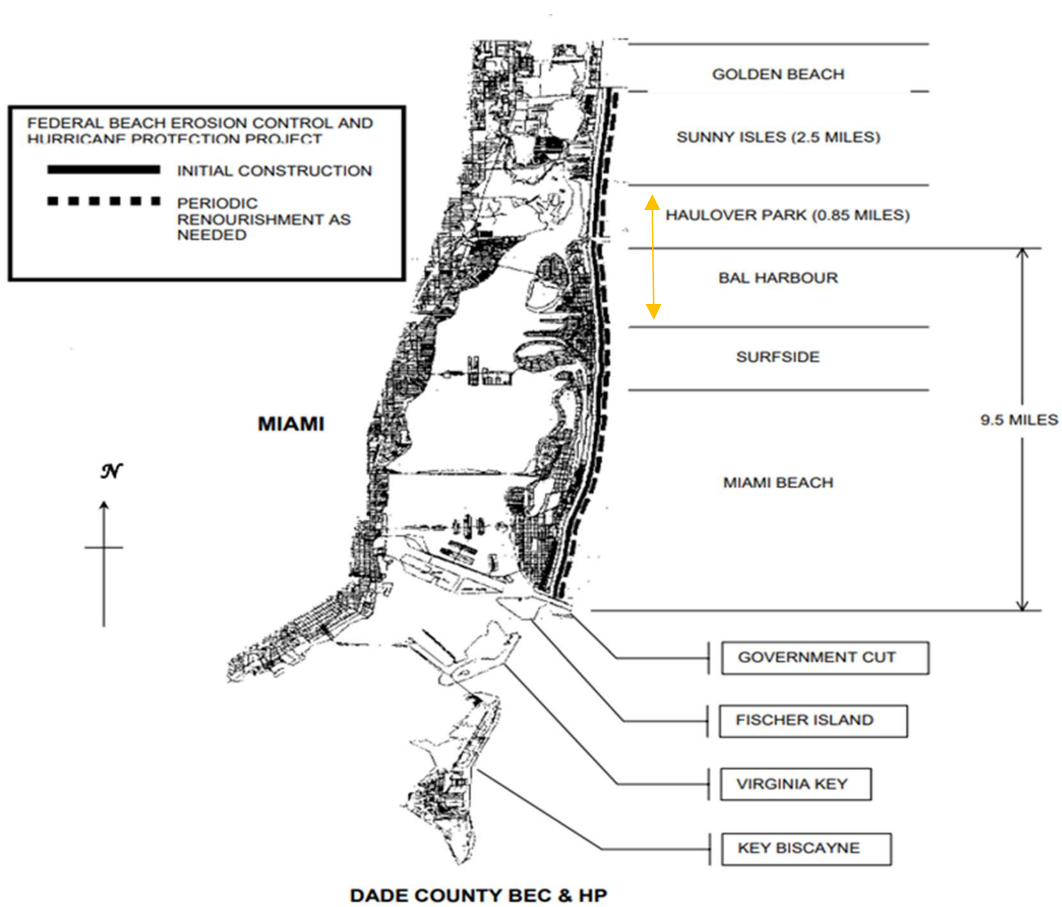

Figure 2. Project Area: Miami Beach, Miami-Dade County Florida

Initial construction began in 1975 and six separate construction contracts extended through 1988. Since that initial work in 1975, a total of 18,401,000 cubic yards of sand has been excavated from borrow sites to provide material for the construction and maintenance of the Miami-Dade Project (Miami-Dade County, 2011). American Shore and Beach Preservation Association has a nationwide renourishment database which shows the location, volume of fill, length of shoreline, and cost for each year of nourishment (American Shore and Beach Preservation Association, 2022). A graph for the Miami-Dade BEC project's volume of fill alongside the length of shoreline nourished for each year is in Figure 3.

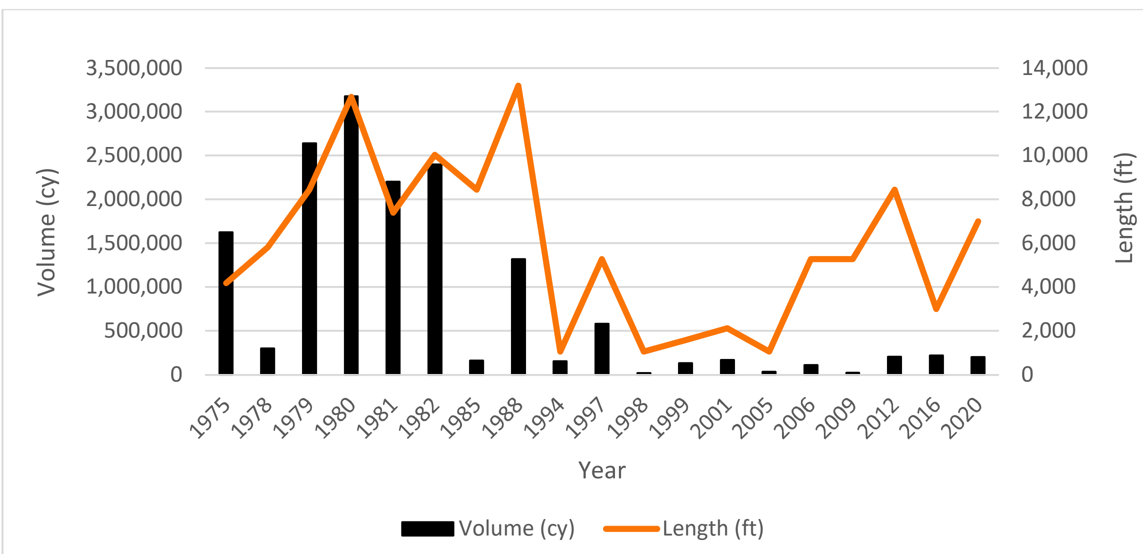

Figure 3. Miami-Dade BEC Fill Volume and Length of Shoreline for Each Year

For the purposes of this research, only the transects that are within the stretch of beach to the north and south of a jetty at Baker's Haulover Inlet are being considered due to availability of data and diversity of landforms. That section includes Haulover Park and Bal Harbour. These cites only had beach nourishment done rather than any measures to combat erosion like the breakwaters constructed at Sunny Isles. This particular project was negatively impacted by Hurricanes Matthew and Irma in 2016 and 2017, respectively. Erosion hotspots, massive dune and berm forms, and variable components make this an interesting site, but there is a lack internal of monitoring through time to feed into tools and metrics within USACE. Lidar data as well as construction templates for the central portion of Miami Beach were available to use for calculations and analysis with a focus on Hurricane Matthew.

CHAPTER II

METHODS

This research analyzes volume change data as well as dune migration where applicable. As such, LiDAR data or DEMs for each region will be acquired and loaded into ArcGIS for use with the JALBTCX Volume Change Toolbox. Some design templates from the project area will also be processed. The templates were provided as point data with eastings and northings in Florida State Plane East and elevations in NAVD 88. That point data was converted into a DEM using the Trend tool within ArcGIS. Trend interpolates a DEM from points using a trend based on a polynomial between orders 1 through 12. A 1st order polynomial would fit a linear trend to the profile. For this application of the tool, a 5th order polynomial was used. The pre-storm (a), post-storm (b), and design (c) DEMs for Bal Harbour and Haulover Beach can be below seen in Figures 4 and 5 respectively.

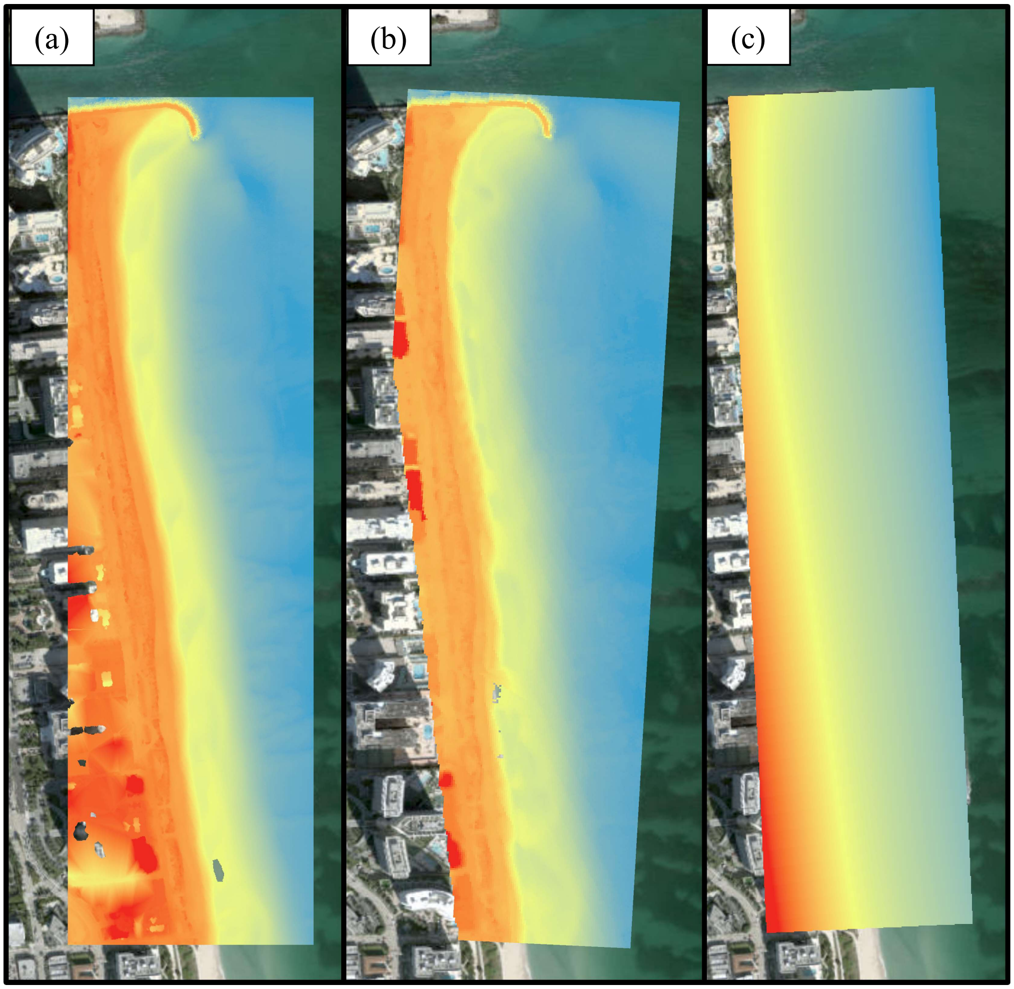

Figure 4. Pre-storm (a), Post-storm (b), and Design (c) DEMs for Bal Harbour

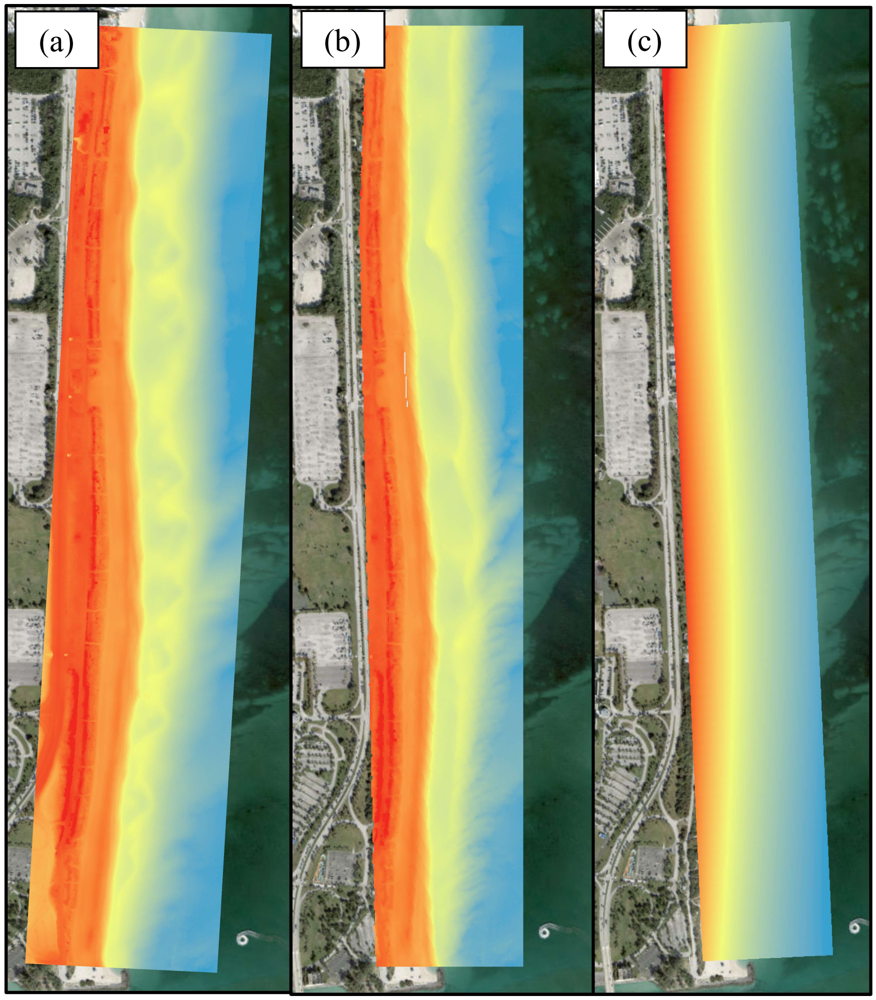

Figure 5. Pre-storm (a), Post-storm (b), and Design (c) DEMs for Haulover Beach

The LiDAR derived DEMs were clipped to match the north and south ends of the design template. As such, the analysis for Haulover Beach did not include the area around the jetty to the south. However, the Bal Harbour analysis did include the area around the jetty at the north end of the site.

NCMP and the JALBTCX have a long history of providing regional coastal surveys after storm impacts and has a collection of shoreline data from various years.

From there, the DEMs, in a GeoTIFF format were processed through the JALBTCX Toolbox as outlined in Figure 6.

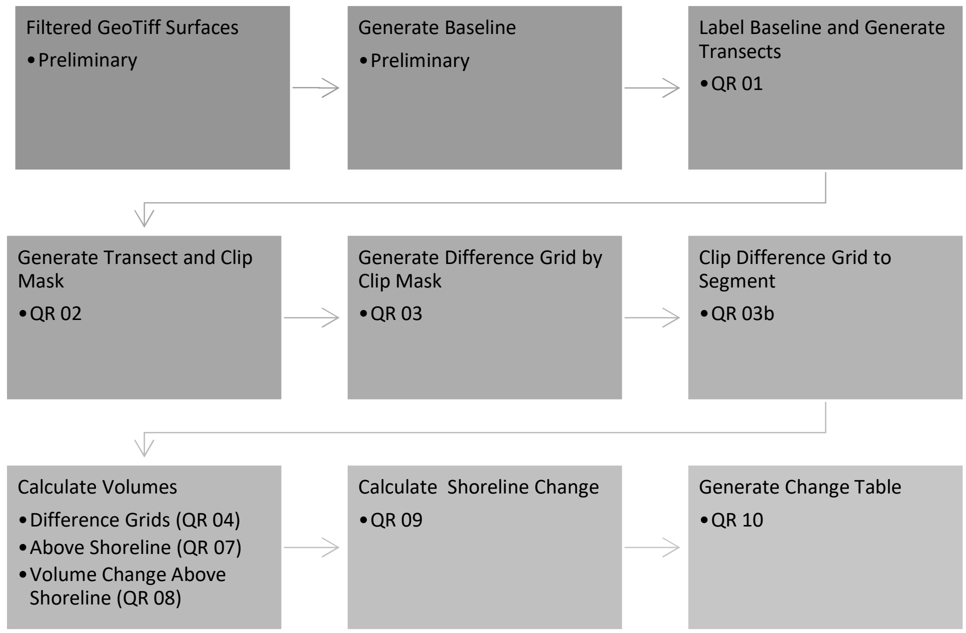

Figure 6. JALBTCX Volume Change Toolbox Workflow

The tool itself includes processes outlined as steps QR 01 through QR 10. Steps QR 01 through QR 02 develop the analysis bins along the shoreline with spacing and inland depth defined by a user-created baseline, which is typically done by tracing the shore-parallel line of infrastructure, first dune, or line of significant vegetation depending on the development of the area. This study will follow the standard JALBTCX storm-response assessments of 100 meter spacing for the larger sets utilizing only LiDAR data or 50 meter spacing for those that focus on the design profiles. Initial transect lengths range between 500 meters and 1,000 meters depending on data coverage (Eismann, et al., October 2019). Step QR 03 creates the elevation difference raster by subtracting the later dated (after) DEM from the earlier dated (before) DEM to show locations of erosion (negative elevation change) and deposition (positive elevation change). That difference raster is then used in step 04 to calculate volume change within each analysis bin. Steps QR 05 through QR 09 deal with MHW shoreline contour, analysis mask, and attributes pertaining to the MHW volume change. The mask is a polygon created using the cross-shore transects as boundaries. The clip mask slices that polygon along the transects to create segments along the shoreline. The mask, transects, and baseline for Bal Harbour are shown in Figure 7. The segments of the mask created by slicing along the transects are numbered from north to south.

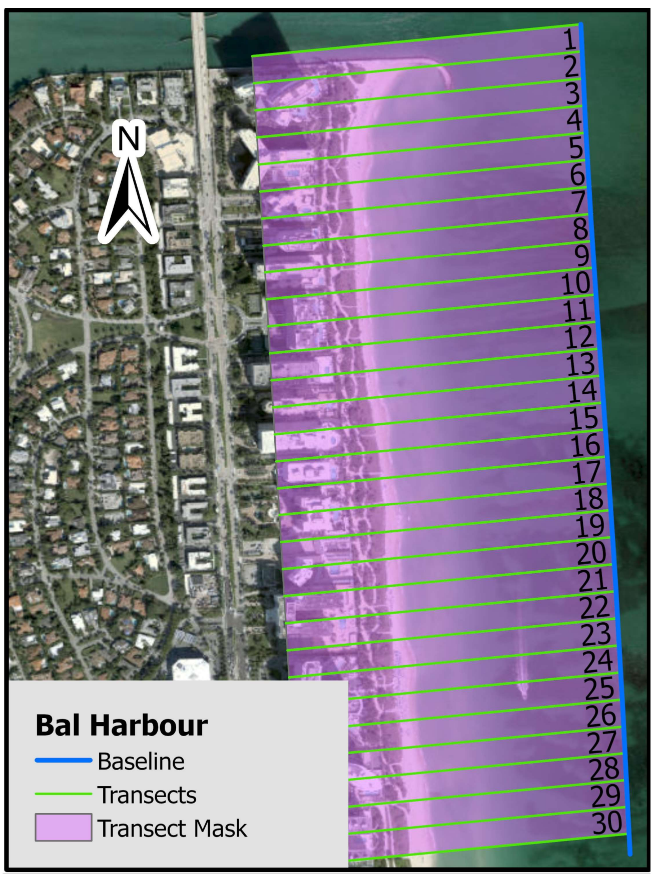

Figure 7. Volume Change Toolbox Transects, Baseline, and Mask Created for Bal Harbour through Steps QR 01 and QR 02

Step QR 05 generates a shoreline contour from the LiDAR grids using ArcGIS's contour creation tool. Once the shoreline has been created, it is input into step QR 06 along with the MHW value which is then copied to the transects and masks from step QR 02. This step uses the shoreline as a seaward boundary and may be skipped to run only the "above" MHW volume calculation which does not require a mask. Step QR 07 references the MHW value assigned in step QR 06 to determine which 1x1 meter raster cells to include in, above-water, or below-water volume calculations and then sums the values of "before" and "after" DEMs separately. This calculates a beach volume for each bin for before and after the storm. Next, the "before" beach volume is subtracted from the "after" beach volume resulting in a beach volume change for each bin. Step 09 calculates the distance from each MHW contour which provides the shoreline change metric. Steps 10 and 11 compile the volume change data into tables. The final table generated by the toolbox produces a file linking bin geometry with associated volume and shoreline change which allows for visualization and comparison.

The design beaches for Miami Beach at Haulover Beach and Bal Harbour were provided as a MicroStation digital terrain model (DTM) and needed to be converted into a compatible file for ArcPro and the associated toolbox. As such, it was exported from MicroStation as a text file with easting, northing, and elevation columns. That data were then converted into a table and brought into the Arc workspace as a point shapefile. The Trend tool was used to interpolate between those points to create a raster file that fits a smooth surface defined by a polynomial to the input sample points. This created a 3D surface of the design template which can be processed by the Volume Change Toolbox using the design derived DEM as “before” data and the post Matthew DEM as “after”. A two-dimensional profile which included both design and constructed beaches for both locations was also provided as a list that was graphed using elevation as a function of horizontal distance from the Erosion Control Line (ECL). The profile width is defined as the distance between the ECL and the beginning of the downward slope or step of the beach berm width. For Bal Harbour the constructed width is 74 meters, which is 44 meters larger than the design width of 30 meters. The overfill in this area is to allow for constructed template to achieve an equilibrium profile matching that of the design template. Haulover Beach has a smaller constructed width of 18 meters which is equal to the intended design width. From this, the constructed and design widths can be directly compared to the post-storm conditions extracted from LiDAR using the Profile tool in ArcGIS. This provides location and elevation data along a specified line feature which were drawn in the bins with the highest volume change or MHW volume change for each site. After adjusting the elevation and location data obtained from the Profile tool to the ECL rather than the edge of the raster, the beach profile was graphed with the designed and constructed beach profiles.

CHAPTER III

RESULTS

The results of this volume change toolkit include the volume change derived from pre and post Matthew LiDAR using JALBTCX DEMs as well as the DEM interpolated from the design profiles for the "before storm" data. Figures 8 and 9 show the volume changes output by the toolbox for each site. Each figure shows bins, or segments, of each respective beach with the volume change in cubic meters shown on each bin. Figures 8a and 9a show the total volume change above and below water (where the lidar produced data in both years of the comparison) along the DEM contained within transect bins while Figures 8b and 9b are a MHW volume change only calculated using the volume above the MHW line at 0.0789 m. Accretion is positive and erosion is negative. The bins with the largest erosional value for each volume change are indicated with a blue star.

Figure 8. Hurricane Matthew Volume Change (a) and MHW (b) Volume Change at Bal Harbour Using LiDAR Derived DEMs for Pre and Post-storm Data

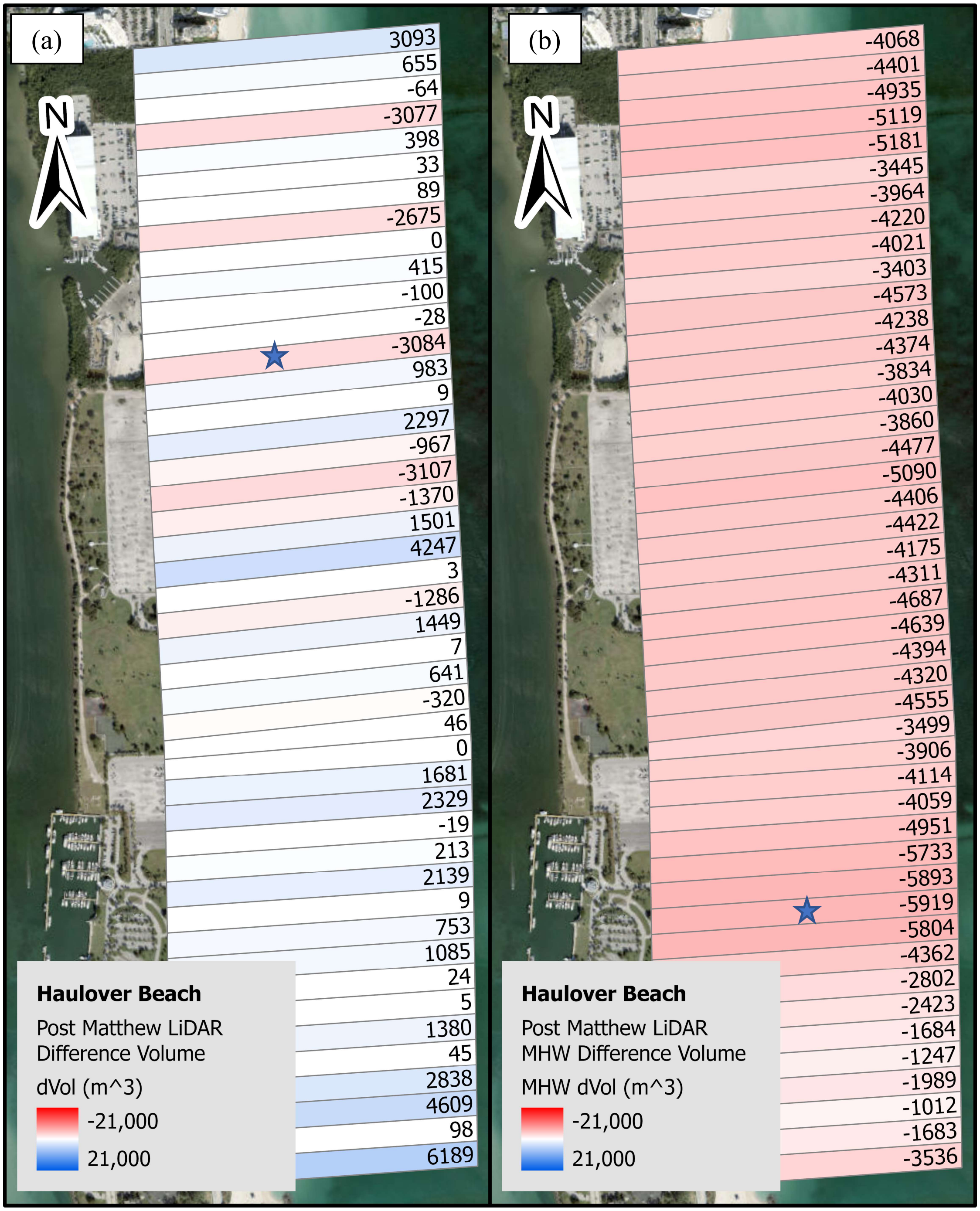

Figure 9. Hurricane Matthew Volume Change (a) and MHW (b) Volume Change at Haulover Beach Using LiDAR Derived DEMs for Pre and Post-storm Data

The same process was repeated using a 3D raster created from the design plans as the "before" raster and the Post Matthew DEM for the "after" raster. Figures 10 and 11 show the volume change results for each section of shoreline. For the design-based volume change analysis in Figure 11a at Haulover Beach, there were no negative or erosional volume changes. The Trend tool was used over the Inverse Distance Weighted (IDW) or Kriging methods due to the spread of the points from the design template. IDW interpolation is a deterministic technique which measures the statistical probability of interpolated points across a DEM through mathematical processes. Kriging is similar to IDW in that it weights surrounding point values to derive a prediction for each location on the DEM. However, Kriging is a geostatistical process that relies on both statistical and mathematical processes, the weights are based on distance as well as the overall spatial arrangement (Johnston et al., 2004). Due to the larger spacing of the points at the edges of the plan template both methods introduced elevation dips not intended in the design.

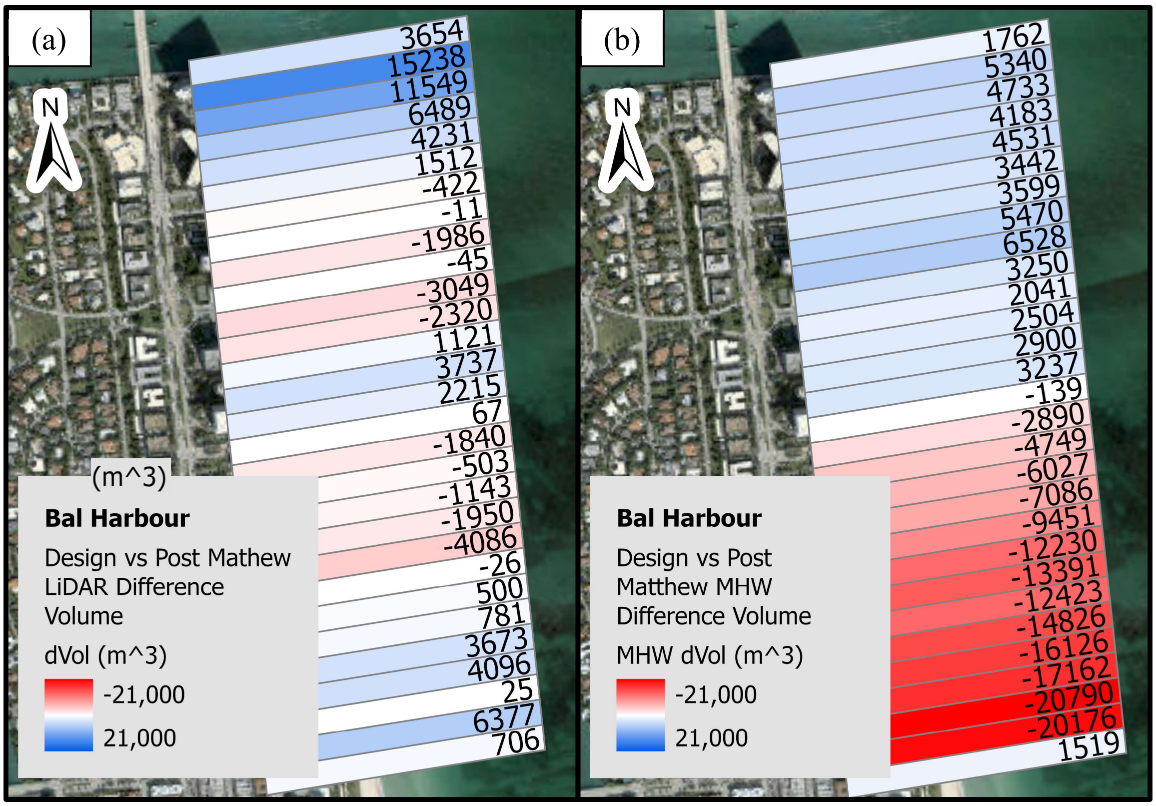

Figure 10. Hurricane Matthew Volume Change (a) and MHW (b) Volume Change at Haulover Beach Using Design Profile Derived DEMs For Pre-storm Data

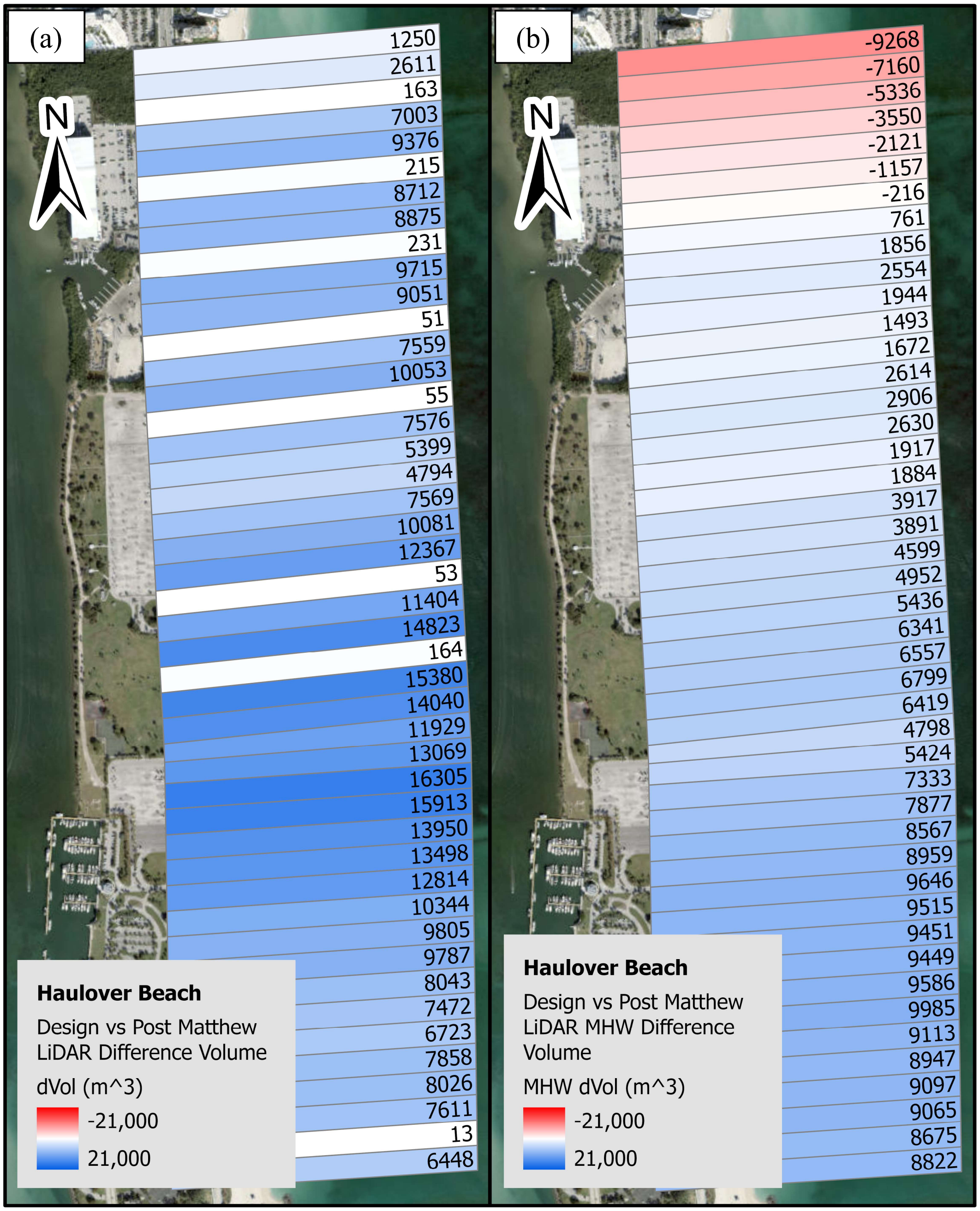

Figure 11. Hurricane Matthew Volume Change (a) and MHW (b) Volume Change at Haulover Beach Using Design Profile Derived DEMs For Pre-storm Data

A MHW shoreline comparison between the design and post Matthew DEMs was done using the Volume Change Toolbox. Figure 12 shows both shorelines as well as the shoreline change along each transect. That change, in meters, is visualized with gradually sized red circles. Negative values indicate the Post Matthew LiDAR shoreline is seaward of the design profile since the tool subtracts the x-location of the “post-storm” shoreline from x-location of the “pre-storm” shoreline along each transect.

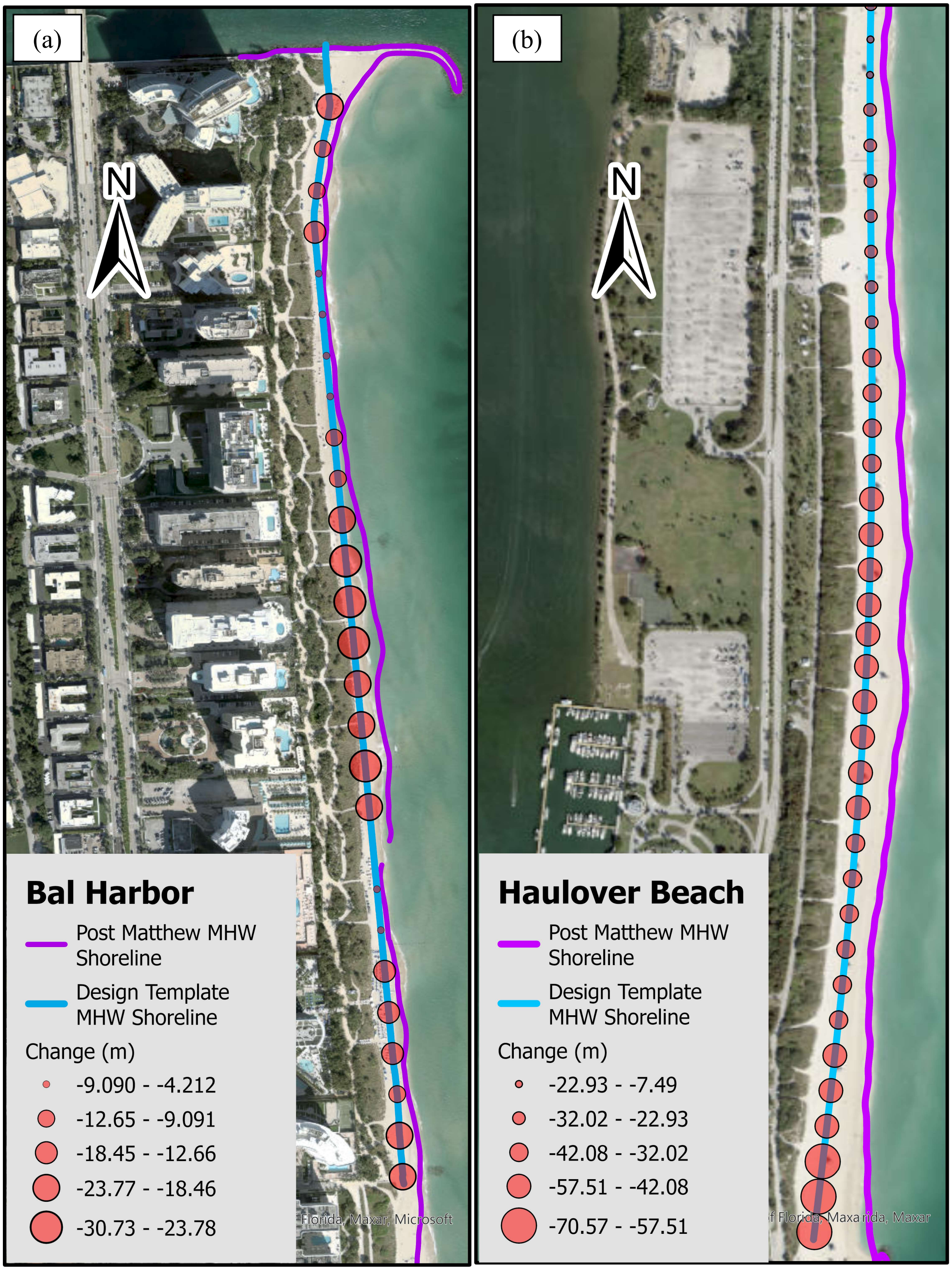

Figure 12. Shoreline Comparisons for Bal Harbour and Haulover Beach

Profiles for the design, constructed, and measured post Matthew beaches were acquired for bins with the highest erosional volume change as well as the highest MHW erosion bins. Those profiles are shown in Figures 13 and 14. The constructed beach profile was the profile, shown in green, that was initially overfilled for each site to allow for the additional volume above the MHW line to obtain equilibrium. The design beach profile in red shows the intended design once a beach has stabilized. The measured profiles shown in blue and black were extracted from the post Matthew DEM using the Profile tool within ArcGIS. To allow for direct comparison these profiles measured from the differing edges of the DEMs had to be corrected so that the location of ECL aligned with a zero distance. This was done by measuring the distance from the edge of the DEM to the ECL and then subtracting that from surveyed point's distance value. The mean high-water level for this area is 0.0789 meters above NAVD88 and that has been added as a dotted line. For both sites, the surveyed profiles extend seaward of the design, but Bal Harbour is experiencing erosion from the constructed profile above the MHW line while Haulover Beach shows accretion away from both the constructed and design profiles above the MHW line. However, around the point at which the downward slope lessens on the Haulover profiles between elevations 0 and -2 meters shows notable erosion of the constructed profile beyond the designed profile. The location of this slope change is indicated by a black triangle on the graph. Bal Harbour profiles appear to converge towards the design profile seaward of 76 meters while Haulover profiles suggest the formation of an offshore bar around 152 meters from the ECL which was not anticipated in the design profile.

30

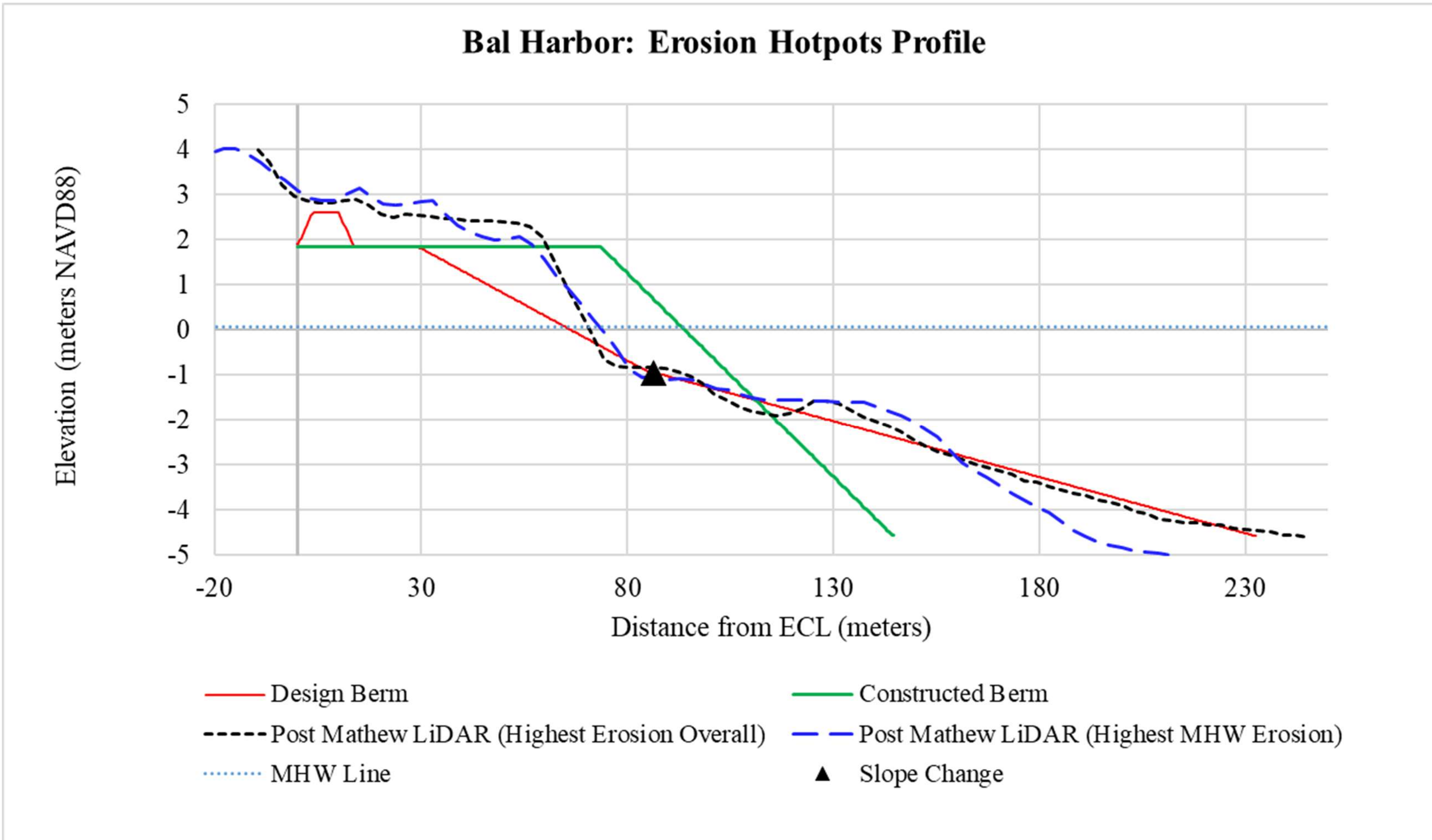

Figure 13. Profile Comparison for Bal Harbour

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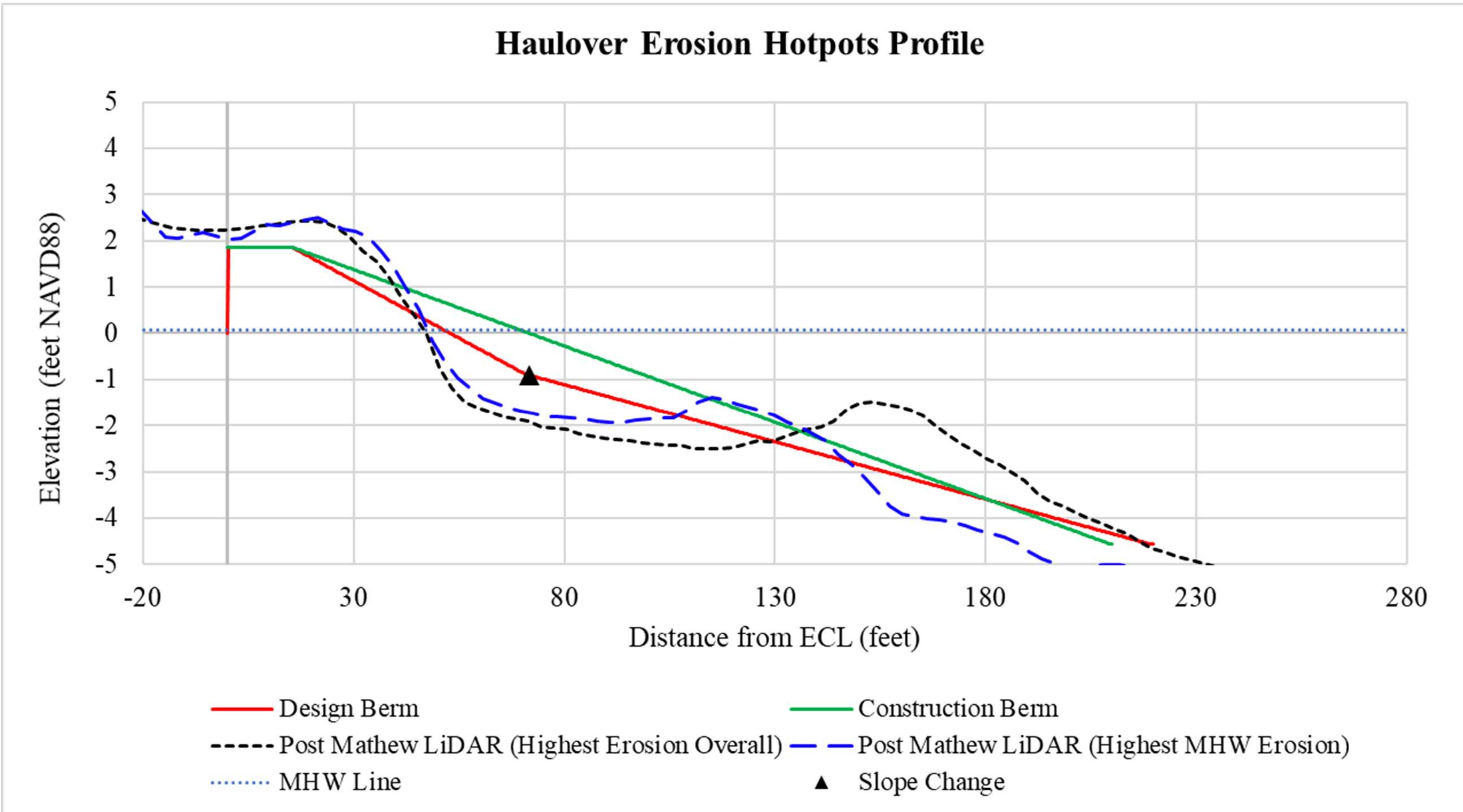

Figure 14. Profile Comparison for Haulover Beach

The survey widths acquired at the elevations corresponding with the slope change in Figures 13 and 14 were directly compared to the design widths in Table 2, which shows the surveyed widths, constructed widths, and the percent change between the two. Negative values indicate a landward change or shoreline loss while positive values indicate seaward change. The values at the slope change for Haulover Beach were added to show a how a negative net volume change within a bin does not cause negative width change across the entire profile. The profile is accreting above the MHW line while also eroding below the MHW line.

Table 2. Beach Width Comparison Metric for Bal Harbour and Haulover Beach

	Point of Interest	Surveyed Width (m)	Constructed Width (m)	Segment	Percent Change
Bal Harbour	Min. dVol	60	74	4	-22.43%
	Min. MHW dVol	57		27	-26.57%
Haulover Beach	Min. dVol at Berm	27	18	18	66.67%
	Min. MHW dVol at Berm	40		35	73.68%
	Min dVol at Slope Change▲	53	71	18	-28.76%
	Min. MHW dVol at Slope Change▲	55		35	-26.54%

The change tables output from the Volume Change Toolbox for both locations and using the LiDAR derived DEMs are located in Appendix A. These tables are the output from step QR 10 of the JALBTCX toolbox and show the segment geometry and volume change values for each bin at Bal Harbour and Haulover Beach. The toolbox summary of the volume and shoreline changes at each site using only LiDAR DEMs can be found below in Tables 3 and 4. These tables provide an overview of the calculations across all the bins and are representative of an entire site in general rather than areas of specific interest. Errors occurred in calculating shoreline change between the two rasters at Haulover Beach with significant overlap occurring between the two LiDAR derived shorelines. The toolbox encountered too many zero or null values while calculating the shoreline change and would not run properly. As such, no shoreline change could be calculated at this time so the "Number of Shoreline Change Quantified" is zero with no average shoreline change or shoreline change rate available in Table 4.

Table 3. Bal Harbour Volume Change Summary for LiDAR Only

Difference Volume	
Number of Volume Change Bins:	29
Total Volume Change (m^3)	17884
Average Volume Change Rate (m^3/yr)	738
Volume Change Density Rate (m^3/m/yr)	5.21
Difference Volume above MHW	
Number of Above MHW Volume Change Bins:	29
Total Above MHW Volume Change (m^3):	-104812
Average Above MHW Volume Change Rate (m^3/yr):	-4328
Above MHW Volume Change Density Rate (m^3/m/yr):	-27.33
Shoreline Change	
Number of Shoreline Change Quantified:	27
Average Shoreline Change (m):	3.89
Average Shoreline Change Rate (m/yr):	4.66

Table 4. Haulover Beach Volume Change Summary for LiDAR Only

Difference Volume	
Number of Volume Change Bins:	43
Total Volume Change (m^3)	23166
Average Volume Change Rate (m^3/yr)	645
Volume Change Density Rate (m^3/m/yr)	4.22
Difference Volume above MHW	
Number of Above MHW Volume Change Bins:	45
Total Above MHW Volume Change (m^3):	-181758
Average Above MHW Volume Change Rate (m^3/yr):	-3697
Above MHW Volume Change Density Rate (m^3/ m/yr):	-29.48
Shoreline Change	
Number of Shoreline Change Quantified:	0

The toolbox provides a volume density change in cubic yards per year per linear foot of shoreline within each bin. Tables 3 and 4 include the average change density for the entire site. This represents the rate of volume change relative to the length of shoreline being analyzed thus providing a time inclusive general metric for future volume change values. The volume density change rate divided by the design width or width at the plunge point of a beach profile provides a rate of volume change in proportion to the overall desired width. Figure 15 shows these values with a graduated color across the Bal Harbour site and Figure 16 shows the same visualization across Haulover.

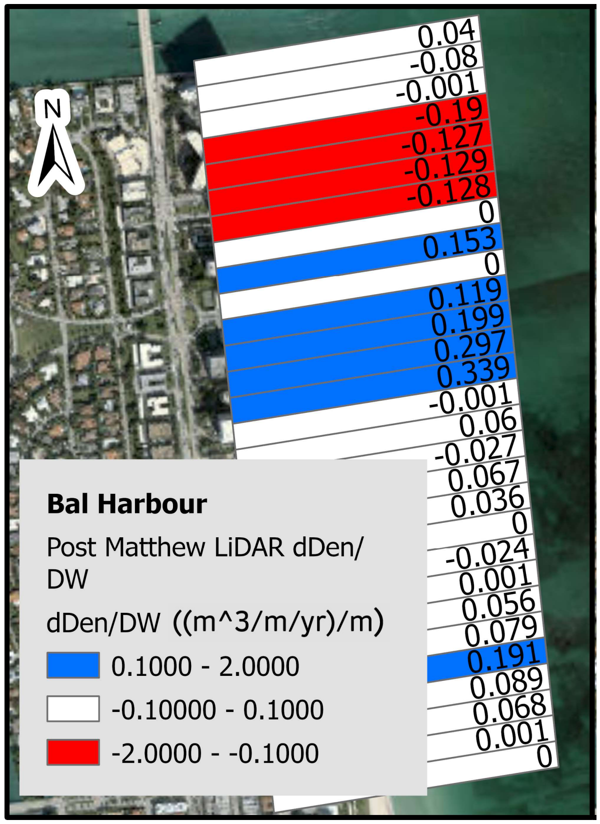

Figure 15. Density Rate / Design Width for Bal Harbour

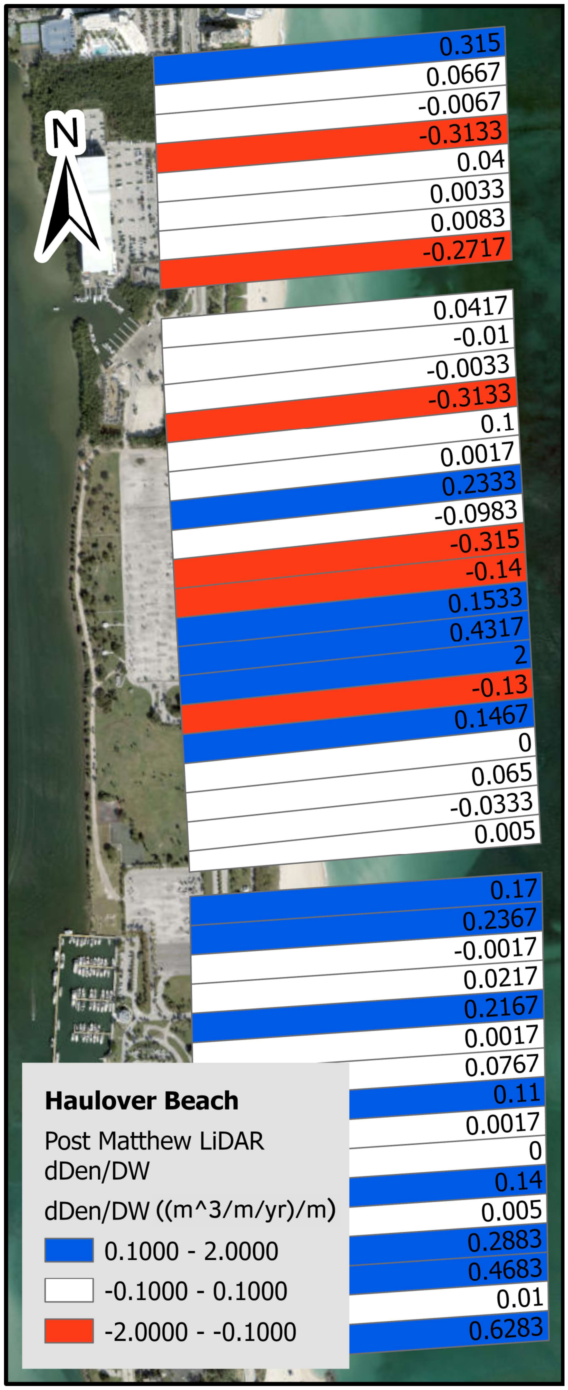

Figure 16. Density Rate / Design Width for Haulover Beach

CHAPTER IV

DISCUSSION

The major trend for the Miami-Dade BEC at Bal Harbour and Haulover Beach shows only the seaward location of the post Matthew shoreline relative to the design shoreline. The net total volume change at both design areas when LiDAR DEMs were used for before and after storm conditions was positive. While beach wide statistics are informative for a beach nourishment project, specific metrics to quantify reliability are the focal point of this study with a specific interest in erosional hotspots. The graphics with volume change bins across the entire site allow for hotspots to be identified. These bins were created using a 50 meter transect distance and the location and width could affect identifying specific erosional hotspot locations. A closer transect spacing would combat this potential skew.

The shoreline change graphics show planform view differences between beach profiles at the MHW while the single transect profile graphs show a slice of the beach at specific points. The shoreline visual from the toolbox covers entire beach sections rather than a single transect. These offer two alternative ways to visualize the beach width differences between DEMs in two dimensions. The toolbox shoreline change graphic shows that both sites have a Post Matthew shoreline seaward of the design profile at MHW, which indicates that the surveyed MHW shoreline has not eroded past the design MHW shoreline. When the negative volume change is factored in alongside the single transect profiles, it shows that the erosional hotspots cannot be determined from only shoreline change. This is clearest on the Haulover hotspot profiles. The profile above the MHW line show accretion away from the design profile while the lower elevations show erosion past the design profile. Areas with a seaward shoreline migration are still experiencing erosion below the MHW line.

For three-dimensional metrics specific to the Volume Change Toolbox, the most simplistic is the total net volume change or MHW total net volume change at each site or across an entire project. Bal Harbour had a total net volume change of 13,673 m^3 while Haulover Beach had a value of 17,712 m^3. Alternatively, a percent erosion metric indicating how much of the project area is experiencing erosion could be used. A value for characterizing the entire site is found using Equation 1. This is a sum of only the negative volume changes between the design and the post-storm LiDAR DEMs divided by the positive volume change for an entire site. This metric indicates what percentage of the desired beach is eroding beyond design conditions. The numerator is the sum of all erosional volume change values divided by the net volume changes for the site.

$$\text{Percent Erosion} = \frac{\sum_{-\infty}^{0} dVol}{\sum dVol} \times 100 \qquad (1)$$

This value is -74.2% for Bal Harbour and -69.08% for Haulover.

The density rate over design width values is representative of the volume change rate for a bin over the scaled area created by multiplying the per unit length of shoreline by width of design berm. The sign is controlled by that of the density rate; therefore, negative values indicate a negative volume change rate and positive values indicate a positive volume change rate. The magnitude of this value is the ratio of density rate to design width. The larger the density rate is, the more rapidly volume change is occurring. A large negative value indicates the volume is eroding rapidly in relation to the design width. When considered in conjunction with total volume change in a cell, a set of reliability indicators can be created for erosion control focused projects. A breakdown of these values into three intervals corresponding with good, intermediate, and bad reliability ratings would require a specific magnitude to mark intermediate values as seen in Table 5.

Table 5. Density Rate / Design Width Metric Breakdown

Good	Intermediate	Bad
dDensity/DW > +X	+X ≥ dDensity/DW ≥ -X	-X > dDensity/DW

Values less than that negative magnitude (-X) would be associated with a bad rating. A good rating would correspond to values larger than the positive magnitude (+X). All Values around zero between those positive and negative magnitude values fall into the intermediate rating class. That “X” value needs be determined from more historical data or larger data sets through extensive statistical analysis and discussions within USACE project leads which are outside the scope of this research. More comparisons are needed to determine what specific magnitude of the density rate over design width is indicative of each reliability rating.

CHAPTER V

CONCLUSIONS

This research provided a set of potential metrics for CSPI to indicate project "reliability". A comparison of post-storm beach width to the design width offers a two-dimensional metric for determining project reliability that could be assigned reliability ratings. This metric not only accounts for changes between constructed, surveyed, and design berms but could be altered to indicate width differences at other depths on the profile like the point of slope change or nearshore bar for the Haulover Beach profiles. LiDAR data increases the number of available profiles beyond single transect surveys and the inclusion of volume change values across the beach would allow for areas of interest to be targeted for profile comparison such as hotspots for erosion or accretion. The Calculate Shorelines and Calculate Shoreline Change portions of the JALBTCX Volume Change Toolbox provide similar data points to the beach profile analysis with different focal points. Rather than charting a traditional beach profile with elevation as a function of depth, it visualizes the cross-shore location of one specific elevation along the longshore length of the site. The tool could be used with "false" MHW elevation values that correspond to points of interest, like design width, plunge points, depth of closure or any profile features in between those depths to provide the beach width metric at each transect as an alternative to selected profiles of interest.

A percent erosion value summarizes the erosion throughout the entire project site. This metric considers the impacts potential hotspots have relative to the total volume change. The volume change rate and volume density rate introduce time averaged values which allow for considerations for how the project will change over its lifetime. Combining those two factors into the Density Rate / Design Width and Density Rate / Net Volume Change provides a potential metric that relates the current state of the project to changes being observed. This represents the rate of volume change relative to the length of shoreline being analyzed thus providing a time inclusive general metric for future volume change values which could be used as a baseline for project reliability with estimated future erosion factored in. The versatility of these metrics is also advantageous. Shifting the focus from erosional or negative volume changes and volume change rates for BEC projects to their positive accretion values may benefit dredging projects within CSPI. A broad overview of the workflow for these metrics can be found in Figure 17.

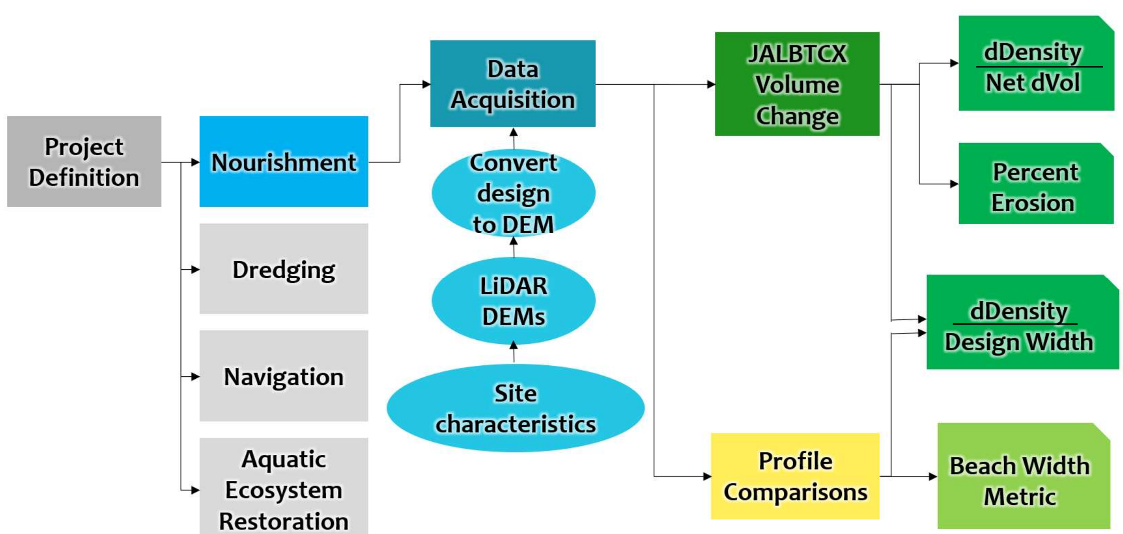

Figure 17. Potential CSPI Reliability Metric Workflow

The potential for sites that experience large erosion values as well as equally large accretion values to not be accurately represented by volume change metrics based on net site volume change should be considered. The specifics of the impacts of structures like jetties and breakwaters on the aforementioned metrics was not considered within the scope of this study. Projects with manmade structures would need to take into account the interrupted sediment transport by either omitting those structures or focusing specifically on how they impact volume change for the entire site. Isolating those bin volumes to compare with the overall site volume change in a manner similar to how erosional values were treated for this study and analyzing that data for skew to potential metrics should be done. A theoretical "structure factor" could be used to correct for higher volume change values around structures like jetties that may already be under project monitoring for separate removal or transport focused projects while still including those volumes in the overall study. Dividing up more expansive projects that cover larger and more varied shorelines, as was done for both this study as well as the project design for Dade County BEC, would ensure the variability does not remove hot spots or erosion from the view of this metric. For locations with high seasonal variability between cross shore profiles, widening time steps between LiDAR surveys and ensuring start and end dates are within similar seasons or wave conditions would minimize potential skew in the data with the caveat that coastal LiDAR surveys cannot always be found.

The intent of this research was to find potential metrics specifically for the CSPI web database to indicate project "reliability" rather than qualitative site visits and reactive beach fill. Currently the database is optimized for numerical metrics, but work is being done to update the system to allow georeferenced images, shapefiles, documentation, and various other files to be hosted on the service. This ArcGIS hub system has been used for the Great Lakes Restoration Initiative (GLRI) at https://glri-usace.hub.arcgis.com to allow USACE researchers to document sediment budget creation and link associated shapefiles by geographic location. A system like this would allow for the volume change bins, shoreline data, and DEMs to be linked to pertinent projects. This system also allows for data gaps to be easily identified. Regardless, potential metrics to include in the absence of external file compatibility include negative volume change over net volume change, beach width comparison, and volume change density over design width. These new metrics are quantitative in nature and those which include the density rate also factor in time to use for evaluating future change. The metrics discussed in this study would shift the current reliability ratings away from being reactive and qualitative in nature.

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APPENDIX

Appendix A: Volume Change Tables Appendix

Appendix Table A1. Change Table Output from JALBTCX Volume Change Toolbox for Bal Harbour

Segment	Azimuth	stTran Num	Shape_Length	Start_Date	End_Date	dDensity	dMean	dVol	dMHW_Vol	dDensity MHW2
1	263.9	1	553.0167424	20160101	20161101	22.3	0.7	3654	1762	0.6
2	263.9	2	553.0167918	20160101	20161101	92.9	0.9	15238	5340	2.7
3	263.9	3	553.0168422	20160101	20161101	70.4	0.69	11549	4733	0.1
4	263.9	4	553.0168925	20160101	20161101	39.6	0.38	6489	4183	-0.2
5	263.9	5	553.016942	20160101	20161101	25.8	0.25	4231	4531	1.1
6	263.9	6	553.0169923	20160101	20161101	9.2	0.09	1512	3442	-1
7	263.9	7	553.0170426	20160101	20161101	-2.6	-0.02	-422	3599	1.1
8	263.9	8	553.0170921	20160101	20161101	-0.1	-0.11	-11	5470	12.9
9	263.9	9	553.0171424	20160101	20161101	-12.1	-0.12	-1986	6528	18.6
10	263.9	10	553.0171927	20160101	20161101	-0.3	-0.29	-45	3250	2.1
11	263.9	11	553.0172422	20160101	20161101	-18.6	-0.18	-3049	2041	1
12	263.9	12	553.0172925	20160101	20161101	-14.1	-0.14	-2320	2504	8.4
13	263.9	13	553.017343	20160101	20161101	6.8	0.07	1121	2900	14.7
14	263.9	14	553.0173933	20160101	20161101	22.8	0.22	3737	3237	17.9
15	263.9	15	553.0174426	20160101	20161101	13.5	0.14	2215	-139	0
16	263.9	16	553.0174931	20160101	20161101	0.4	0	67	-2890	-29.8
17	263.9	17	553.0175434	20160101	20161101	-11.2	-0.11	-1840	-4749	-34.5

Appendix Table A1 Cont. Change Table Output from JALBTCX Volume Change Toolbox for Haulover Beach

Segment	Azimuth	stTran Num	Shape_Length	Start_Date	End_Date	dDensity	dMean	dVol	dMHW_Vol	dDensit yMHW2
18	263.9	18	553.0175927	20160101	20161101	-3.1	-0.03	-503	-6027	-32.9
19	263.9	19	553.0176432	20160101	20161101	-7	-0.07	-1143	-7086	-36.6
20	263.9	20	553.0176935	20160101	20161101	-11.9	-0.13	-1950	-9451	-46.6
21	263.9	21	553.0177428	20160101	20161101	-24.9	-0.28	-4086	-12230	-44.8
22	263.9	22	553.0177933	20160101	20161101	-0.2	-0.31	-26	-13391	-77.4
23	263.9	23	553.0178436	20160101	20161101	3	0.03	500	-12423	-91.1
24	263.9	24	553.0178939	20160101	20161101	4.8	0.06	781	-14826	-94.4
25	263.9	25	553.0179432	20160101	20161101	22.4	0.27	3673	-16126	-61.7
26	263.9	26	553.0179937	20160101	20161101	25	0.3	4094	-17162	-19.1
27	263.9	27	553.018044	20160101	20161101	0.2	0.45	25	-20790	-72.7
28	263.9	28	553.0180934	20160101	20161101	38.9	0.49	6377	-20176	-77.2
29	263.9	29	553.0181438	20160101	20161101	4.3	0.18	706	1519	-0.3
30	263.9	30	553.0181941	20160101	20161101					
31	263.9	31	553.0182435	20160101	20161101					

Appendix Table A2. Change Table Output from JALBTCX Volume Change Toolbox for Haulover Beach

Segment	Azimuth	stTran Num	Shape_Length	Start_Date	End_Date	dDensity	dMean	dVol	dMHW_ Vol	dDensity MHW2
1	268.2	1	603.2906171	20160101	20161101	18.9	0.18	3093	-4068	-24.8
2	268.2	2	603.2906339	20160101	20161101	4	0.03	655	-4401	-26.9
3	268.2	3	603.2906497	20160101	20161101	-0.4	-0.36	-64	-4935	-30.1
4	268.2	4	603.2906655	20160101	20161101	-18.8	-0.16	-3077	-5119	-31.2
5	268.2	5	603.2906812	20160101	20161101	2.4	0.02	398	-5181	-31.6
6	268.2	6	603.290697	20160101	20161101	0.2	0.19	33	-3445	-21
7	268.2	7	603.2907127	20160101	20161101	0.5	0	89	-3964	-24.1
8	268.2	8	603.2907295	20160101	20161101	-16.3	-0.14	-2675	-4220	-25.8
9	268.2	9	603.2907452	20160101	20161101		-0.00117	0	-4021	-24.5
10	268.2	10	603.290761	20160101	20161101	2.5	0.02	415	-3403	-20.7
11	268.2	11	603.2907767	20160101	20161101	-0.6	0	-100	-4573	-27.9
12	267	12	603.2907994	20160101	20161101	-0.2	-0.14	-28	-4238	-25.9
13	267	13	603.2908257	20160101	20161101	-18.8	-0.16	-3084	-4374	-26.6
14	267	14	603.2908533	20160101	20161101	6	0.05	983	-3834	-23.3
15	267	15	603.2908809	20160101	20161101	0.1	0.04	9	-4030	-24.5
16	267	16	603.2909085	20160101	20161101	14	0.12	2297	-3860	-23.5
17	267	17	603.2909361	20160101	20161101	-5.9	-0.05	-967	-4477	-27.3
18	267	18	603.2909637	20160101	20161101	-18.9	-0.16	-3107	-5090	-31.1
19	267	19	603.2909913	20160101	20161101	-8.4	-0.07	-1370	-4406	-26.9
20	267	20	603.2910189	20160101	20161101	9.2	0.08	1501	-4422	-26.9
21	267	21	603.2910455	20160101	20161101	25.9	0.22	4247	-4175	-25.4
22	267	22	603.2910731	20160101	20161101	0	0.02	3	-4311	-26.3
23	267	23	603.2911008	20160101	20161101	-7.8	-0.07	-1286	-4687	-28.5
24	267	24	603.2911284	20160101	20161101	8.8	0.08	1449	-4639	-28.3
25	267	25	603.291156	20160101	20161101	0	0.04	7	-4394	-26.8
26	267	26	603.2911835	20160101	20161101	3.9	0.03	641	-4320	-26.3
27	267	27	603.2912111	20160101	20161101	-2	-0.02	-320	-4555	-27.8

Appendix Table A2 Cont. Change Table Output from JALBTCX Volume Change Toolbox for Haulover Beach Cont.

Segment	Azimuth	stTran Num	Shape_Length	Start_Date	End_Date	dDensity	dMean	dVol	dMHW_ Vol	dDensity MHW2
28	267	28	603.2912387	20160101	20161101	0.3	0	46	-3499	-21.3
29	268.3	29	603.2912593	20160101	20161101		-0.00253	0	-3906	-23.9
30	269.1	30	603.2912712	20160101	20161101	10.2	0.09	1681	-4114	-25.1
31	269.1	31	603.2912794	20160101	20161101	14.2	0.13	2329	-4059	-24.7
32	269.1	32	603.2912876	20160101	20161101	-0.1	-0.14	-19	-4951	-30.2
33	269.1	33	603.2912957	20160101	20161101	1.3	0.01	213	-5733	-35
34	269.1	34	603.2913039	20160101	20161101	13	0.12	2139	-5893	-35.9
35	269.1	35	603.2913121	20160101	20161101	0.1	0.06	9	-5919	-36
36	269.1	36	603.2913203	20160101	20161101	4.6	0.04	753	-5804	-35.4
37	269.1	37	603.2913284	20160101	20161101	6.6	0.06	1085	-4362	-26.6
38	269.1	38	603.2913366	20160101	20161101	0.1	0.16	24	-2802	-17
39	269.1	39	603.2913448	20160101	20161101	0	0	5	-2423	-14.8
40	269.1	40	603.2913529	20160101	20161101	8.4	0.08	1380	-1684	-10.3
41	269.1	41	603.2913612	20160101	20161101	0.3	0.28	45	-1247	-7.6
42	269.1	42	603.2913693	20160101	20161101	17.3	0.16	2838	-1989	-12.2
43	269.1	43	603.2913775	20160101	20161101	28.1	0.26	4609	-1012	-6.2
44	269.1	44	603.2913857	20160101	20161101	0.6	0.66	98	-1683	-10.3
45	269.1	45	603.2913938	20160101	20161101	37.7	0.35	6189	-3536	-21.6
46	269.1	46	603.291402							

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