Mapping and Analysis of Privately-Owned Structures along the Massachusetts Shoreline

Appendix A – Elevation Extraction

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1 Introduction

Coastal structures were assigned elevations using LiDAR datasets for coastal Massachusetts made available by Massachusetts Office of Geographic Information (MassGIS, 2012). LiDAR datasets were downloaded as tiled Digital Elevation Models (DEMS) and aggregated to cover the project area. Elevations were extracted using two distinct approaches, one for structures oriented perpendicular to the shore, and another for structures that are shore-parallel. All groin/jetty structures were considered perpendicular; the remaining structures were treated as parallel.

2 LiDAR Data Compilation

Between 2002 and 2011 various government agencies and/or partnerships acquired 17 distinct LiDAR datasets for Massachusetts. Datasets vary in terms of the instruments used to acquire the data, the processing software, accuracy, point spacing, format, tiling schemes, and most importantly their acquisition dates, projections, and units.

To cover the project area eight of these datasets (summarized in Table 1) were used. Figure 1 shows the tiled coverage of each of these datasets.

Table 1. LiDAR datasets used for project.

Year and Project Name	Acquisition Dates	Tiles Downloaded	Projection	Units	Resolution (meters)	Priority Order
2011_Northeast_LIDAR	Winter/Spring 2011	1076	UTM Zone 19N	Meters	1	1
2010_DukesCounty	Nov. 2009 - Feb. 2010	154	MA SPC Island Zone	Feet	1	2
2010_Nantucket	Nov. 2009 - Feb. 2010	81	MA SPC Island Zone	Feet	1	2
2010_Quincy	Dec 2010	115	UTM Zone 19N	Meters	1	2
2009_Boston	Nov 2009	179	MA State Plane	Feet	1	3
2006_Bristol_County	Nov 2006	113	MA State Plane	Feet	1.2	4
2006_PlymouthCountySouth	Nov 2006	91	MA State Plane	Feet	1.2	4
2002_Boston	Apr 2002	27	MA State Plane	Meters	1	5

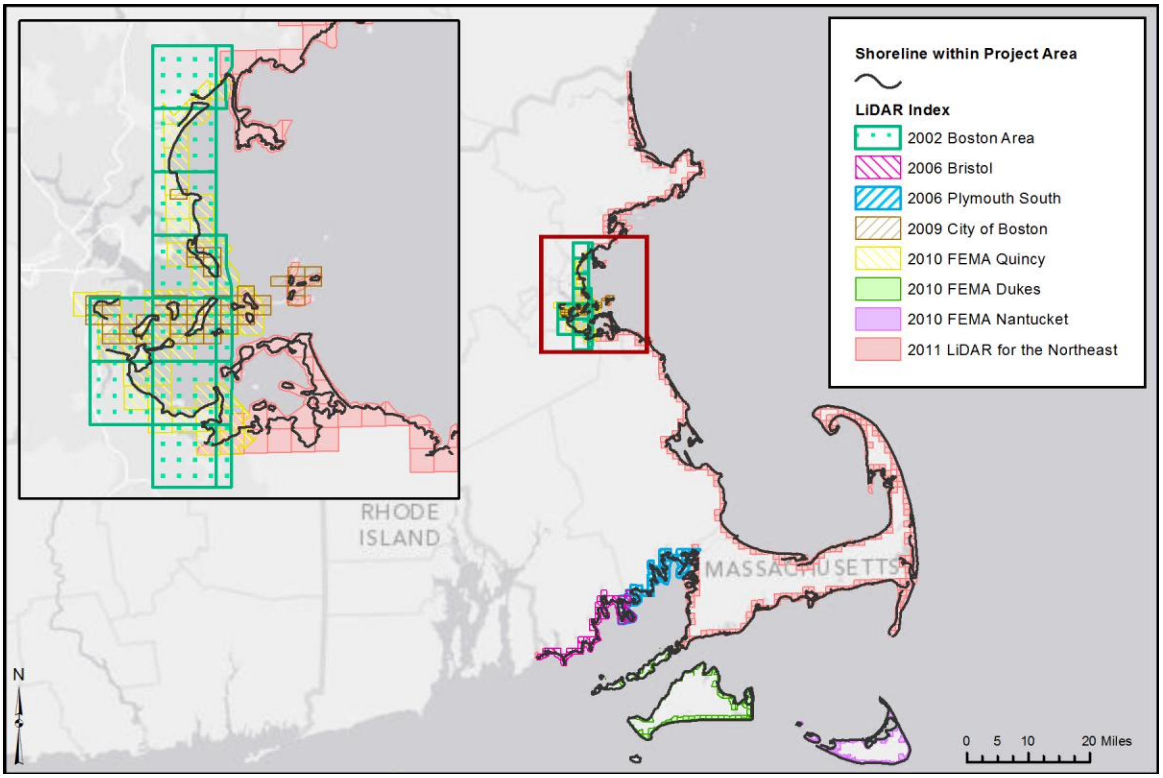

Figure 1. LiDAR tiles used for attribution of privately-owned coastal structures. Colors indicate source and date of acquisition.

The most efficient method for combining individual LiDAR surveys was to create an ArcGIS mosaic dataset. This format allows raster datasets with different projections, resolution, units, and acquisition dates to be managed and served as a single layer, without requiring reprocessing of tiles to a consistent projection and units. For overlapping datasets, the most recent files are preferentially used.

The following steps were completed to build the mosaic dataset:

1. The extent of required data was determined by selecting all LiDAR tiles within 500 meters of the project shoreline. Approximately 1,800 tiles were needed to cover the project area. An automated process was used to download individual tiles from the MassGIS website, and to extract the GeoTiff DEM files from each compressed file.
2. The ArcGIS "Build Pyramids and Statistics" tool was used to calculate statistics and build pyramids for each tiled DEM. Calculating statistics ensures that the data displays correctly; building pyramids improves display speed. Values representing pixels of 'no data' were excluded from the statistics for each dataset to avoid skewing the range.
3. The LiDAR times were imported into a new mosaic dataset.
4. All tiles with elevation units of feet were converted to meters. The conversion was handled by the mosaic dataset "Raster Functions." A mathematical function was applied to all tiles with units of feet. In this case each raster pixel was multiplied by 0.3048. This

function is applied to the data as it is loaded into the map. It does not change the source data.

5. Lastly, the priority order of tiles was set. This was done through the “mosaic properties” of the dataset. The mosaic properties define the order in which the tiled rasters are mosaicked together. In this case, the order was based on the tile attributes. A mosaic dataset has an attribute table listing all the tiles and their properties. A field for “Order” was added to this table and calculated from the priority listing shown in Table 1. This order ensures that the most recent tiles are used in place of older ones, and that tiles of higher resolution are used before those of lower resolution.
6. An ArcGIS layer (.lyr) file was created to save all settings and was used for all subsequent elevation processing.

3 Elevations for Shore-Perpendicular Structures

Assigning elevations to shore-perpendicular features was completed by extracting elevation at points along digitized structures and recording the highest elevation. All of these structures were groins/jetties (predominantly stone), and typically the highest elevation occurred at the landward end of the feature. An elevation profile was generated and saved for each structure.

The following steps describe the extraction of shore-perpendicular structure elevations:

1. Points were created at a 1 meter interval from the starting point of each linear feature. A 1-meter interval was chosen because the mosaic LiDAR dataset has a minimum resolution of 1 meter. Each point was assigned the structure ID number and the distance along the structure (in meters). Because structures were not digitized in a specific direction, the starting point could occur at either the landward or seaward end.

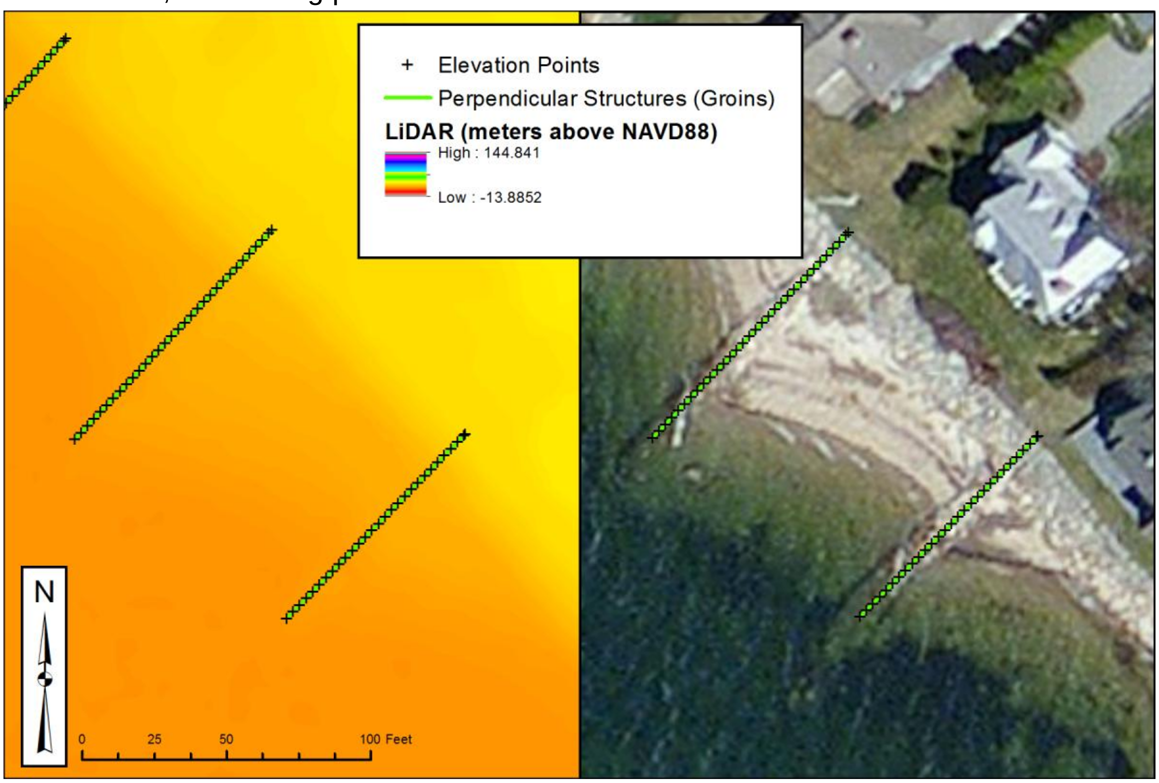

Figure 2. Shore-perpendicular structures with elevation points spaced at a one meter interval. Elevation points plotted over LiDAR (left) and ortho imagery (right).

2. Elevations from the mosaic LiDAR dataset were assigned to each point using the ArcGIS "Extract Values to Points" tool. The elevation (in meters NAVD88) was then added to the point layer attribute table.
3. Points located outside the extent of the LiDAR data coverage were assigned the corresponding "No Data" value, which varied by LiDAR source. These points were

removed from the dataset. Figure 3 shows examples of groins/jetties in Oak Bluffs on Martha's Vineyard with either partial and/or no corresponding LiDAR coverage.

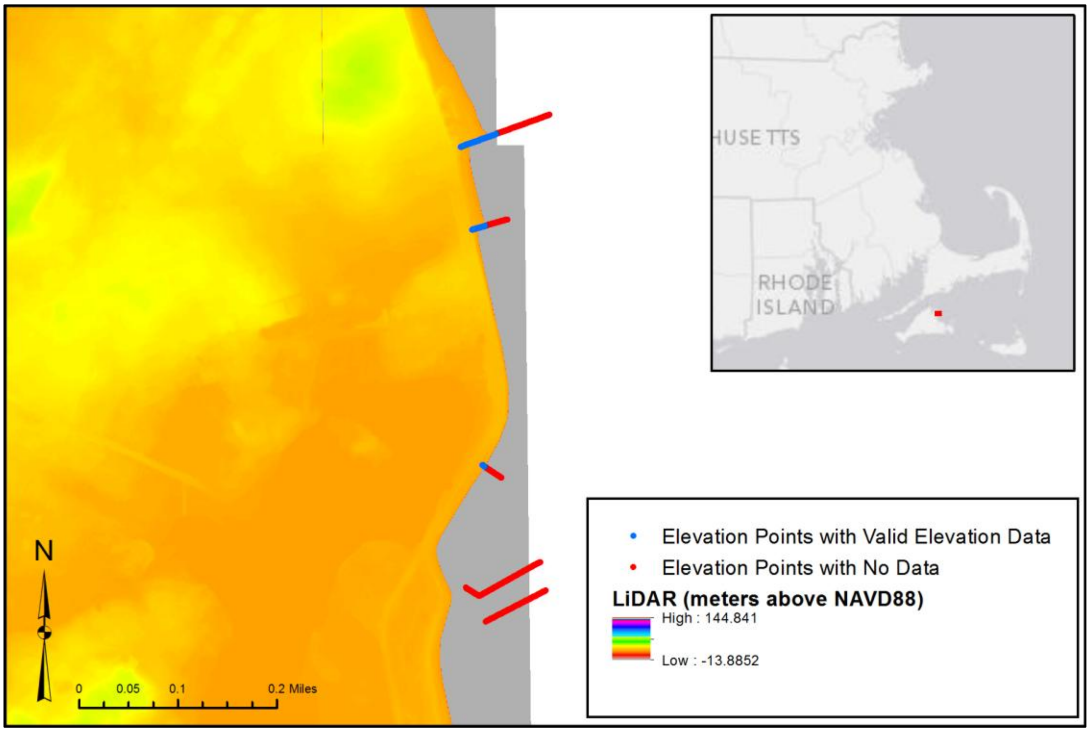

Figure 3. Shore-perpendicular structures with incomplete LiDAR coverage. Points in blue have elevation data and points in red do not.

4. The maximum elevation associated with each structure was assigned as the structure elevation. Elevation profiles were also generated for each structure (an example is shown in Figure 4).

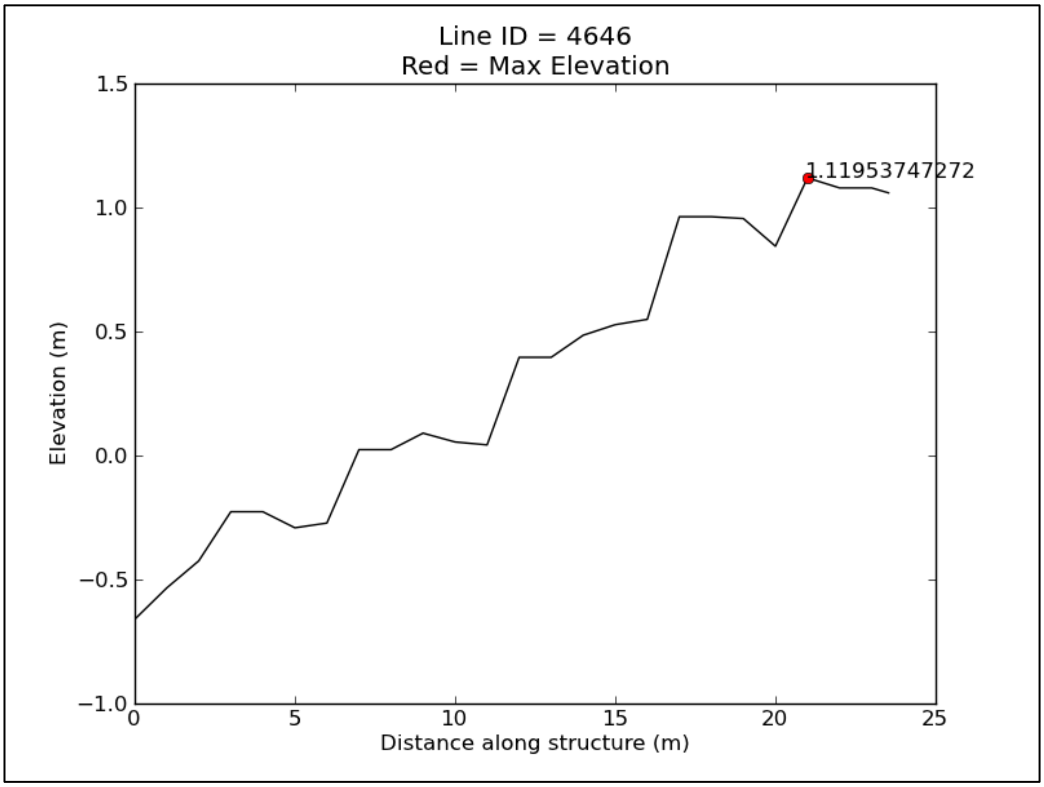

Figure 4. Example elevation profile for a shore-perpendicular structure. The red point shows the maximum elevation, which was entered as the structure elevation.

4 Elevations for Shore-Parallel Structures

Elevation for structures parallel to the shore (bulkheads, seawalls, revetments, etc.) were extracted from a series of cross-shore profiles created along the length of each structure. This procedure was used to account for potential offset between the structures (digitized from imagery) and the elevation data sources. The maximum elevation along each profile line was assumed to represent the structure. The maximum profile elevations were then averaged for each structure and assigned as the structure elevation. The majority of these steps were performed using automated processes, except where noted.

4.1 Glossary of Terms

The process for extracting shore-parallel structure elevations is outlined in Section 4.2. As this process is fairly complex, a glossary of terms used in the explanation of the process is provided below. An illustration of the terms is provided in Figure 5.

- **Structure line**: polyline feature of digitized coastal structure. Each structure is represented by a single feature. Figure 5 shows a single shore-parallel coastal structure (in blue) that has been digitized from north to south.
- **Vertices**: Points indicating the position of each structure line vertex. Polylines have multiple vertices including the start and end points (at a minimum), and at the location of each change in direction. The structure line in Figure 5 has three vertices, indicated by the green points.
- **Segment**: Length of the structure line between a pair of vertices. A segment is always a straight line connecting two vertices. The structure line in Figure 5 has two segments.
- **Segment angle**: The direction, in degrees clockwise from the north, in which the segment was digitized. The northern and southern segments in Figure 5 have segment angles of 170° and 190°, respectively.
- **Profile location**: The point along a structure line where a profile will be created if all criteria for profile generation are met.
- **Profile line**: Line created perpendicular to the structure line, along which elevations were extracted. Each structure line contains multiple profile lines. Figure 5 shows four profile lines (in black) along the structure line, each drawn perpendicular to the segment that they cross.
- **Baseline**: Offshore reference layer used to determine structure orientation to the coastline. In Figure 5, the baseline is shown in red.
- **Seaward angle**: Direction, in degrees clockwise from the north, to the nearest baseline feature from each profile location. Represents the direction to the coastline. The brown vectors in Figure 5 show the direction to the nearest baseline feature. Because the

baseline in Figure 5 is oriented in a north-south direction, the seaward angle for each profile location is 90°.

- **Profile/Elevation points**: Points along the profile line where elevation values are extracted from the LiDAR. In Figure 5, the profile/elevation points are represented by red points.

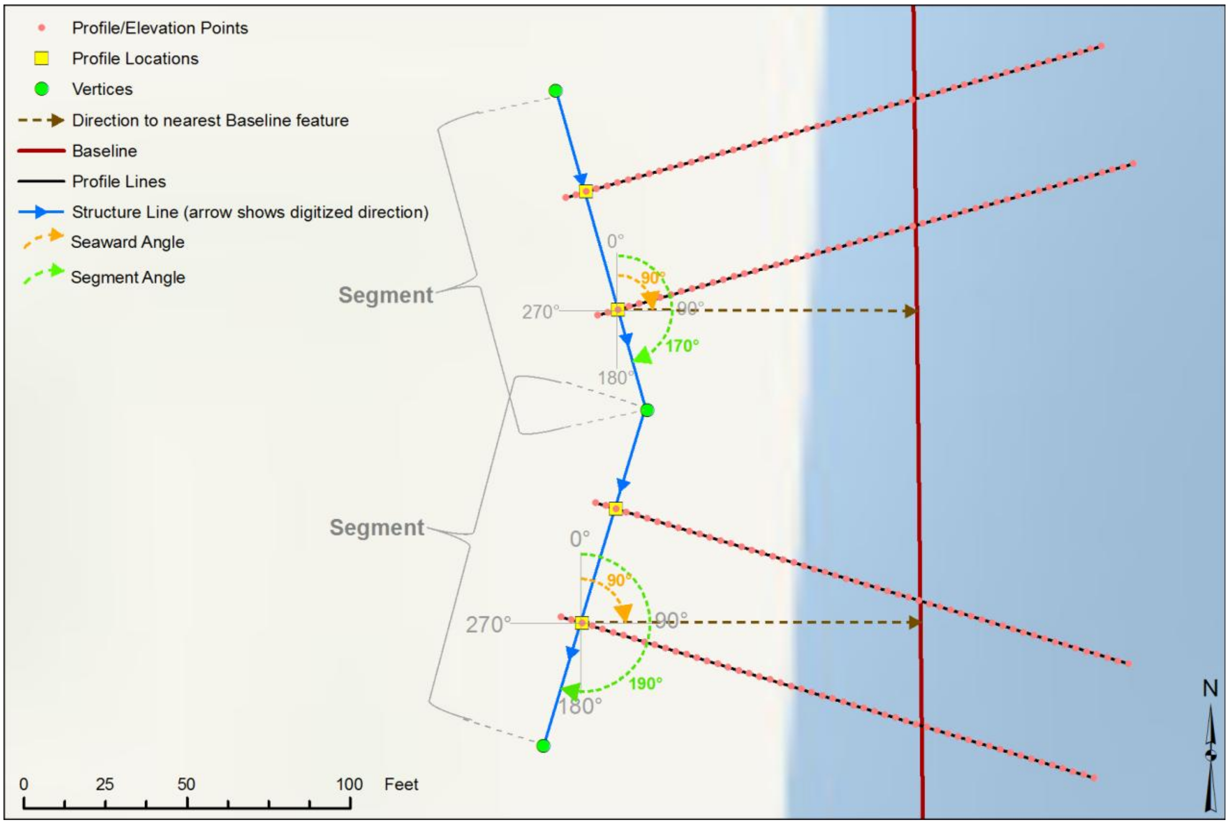

Figure 5. Diagram showing examples of all the terms used to describe the shore-parallel structure elevation extraction process.

4.2 Processing Steps

1. An offshore reference layer ("baseline") was needed to determine the orientation of each structure with respect to the coastline. MACZM provided a polyline layer that was initially developed to calculate shoreline-change rates as part of the MACZM Shoreline Change Project (MACZM, 2011). The line was created as an offshore reference for use with the US Geological Survey Digital Shoreline Analysis System software. Because the baseline is situated offshore and roughly approximates the shape of the natural coastline, it is ideal for the purposes of determining the orientation of each structure relative to the shoreline. The layer was modified slightly to ensure that no digitized structures intersected the line (see Figure 6).

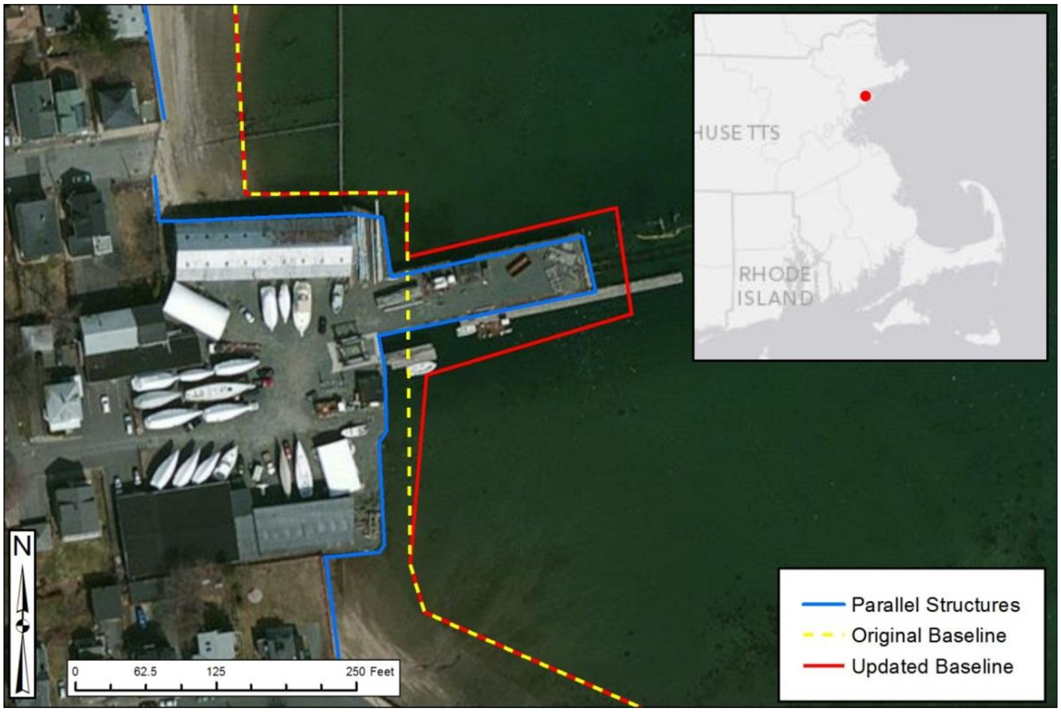

Figure 6. The original baseline layer (yellow line) was edited to extend around the bulkhead/seawall structure (blue line). The adjusted baseline is shown in red.

2. Each linear coastal structure was broken into segments defined as the part of the line between each set of vertices. Each segment was processed separately.

3. The angle of each segment ("segment angle", degrees clockwise from north) was determined based on the direction of digitization. An example is shown in Figure 7.

Figure 7. Angle of each segment of a bulkhead/seawall structure.

4. Profile lines were created for each segment at a maximum interval of 5 meters. The locations of profile lines along each segment was determined using one of two methods (Figure 8):
    a. If the segment length was less than or equal to 10 meters, one profile line was created at the segment midpoint.
    b. For segments longer than 10 meters, the number of profiles was determined by dividing the segment length by 5 meters and rounding up to the nearest whole number. The profiles were then evenly spaced along the segment length.

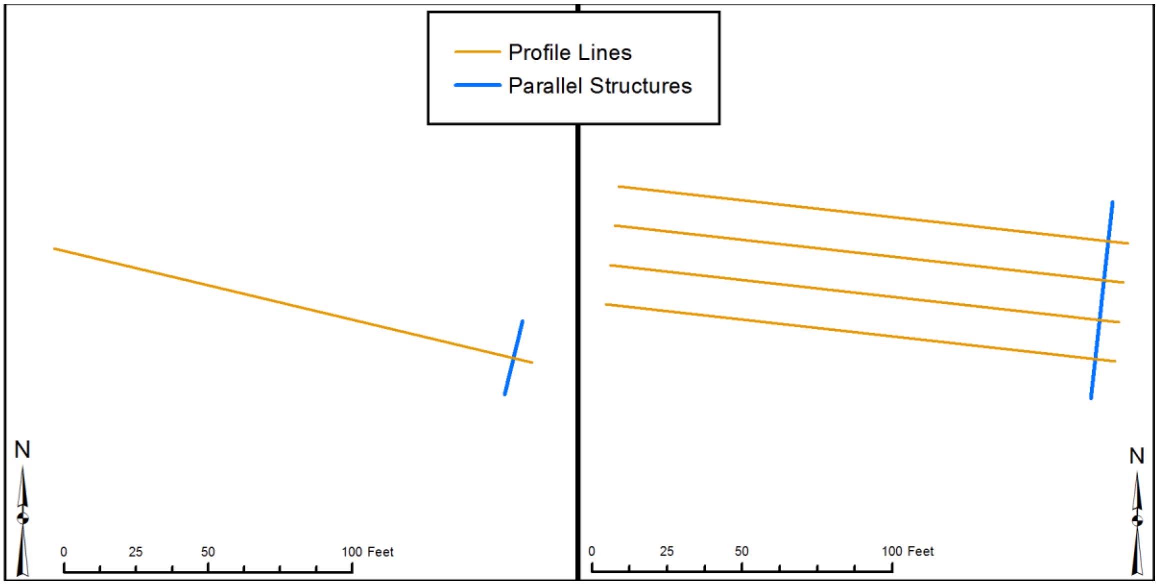

Figure 8. Examples of variable profile spacing. Profile spacing for a segment shorter than 10 meters (left) and a segment longer than 10 meters (right).

5. At each profile location, the direction (in degrees clockwise from north) to the nearest "baseline" feature was determined. This is the seaward angle described in the glossary of terms. The examples in Figure 9 show vectors pointing from each profile location to the nearest baseline feature and the associated direction in yellow.

Figure 9. Nearest baseline feature angle. The yellow arrows represent the direction of the nearest baseline feature (red line) at each location where a profile line is to be created, along the structure (blue line). The angles are labeled in yellow.

6. If the difference between the segment angle (digitized direction of the segment in degrees clockwise from north) and the seaward angle (direction between the profile location and the nearest coastline feature) was greater than 30 degrees, the segment was considered parallel to shore and a profile line was created at the profile location. When the segment angle was within 30 degrees of the seaward angle, the segment was considered to be perpendicular to shore, and no profile line was created. This was done to eliminate profile lines that may cross features (in the alongshore direction) other than the structure of interest. Figure 10 shows examples of two segments that are perpendicular to shore and two that are parallel to shore.

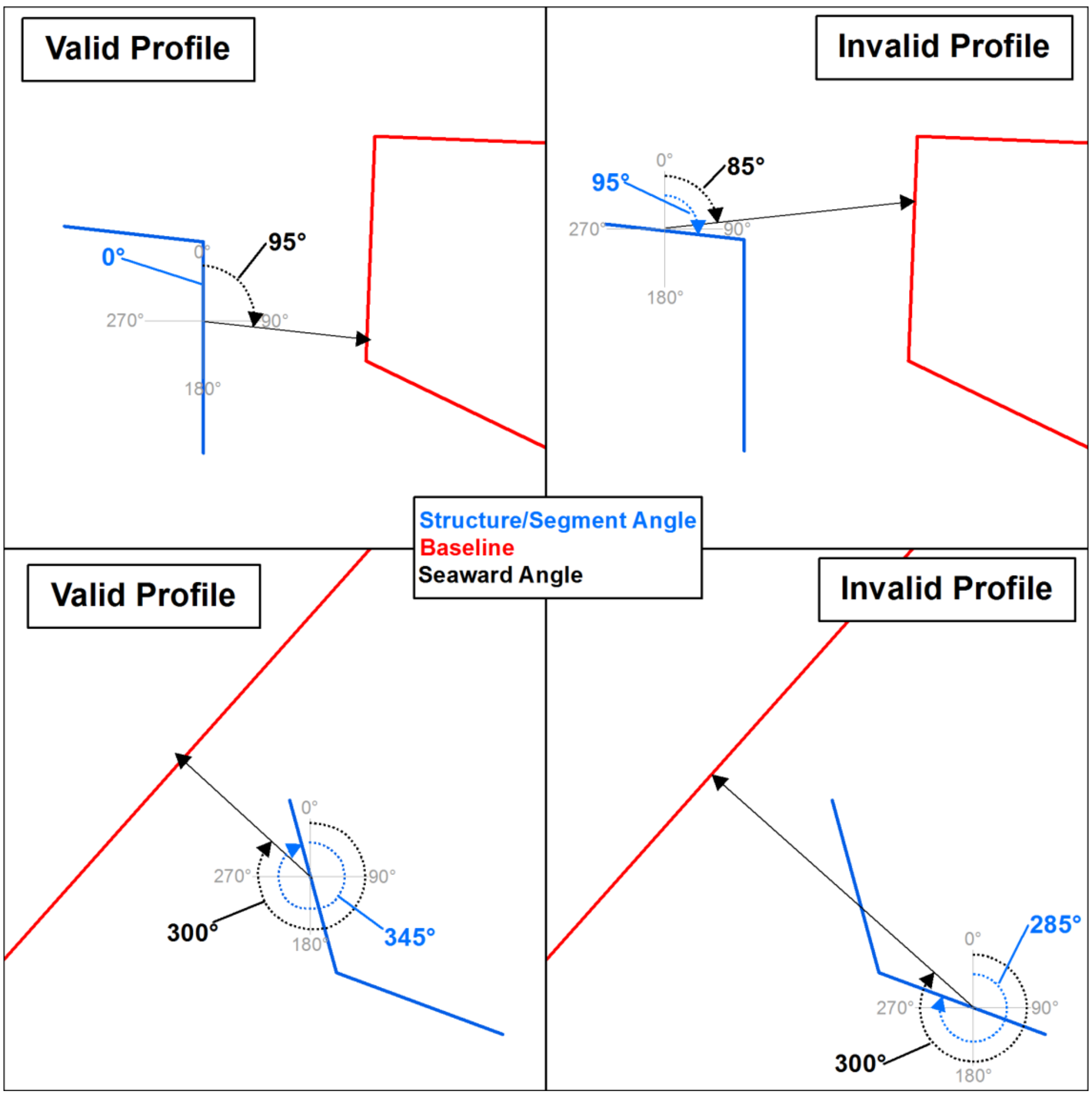

Figure 10. Segment orientation with respect to the baseline. Examples on the left show segments considered parallel to shore (will receive profile lines). The examples on the right show segments considered perpendicular to shore (will not receive profile lines).

7. Profile lines were generated for each location where the angle criteria were met. Profile lines were created exactly perpendicular to the corresponding structure segment. The profile lines extended 2 meters in the landward direction and 50 meters in the seaward direction. The 2 meter landward overlap was used to ensure that a representative elevation was chosen for each structure regardless of any potential misalignment with the DEM. Figure 11 shows an example of a complex structure consisting of many segments, and the valid profile lines created using the methods above.

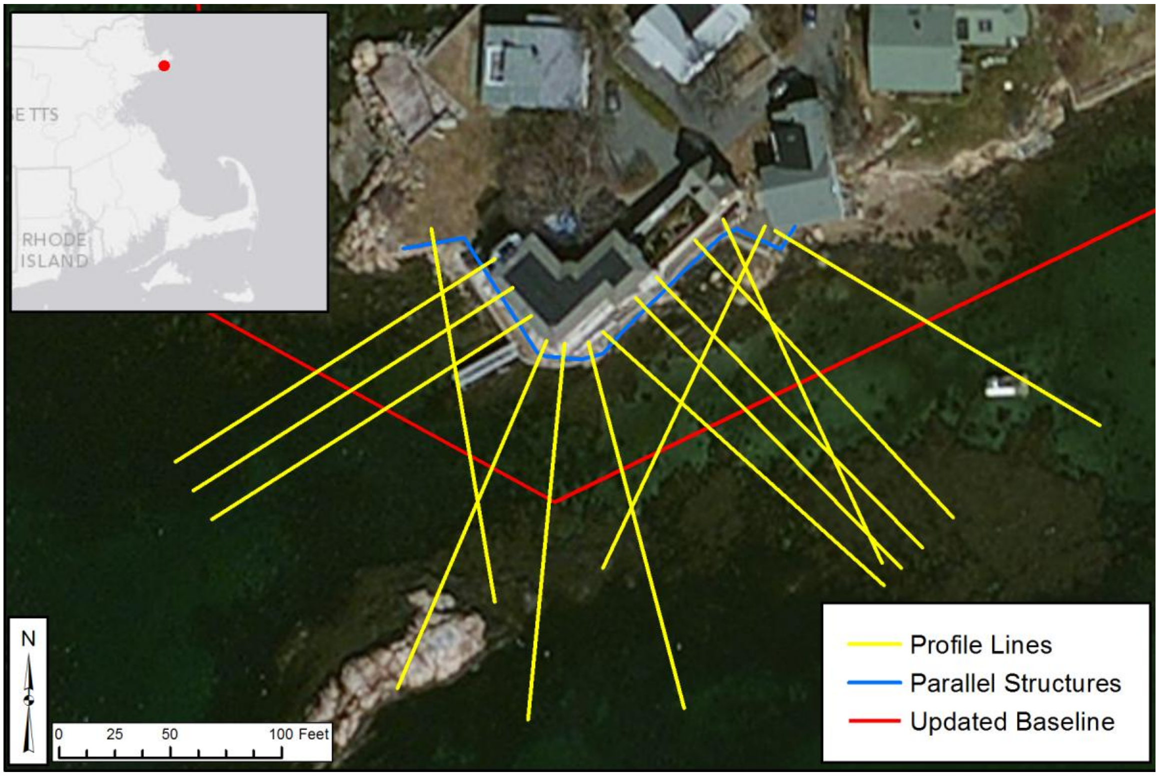

Figure 11. Profiles (yellow lines) created for a shore parallel structure (blue line). The profile lines are perpendicular to the structure segment they intersect.

8. If the entire structure was less than 15 meters in length and had fewer than 3 valid profile lines, additional profiles were added at the start and end points (vertices) of the structure. This was done to ensure that, if possible, structure elevations were based on an average using at least 3 profiles. However, if the angle criteria were not met at these locations, the profiles were not added.

9. Points were then created along each profile line at a 1 meter interval. The first point was created at the seaward end of the profile; points were then added every meter along the length of the line, ending with a point at the landward end of the profile (see example in Figure 12). In total, 53 points were placed along each profile line; the point at 50 meters corresponds to the point of intersection with the structure. Each point was assigned the following attributes: the structure ID, a profile line ID, and the distance from the seaward end of the profile.

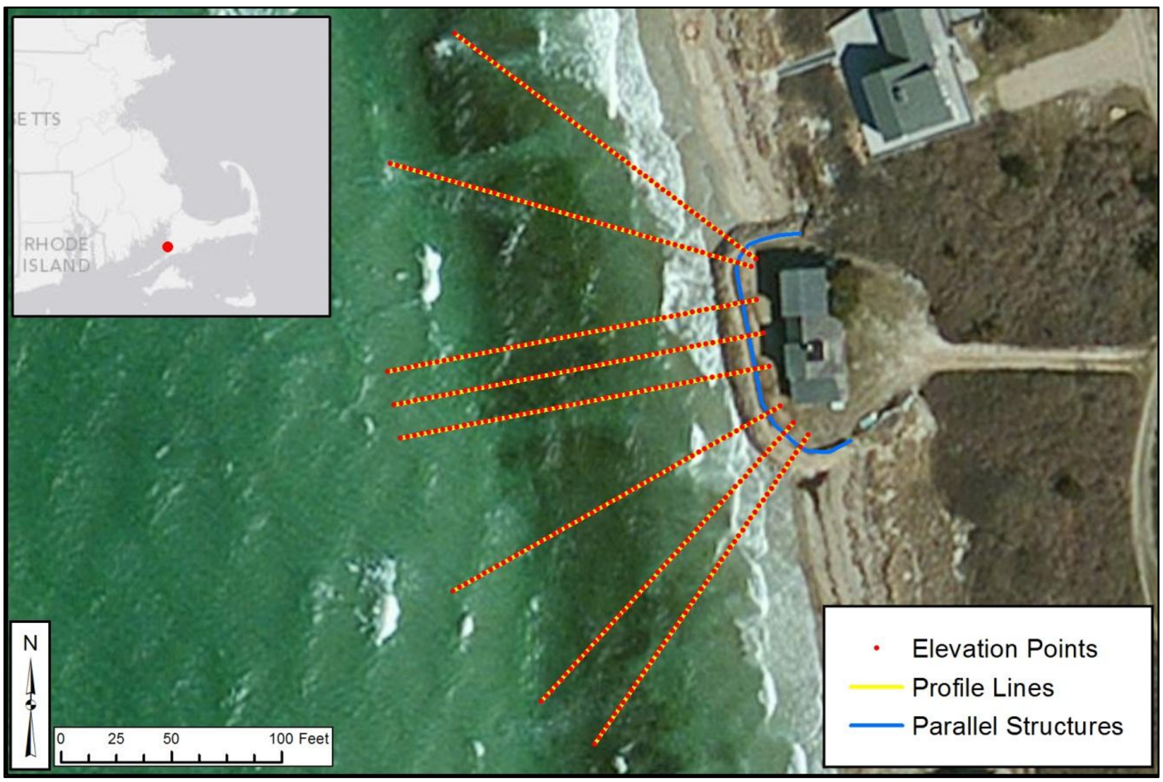

Figure 12. Elevation points (red) created along the profile lines (yellow) for a shore parallel structure (blue).

10. Elevations from the mosaic LiDAR dataset were assigned to each point using the ArcGIS “Extract Values to Points” tool. The elevation (in meters NAVD88) was then added to the point layer attribute table.

11. Points located outside of the extent of LiDAR coverage data were assigned the corresponding “No Data” value, which varied by LiDAR source. These points were removed from the dataset.

12. Points along each profile line were summarized as follows:
    a. Maximum elevation: the highest elevation value of all points on the profile line.
    b. Maximum distance: the distance along the profile line (from seaward end) to the maximum elevation point.
    c. Distance Difference: the difference between the maximum distance (b) and the structure location (50 meters).

13. Each profile line was plotted (example in Figure 13), showing the elevations from the seaward end of the profile (distance = 0) to the landward end (distance = 52 meters).

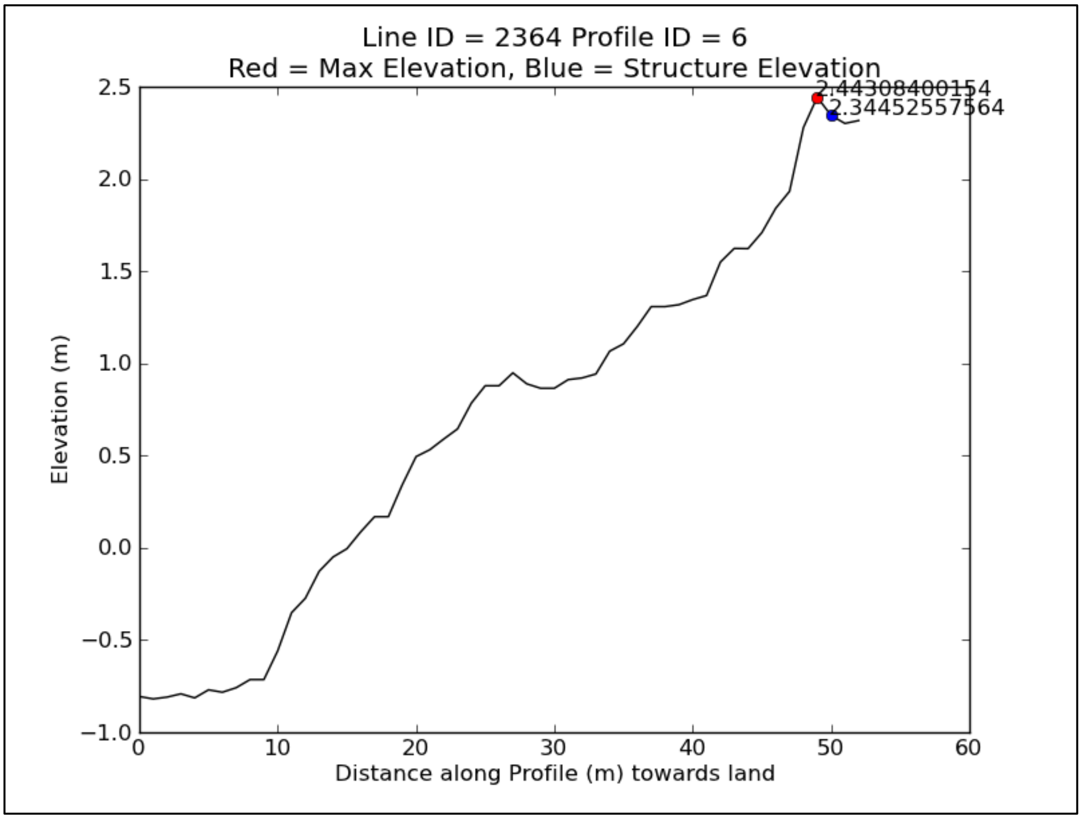

Figure 13. Example of coastal elevations corresponding to a single profile line. The maximum elevation point is shown in red, and the location of the digitized structure (always at a distance of 50 meters) is highlighted in blue.

14. Basic filtering steps were used to ensure that accurate structure elevations were obtained. Two filtering methods (or "rules") were used for the majority of the shore-parallel structures.
    d. If the maximum elevation along a given profile was not within 3 meters of the location of the structure, the profile was excluded. This typically indicated that the profile was including substantial elevations from features other than the structure. For example, Figure 14 shows profiles that intersect with maximum elevations after crossing a narrow channel. These profiles were excluded from the averaging done to determine this structure's elevation.
    e. A minimum of 3 profiles per structure was required to sample a representative range of structure elevations.

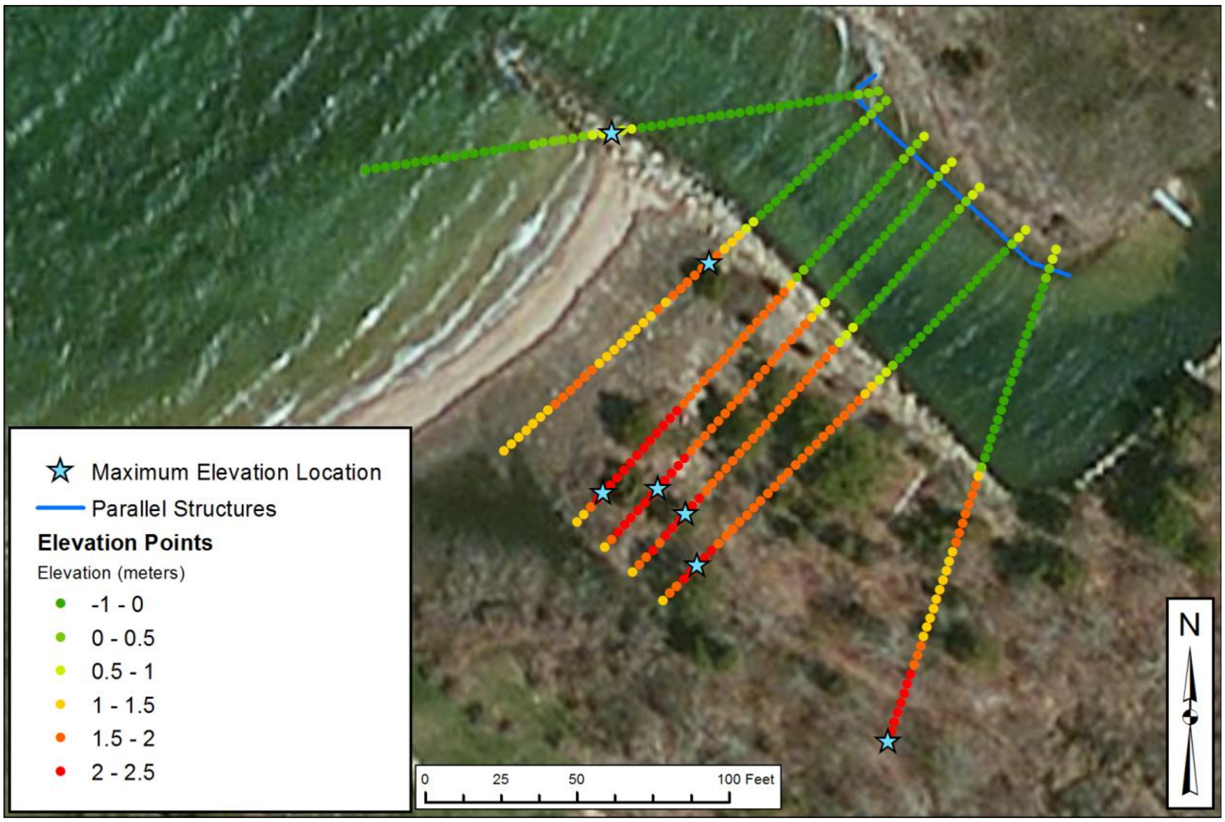

Figure 14. Invalid profiles due to maximum elevation locations (blue stars) encountered at a distance greater than 3 meters from the structure location.

15. Structure elevations were then determined by averaging the maximum elevation from each valid profile line for that structure (Figure 15).

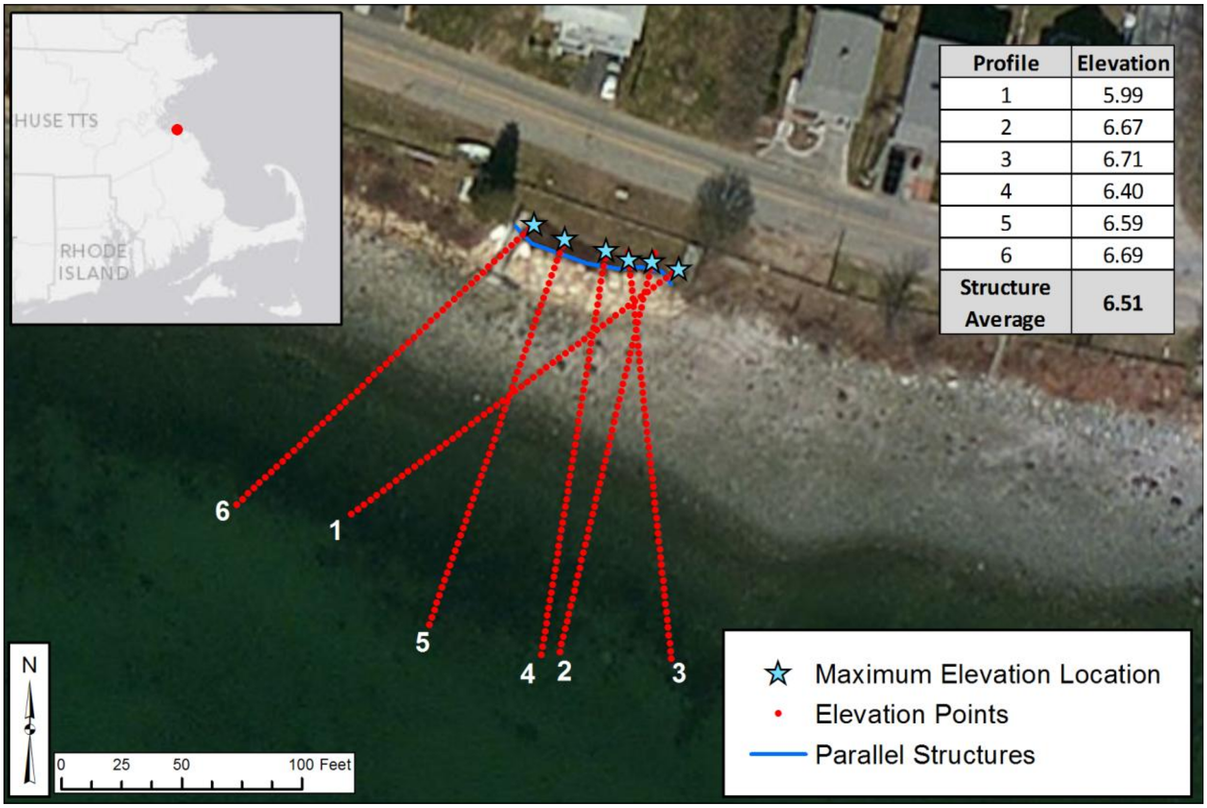

Figure 15. Overall structure elevation based on 6 profile lines. The maximum elevation points were averaged to determine the structure elevation.

16. Using this approach, 4,248 of the 4,819 shore parallel structures were successfully assigned an elevation. The rules above (step 14) were modified for the remaining 571 structures that had too few or no valid profile lines. The steps below were performed in order to assign elevations to as many structures as possible.
    f. Elevation points further than 3 meters from the structure were excluded from the analysis. This excluded the influence of any natural coastal features and/or infrastructure outside of the immediate vicinity of the structure that may have contributed to invalid profiles.
    g. The minimum requirement for number of profiles per structure was removed. Any structure with at least one valid profile was assigned an elevation.

Collectively, these two changes produced valid elevations for an additional 463 structures.

17. For the remaining 108 structures, cross-shore profiles were manually digitized (3 per structure). Elevations were extracted at the standard 1 meter interval and the maximum elevation of each profile was averaged and assigned to the structure. Each profile was manually reviewed to ensure that the maximum elevation was representative of the coastal structure. An additional 101 structures were assigned an elevation using this approach.

18. Seven of the shore-parallel structures were completely outside the coverage of the LiDAR dataset and therefore received no elevation.