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Title:

High-precision, High-accuracy Elevation Data Acquisition and Geospatial Mapping for the Charlestown Navy Yard at Boston National Historical Park to Inform Climate Change Adaptation Planning for the National Park Service

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Introduction

The Charlestown Navy Yard

The Charlestown Navy Yard was established in 1800 by President John Adams as one of the nation's six original navy yards. After 174 years of operation, the navy yard officially ceased fleet servicing and manufacturing operations on December 31, 1973. On October 1, 1974, President Gerald Ford passed the Boston National Historical Park Act of 1974, designating seven sites in downtown Boston and Charlestown as the components of Boston National Historical Park. The Charlestown Navy Yard has made many contributions to American Navy history, the history of technology, the history of social and worker movements, and the history of American architectural design and planning (Stevens et al., 2005, pp. 145, 8). However, the Navy Yard's proximity to Boston Harbor makes it susceptible to the effects of climate change-induced sea level rise and storm surge.

The Effects of Climate Change at the Charlestown Navy Yard and Surrounding Area

Boston's historic land use pattern has influenced its coastal flooding vulnerability. Much of the Charlestown area was created through filling low-lying areas that were historically below high tide levels. Consequently, these areas are at a higher risk of flooding from coastal storms and extreme high tides because the water naturally flows to lower-lying areas (City of Boston, 2022, p. 26).

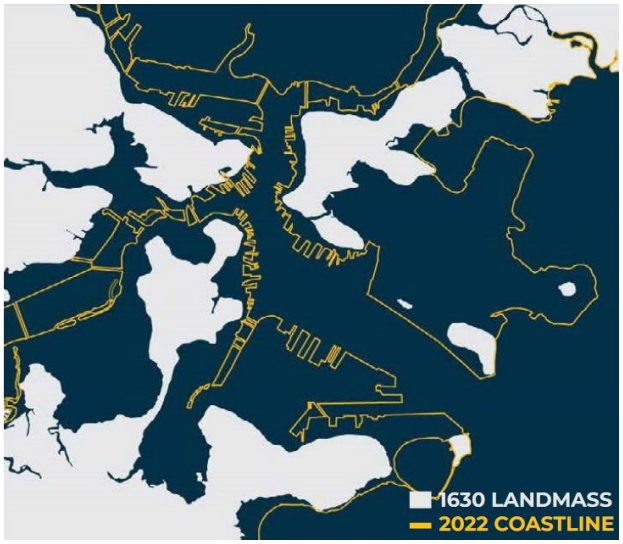


Figure 1. Boston's historic landmass at time of settlement (white) and Boston's present coastline (yellow). Source: Climate Ready Boston.

Most of Charlestown's coastline has been developed with bulkheads, seawalls, piers, and other waterfront structures because of the presence of waterfront industries. However, "due to the nature of the Navy Yard's development and use over time, many structures were built very close to the coastline. Because of this, there is often a narrow distance between the developed property and the water, limiting the on-land space for future coastal protection strategies" (City of Boston, 2022, p. 38).

Current projections from the Phase II Climate Ready Boston report estimate 9 inches of sea-level rise in the 2030s, 21 inches in the 2050s, and 40 inches in the 2070s relative to average sea level. As the report states, "During a severe coastal storm with a 1% annual chance or less of occurring, new flood pathways from the Little Mystic Channel will merge with flood pathways

entering from the Navy Yard. This will result in flood pathways connecting through the low-lying area of homes, businesses, community landmarks, and the Charles/Newtown and Bunker Hill affordable housing developments" (City of Boston, 2022, pp. 77–79). Consequently, addressing the risks of flooding due to storm surge and sea level rise is not only necessary for the sake of protecting the cultural resources at the Charlestown Navy Yard, but also for mitigating the effects of flooding in the surrounding areas.

Previous Geospatial Data Collection in National Parks in Response to Climate Change

According to the 2023 update of the National Park Service's (NPS) Climate Change Response Plan, "The effects of climate change are evident across the National Park System, with impacts permeating every aspect of National Park Service (NPS) responsibilities, including natural and cultural resource stewardship, facility management, planning, park operations, and visitor experiences" (National Park Service, 2023, p. 3). Several geospatial studies have been done in the context of NPS and cultural resource management to demonstrate the ways in which geospatial technologies are a powerful asset in interpreting the extent and effects of sea level rise and storm surge predictions. Across multiple studies, an important conclusion from the data is that having localized, site-specific data is vital to having accurate model predictions.

A study by Murdukhayeva et al. examined the role of using real-time kinematic global position system (RTK GPS) data to assess storm surge and sea level rise at Cape Cod National Seashore (CACO) and Assateague Island National Seashore (ASIS). The goal of the study was to "explore how widely accessible data and tools can be used for highly localized assessments of inundation risk" (Murdukhayeva et al., 2013, p. 1). Inundation risk for sea level rise and storm surge was modeled at 97 sentinel sites from CACO and ASIS. This study used Light Detection and Ranging (LIDAR) data and RTK GPS data. It used three sea level rise scenarios and four storm surge scenarios with the bathtub inundation model and the Sea Level Affecting Marshes Model (SLAMM) as well as the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model (Murdukhayeva et al., 2013, p. 2).

One of the results from the study was the noticeable difference in elevations measured using RTK GPS and those obtained from the DEMs created from the LIDAR data. The researchers concluded, "The high accuracy of the elevations measured with RTK GPS was an important asset for this project. The GPS field surveys allowed us to collect accurate elevations of sentinel sites that were hidden from LIDAR signals and sensors" (Murdukhayeva et al., 2013, p. 10). Highly accurate RTK GPS data helps mitigate errors when the data is used in modeling scenarios (Murdukhayeva et al., 2013, p. 10).

In 2018, a group of researchers at University of Colorado, Boulder supported by NPS published a report that provides consistent sea level rise and storm surge projections for all coastal national parks. It processed data from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from the National Oceanic and Atmospheric Administration (NOAA) SLOSH models. The report states, "This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks" (Caffrey et al., 2018, p. viii). The report provides predictions on potential future inundation and storm surge for four greenhouse gas emission scenarios for 2030, 2050, and 2100. The sea level rise projections have been done for 118 park units, 79 of those park units also have storm surge projections. The purpose of the study was to create and analyze data for park managers to use for park planning and adaptation strategies (Caffrey et al., 2018, p. viii). The goals of the report are to "quantify projections of sea level rise in coastal National Park

Service units over the next century based on the latest IPCC (2013) models and show how storm surge generated by hurricanes and extratropical storms could also affect these parks" (Caffrey et al., 2018, p. 2).

The study involved preparing sea level projections over different time intervals for each park unit; estimating storm surge through NOAA's SLOSH Model; and creating wayside exhibits explaining the impacts of climate change at three National Park Service units (Caffrey et al., 2018, p. 5). The researchers concluded that "a key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas" (Caffrey et al., 2018, p. 28). However, the modeling technique is a simplified method that does not account for the effects of buildings or dune systems on inundation or flooding (Caffrey et al., 2018, p. 11). Additionally, the study is now out of date relative to the Interagency Sea Level Rise Scenarios (Sweet et al., 2022).

While geospatial data has been used extensively for ecological purposes, it also has applications that blend natural resource management with cultural resource management. Cultural resources in coastal locations face imminent threats, and existing geospatial data can be combined with cultural resource data to indicate site-specific potential inundation levels for different climate change scenarios. However, in light of the complexity of climate change, more sophisticated data and analyses are necessary. Howey used a simple methodology to combine scientific geospatial data with cultural resource geospatial data to bridge the gap between natural resource management and cultural resource management. Although her research only goes so far as to highlight which cultural resources face the threat of inundation from storm surge under certain sea level rise scenarios, her work emphasizes the need to expand the application of geospatial technology in cultural resource management (Howey, 2020). While NPS has extensively used geospatial data for climate change and sea level rise projections, the literature shows that the focus has mostly been on natural resources, such as salt marshes. However, new methods are needed to put climate change adaptation for natural and cultural resources in dialogue with each other.

Research has been done on modeling and predicting the extent of sea level rise at coastal national park units and recent studies emphasize the importance of using more location-specific data collected through higher-accuracy means, such as RTK GPS. The NPS Climate Change Response Program emphasizes that "adaptation in the coastal environment involves cultural and natural resources" (Climate Change Response Program, 2019). The next step is to interpret these predictions in light of the infrastructure and cultural resources at park sites, which requires obtaining more localized geospatial data. However, these localized geospatial needs have not yet been met at any park. There is a need to have infrastructure-specific, building-specific, and cultural resource-specific geospatial data to put into conversation with sea level rise and storm surge projections derived through geospatial means. Two of the main cornerstones of the 2023 updated National Park Service Climate Change Response Strategy are understanding and adaptation, defined as follows: "Understand how climate projections for our parks differ from historical conditions and what the potential effects might be on park resources, facilities, and operations; adapt through strategies that reduce the vulnerabilities of resources, facilities, and operations to climate change effects" (National Park Service, 2023, p. 7). Using high-accuracy, high-precision geospatial technology to get elevation data for vulnerable infrastructure and cultural resources is key for bridging the gap between understanding and adaptation, allowing

park planners and managers to make sense of sea level rise and storm surge models and predictions in light of future management decisions and climate change adaptation at NPS sites.

Methods

There were three main goals for the data collection. The first was to provide baseline data to plan and prioritize future climate change resiliency plans and create a robust geodatabase for BOST. The second goal was to organize the data into a robust geodatabase so that the data could be accessible and usable for current planning projects, such as the Gateway Connector Project, and future projects. The last goal was to model a climate change planning data collection standard for other national parks. Geospatial data collection with the Trimble Total Station for climate change adaptation planning had never been done before in a national park, and BOST hopes to serve as an example for data collection, management, and use for other national parks in their attempts to address climate change.

To organize the workflow, the Charlestown Navy Yard was divided into first priority and second priority areas. The categorization resulted from a conversation with members of the regional GIS team, BOST Resource Planning and Preservation team members, the director of facilities, and the BOST deputy superintendent. The following Charlestown Navy Yard buildings were determined to be first priority for data collection: Building 107; Building 10; Building 4/5; Building 265; Building 22; Building 28; Building 24; Building 32; Building 109; and Building 125. Cultural resources, such as the crane hoppers and other monuments, surrounding the first priority buildings were also categorized as first priority. The following buildings were categorized as second priority: Building I, Quarters G (Commandant's House), Building 1, Building 269, and Building 58 (Ropewalk). The priority areas were determined based off flood zone mapping, cultural and historical significance, and importance to park maintenance and operations. The buildings considered to be first priority for data collection lie most immediately in the areas at risk for flooding from storm sure and sea level rise. The second priority buildings area either outside of the flood zone due to sitting at a higher elevation or do not bear as much cultural and historical significance as other buildings. For each building, the areas of concern were potential flooding entryways, such as doorways, windows, and basement windows.



Figure 2. Aerial view of the Charlestown Navy Yard with buildings labeled as first priority and second priority for sea level rise and storm surge concern. Image overlain with a layer depicting areas at risk of inundation at nine inches of sea level rise.

Once the priority areas were established, Andy Steel from New River Gorge National Park in West Virginia came to BOST to provide training on the equipment. There was a significant amount of equipment required for the data collection. Practical equipment included one-inch Magnails, six-inch Mag Hub Nails, a mallet, and flagging. Technical equipment included the BOST NTRIP base station located on the top of Building I at the Charlestown Navy Yard, the Trimble TSC7 Controller, the Trimble R12i GNSS receiver, the Trimble SX12 Scanning Total Station, and a Trimble prism. Software included Trimble Access, Trimble Business Center, and ArcGIS Pro.

There were two main steps to the data collection: Setting control points and performing the scans. Setting control points involved the R12i GNSS receiver and the NTRIP base station. The SX12 scanner requires two GPS-referenced control points in order to orient itself in space. Consequently, the scanner must be able to point to two control points from where it is stationed to be able to complete a scan. The control points were set based off estimated locations for scans. The most efficient way to capture point cloud data for an entire building would be to set the scanner up to scan two sides of a building at a time and then complete another scan to capture the other two sides of the building. Consequently, control points were established based off where the scanner would be positioned to scan two sides of a building at once. In more open areas, with few obstructions such as along Pier 1, the same control point could be used for multiple scans.

Control points were marked with a one-inch Magnail on pavement, a six-inch Mag Hub Nail with flagging on grass or dirt, or by using existing nails from previous surveys or the letters in manhole, pipe, or sewer drain covers. The points were numbered, beginning with C1 and going up to C41. Control point C1 was excluded from the study because it was originally connected to the incorrect NTRIP station. The tip of the GNSS receiver was placed on the divot on the head of the nail or on a repeatable location on a manhole cover, such as inside a capital "A." The R12i GNSS receiver was connected to the Trimble TSC7 controller with Trimble

Access, which was used to connect to the BOST NTRIP base station. Survey control was primarily set with single-baseline RTK corrections from the ntrip.geoplatform.gov real-time GNSS network. The projected coordinate system used in Trimble Access and Trimble Business Center was NAD 1983 (2011) UTM Zone 19. The vertical datum was NAVD88 with the Geoid model GEOID18. Measurements for the R12i GNSS receiver were based off the bottom of the quick release on the 2m GPS pole. The projection used in Trimble Access and Trimble Business Center was UTM Zone 19 and the coordinate system was NAVD88 (2011). Once the GNSS receiver was leveled using a bubble and the eBubble on the Trimble TSC7 controller, it would communicate with the base station for about three minutes. The precision of the geospatial position of the control point was recorded for each point and its data was stored in Trimble Access to be used for the scans. The process was repeated throughout the NPS property of the Charlestown Navy Yard for 40 usable observed control points.

The second main step for data collection was completing the scans. First priority buildings were scanned first, followed by the second priority buildings, to ensure that data was collected for the first priority buildings within the timeframe. There was a total of 36 scans completed. Because many of the scans overlapped and all the scans were 360-degree full-dome scans, the scans captured cultural resources and natural resources throughout the park.

Completing a single scan was a three-step process that involved performing the resection, taking panoramic photographs, and completing the scan itself. Prior to each scan, the SX12 scanner had to be attached to its tripod and the tripod had to be leveled using the bubble and eBubble on the Trimble TSC7 controller. The tripod was set up in a position to capture the area of interest (such as two sides of a specific building) where it would be able to point to two control points. Once the scanner tripod was set up, it was to complete a resection. The Trimble 360 prism was set up and leveled on one of the control points. The height of the prism head had to be recorded each time. For most scans, it was set at 1.9812 meters. However, if it was adjusted to be visible over a structure over a fence, the change had to be recorded in Trimble Access. Using the auto lock setting, the control point on which the prism stood was selected, and the scanner completed the first phase of the resection. After referencing the first control point, the prism was moved to the second control point being used for the scan. Using the auto lock setting, the second control point on which the prism stood was selected, and the scanner completed the second phase of the resection. The resection was completed for every scan.

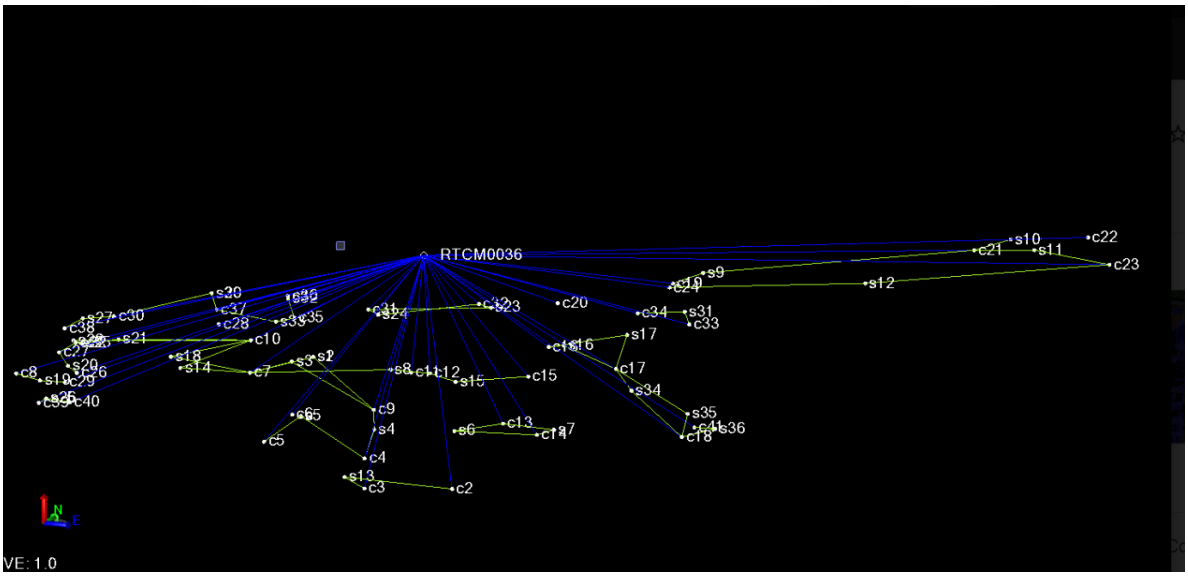


Figure 3. Two-dimensional view of each control point and scan. The blue lines represent the control points' connection to the NTRIP base station and the green lines represent the resection for each scan, depicting which control points were used for a given scan.

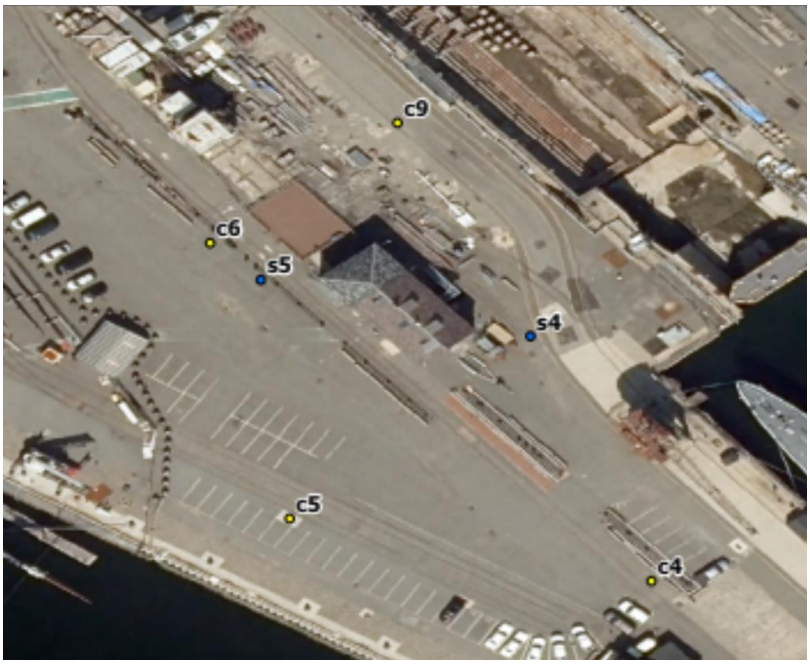


Figure 4. Aerial view of the Charlestown Navy Yard over Building 10 and Pier 1depicting two scan locations and four control points. Scan s4 used control points c9 and c4 for resection, and scan s5 used control points c5 and c6 for resection.

Following the resection, the parameters of the scan were set to full-dome and coarse resolution. The scanning radius was set to one meter from the scanner up to 200 meters away. At 20 meters, the points would be spaced two centimeters apart. The atmospheric pressure and temperature were recorded for each scanned and measured using the Apple iPhone weather app. Prior to beginning the scan, the scanner would take 40 panoramic photographs of the area to be scanned, which would be used to colorize the points once the data was uploaded and processed in Trimble Business Center. Taking the panoramic photographs took about three minutes. After

the scanner finished the photographs, it began the full-dome scan, which took about twelve minutes. Each scan generated millions of points, and there were 36 scans completed in total. Each scan took about half an hour from start to finish.

After the data was collected, it was uploaded into Trimble Business Center by exporting it off the controller onto a thumb drive and then using the thumb drive to import the data into the software program. The points were colorized using the panoramic photographs.

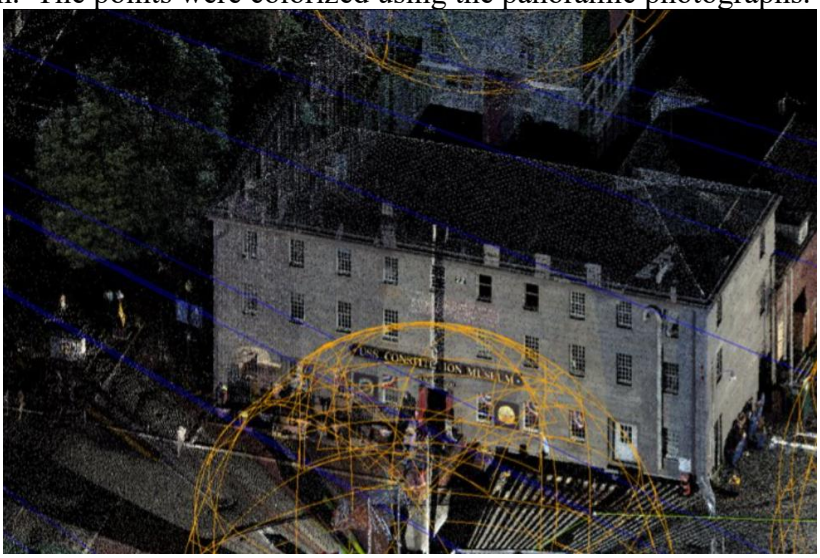


Figure 5. Point cloud view of the USS Constitution Museum. The image is entirely generated by points and colorized by the panoramic photographs taken before the scan. The orange sphere represents the path of the scanner while scanning.

The points were also categorized into regions. Trimble Business Center has the capability to sort points into regions, such as buildings, poles, low vegetation, and ground.

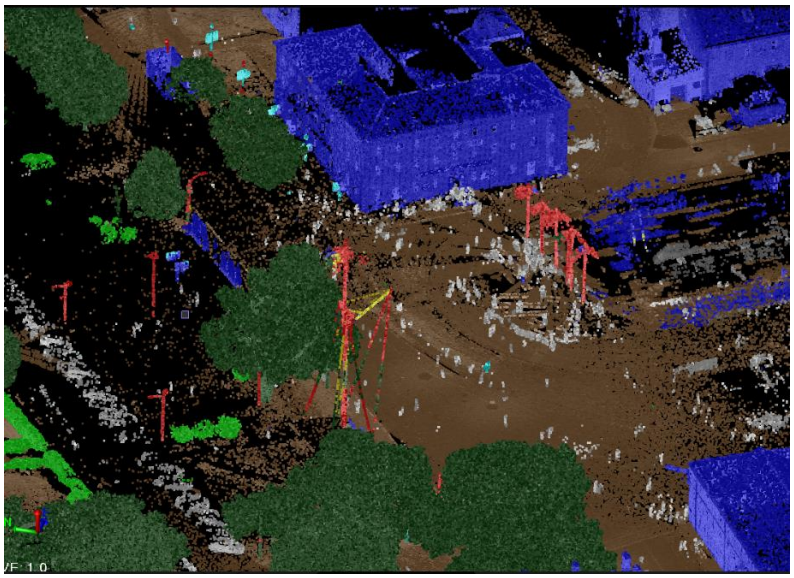


Figure 6. Point cloud view of the USS Constitution Museum and other features at the Charlestown Navy Yard. Blue points represent buildings, dark green points represent high vegetation, light green points represent low vegetation, red points represent poles, brown points represent the ground, and white points represent noise.

Categorizing the points into regions allows for certain regions to be turned on and off like layers in ArcGIS Pro or in AutoCAD. For the purposes of this data collection, being able to turn off

layers other than buildings and ground made the data points of interest easier to see. Because Dry Dock 1 did not fit easily into a category, the data points for Dry Dock 1 were selected and categorized into their own region.

To extract critical elevation data, points were copied from doorways, windows, and basement windows for each building and added to one of two layers. One layer was created for points representing doorway elevations, and one layer was created for points representing window elevations. One point was selected for each visible doorway for each building and for at least one window for each building when possible. Some buildings, such as Building 269, do not have windows. Building 265 was the only building that had first floor windows as well as basement windows, so points were also selected from the basement windows to record their elevations. Only one window was selected due to the assumption that all windows at the same floor level would have the same elevation within a very small range of error. Windows that were above a reasonable first-floor elevation, such as the windows on the back of Building 24, were not included because their elevations exceed reasonable threats from sea level rise and storm surge. The points were named using a naming convention that detailed which building the point came from, the scan, whether the point came from a doorway, window, or basement window, and where the feature was located on the building. Point name references to "left side" or "right side" refer to the perspective of a person facing the building. The point ID, latitude, longitude, and elevation were exported as a CSV file into Excel. Additionally, the points were exported as a shape file into ArcGIS Pro with critical data such as the latitude and longitude of each point as well as the elevation in meters for each point. The points were projected using NAD 1983 (2011) UTM Zone 19 coordinate system and vertical datum was NAVD88 with the Geoid model GEOID18.

The data is currently stored in a zip file where it can be accessed and opened in Trimble Business Center. As concrete needs for the data emerge, the data can be downloaded in its entirety or in sections, such as by building, where it can be converted into LAS files and used in ArcGIS Pro.

Results

One of the main appeals of using the Trimble Total Station to collect high-precision, high-accuracy geospatial data is having low vertical and horizontal error. The vertical and horizontal precision for the control points measured using the R12i GNSS receiver is critical because the SX12 scanner uses the control points to georeference itself before scanning. The minimal amount of horizontal accuracy across the forty control points was associated with control point c7, which had 1.71 millimeters of error. The point that had the greatest amount of horizontal error was control point c33, which had 8.31 millimeters of error. Consequently, the horizontal error for all control points remained in a range of 6.60 millimeters. The average horizontal precision was 3.15 millimeters.

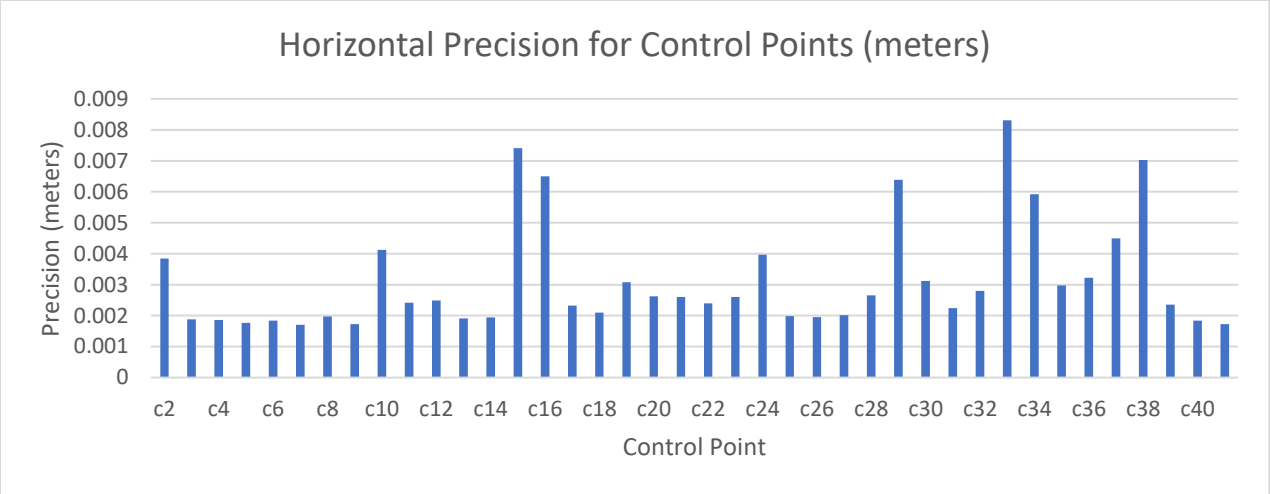


Figure 7. Graph comparing the horizontal precision for control points set using the R12i GNSS receiver and the NTRIP base station.

Control point c40 had the least amount of vertical error, with a vertical precision of 2.62 millimeters. The greatest amount of vertical error was at control point 15, which had a vertical precision of 16.73 millimeters. The range for vertical precision was 14.11 millimeters. The average vertical precision was 5.20 millimeters. While having the NTRIP base station in such close proximity helps to reduce error in the geospatial precision of the control points, the number of tall buildings can create some interference. Consequently, some of the control points that were set surrounded by buildings or other tall structures like the crane hopper, which was the case for control point c15, had less precision than other points set in more open areas of the Charlestown Navy Yard, such as control point c7.

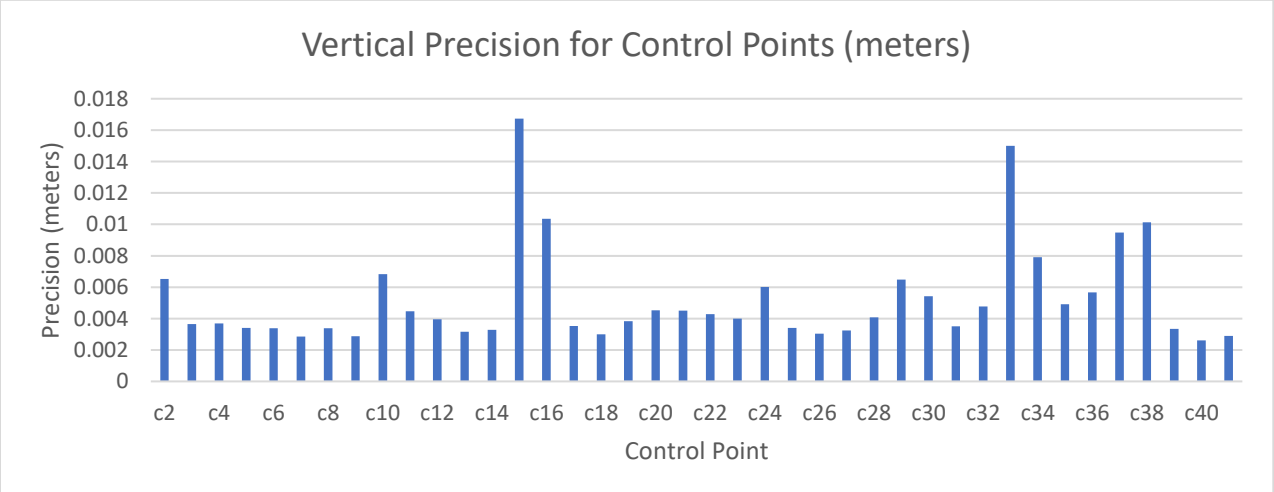


Figure 8. Graph comparing the vertical precision for control points set using the R12i GNSS receiver and the NTRIP base station.

From the 36 scans of the Charlestown Navy Yard, 101 points were selected and copied to a new layer in Trimble Business Center. The points represent the lowest part of doorways, windows (above the sill), and basement windows on the eleven first-priority buildings and the five second-priority buildings at the Navy Yard. Data was collected for all buildings on the NPS property, but the scope of this study focuses on the sixteen prioritized buildings.

Doorways, windows, and basement windows represent potential flood entryways, so their elevation can be compared to sea level rise projections to identify flooding concerns for individual buildings. The minimum doorway elevation was found at Building 125, which is the building closest to Boston Harbor within the NPS boundary of the Navy Yard. The minimum elevation, recorded for the front doors of Building 125, is 2.667 meters above sea level. The first priority building with the greatest minimum doorway elevation was Building 265, with a minimum doorway elevation of 5.043 meters above sea level. The average minimum doorway elevation for first priority buildings was 3.230 meters above sea level. Building 58 was the second priority building that had the lowest minimum doorway elevation at 3.966 meters above sea level. Quarters G, which sits atop a small hill, has a minimum doorway elevation of 8.487 meters above sea level, which is significantly higher than the other second priority buildings. The average minimum doorway elevation for the second priority buildings is 5.771 meters above sea level.

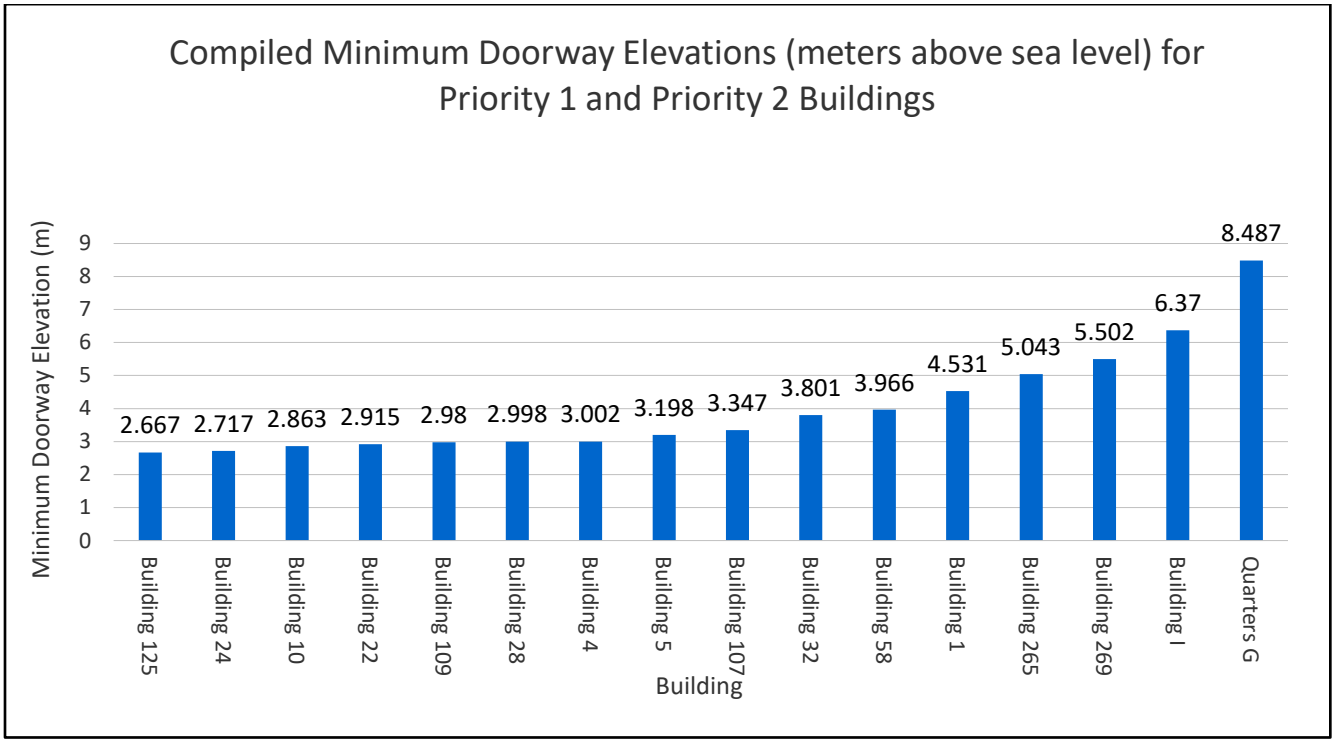


Figure 9. Graph showing the minimum doorway elevations for the sixteen first priority and second priority buildings.

All of the first-priority buildings had lower minimum doorway elevations than the second-priority buildings, with the exception of Building 265. However, Building 265 has basement windows that had elevations ranging from 3.453 meters above sea level to 4.365 meters above sea level. Comparing minimum doorway elevations helps justify prioritizing buildings based off level of concern for sea level rise and storm surge vulnerability.

While doorways are the main potential entryway for flooding, windows also serve as a potential entryway. Having high-precision, high-accuracy elevation data is valuable for climate change planning because windows vary by building in elevation above the ground. For example, while Building 125 has the lowest minimum doorway elevation, The Building 22/28 connector, which is primarily constructed out of windows, has the lowest minimum window elevation at 3.118 meters above sea level. Building 265 had the greatest minimum window elevation of the

first priority buildings with a window elevation measurement of 5.142 meters above sea level. The average minimum window elevation for the first priority buildings was 3.980 meters above sea level. The second priority building with the lowest minimum window elevation was Building 58 at 4.673 meters above sea level. Quarters G had the highest minimum window elevation with a measurement of 9.353 meters above sea level. Building 1 and Building 2, which are both second priority buildings, do not have windows, so they were excluded from the analysis. The average minimum window height for the second priority buildings was 7.164 meters above sea level.

Comparing window elevations is also valuable because changes in grade can place some windows at a lower elevation. For example, the minimum elevation measurement for the basement windows on Building 265 is only 0.275 meter below the lowest window measurement on Building 10, which does not have basement windows. Having elevation data to compare window heights can offer more insight for more careful, building-specific climate change adaptation planning.

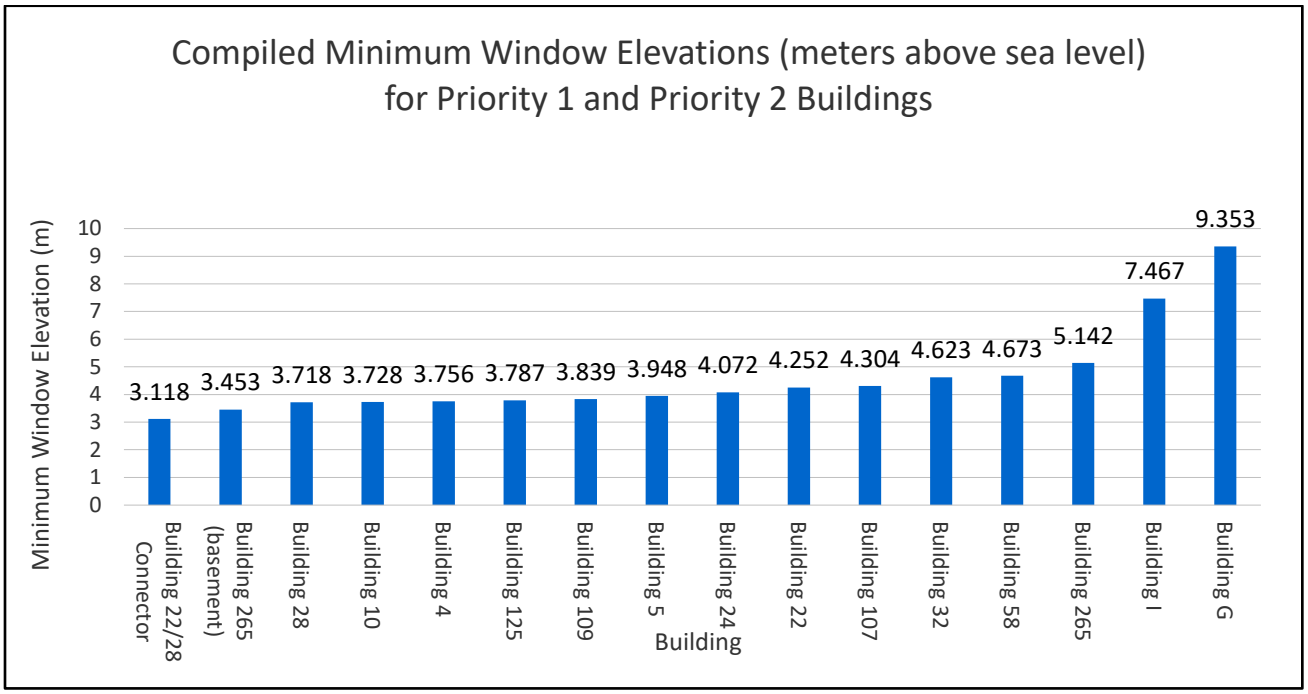


Figure 10. Graph showing the minimum window elevations for the fourteen first priority and second priority buildings with windows, the Building 22/28 connector, and the minimum basement window elevation for Building 265.

Building 265 is the only building with basement windows of the sixteen first priority and second priority buildings. However, because Building 265 has the greatest minimum doorway and minimum window elevations of the first priority buildings, the elevations of the basement windows are especially crucial for sea level rise and storm surge adaptation planning. The basement window on Building 265 with the lowest elevation is located to the left of the front door to Quarters B, measuring 3.453 meters above sea level. The basement window with the greatest elevation is the middle basement window on the west side of the building, facing Quarters G, with an elevation of 4.365 meters above sea level. The average window elevation for the basement windows of Building 265 is 3.898 meters above sea level, which is the lowest minimum window elevation behind the Building 22/28 Connector.

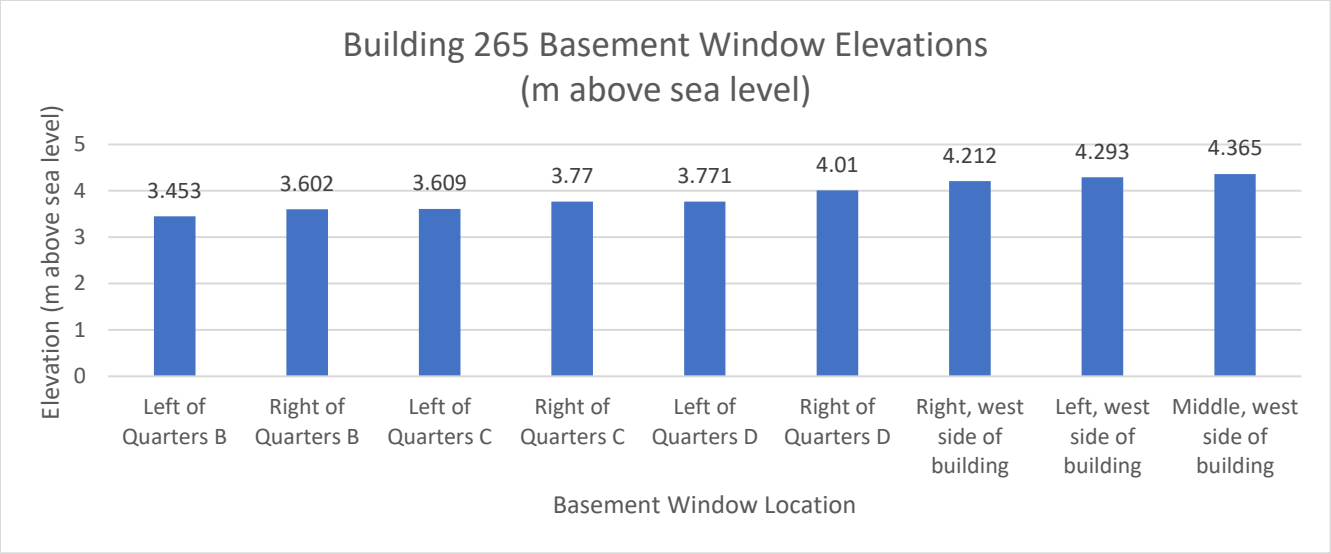


Figure 11. Graph depicting the elevations of the basement windows on Building 265.

Having high-precision, high-accuracy elevation data highlights the nuances and detailed planning that must be used for site-specific, facility-specific sea level rise and storm surge adaptation planning. Not only are there variations across the Navy Yard, but there are also variations by building, highlighting factors that must be considered in climate change adaptation planning and decision-making.

Discussion

Immediate Uses for the Data

The high-precision, high-accuracy elevation data collected through the Charlestown Navy Yard geospatial mapping project has immediate uses for ongoing climate change adaptation plans. Having elevation data will help inform some of the management decisions laid out in Phase II of Climate Ready Boston. As a lower-lying area, Charlestown faces two types of flooding threats: flooding from rising tide levels on a daily and monthly basis from climate change-induced sea level rise and flooding caused by storm surge from increasingly intense storms. With an understanding of potential flooding risks in the near future comes an understanding of the importance of design flood elevation (DFE) in adaptation response planning. The design flood elevation is "the recommended elevation required to protect an area from a specific level of coastal flooding including water levels and waves" (City of Boston, 2022, p. 60). The DFE for Charlestown was derived using data from the Boston Harbor Flood Risk Model based off 0.1% chance of annual flooding. DFEs are very specific to location due to a number of factors such as distance from the ocean, exposure to waves, currents, existing coastline infrastructure, and the presence of wetlands.

For Charlestown, the long-term DFE is 15.5 feet, or 4.72 meters, relative to the North American Vertical Datum of 1988 (NAVD88) (City of Boston, 2022, p. 60). The preliminary results of the critical elevation data collected for doorways and windows for the first and second priority buildings at the Charlestown Navy Yard indicate that all the buildings first priority buildings except for Building 265 are below Charlestown's long-term DFE. However, this knowledge allows park managers to make science-backed, site-specific adaptation decisions going forward, bridging the gap between understanding the threats and adapting to them.

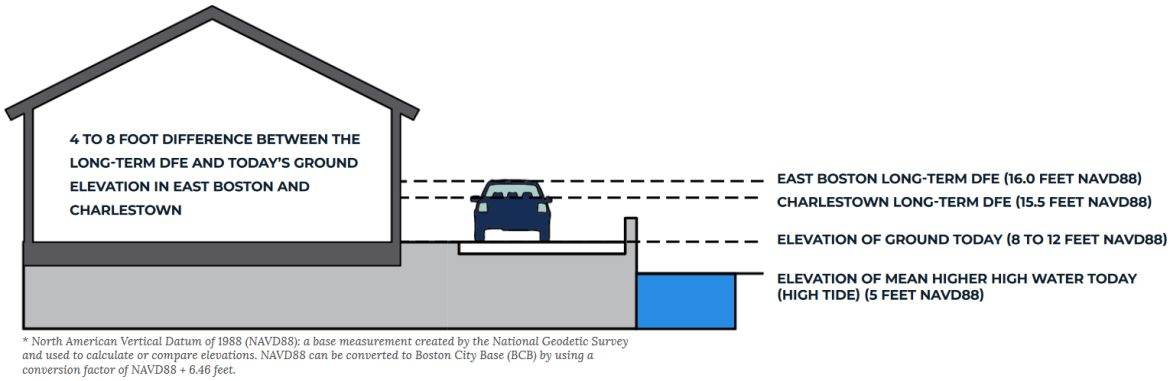


Figure 12. Diagram explaining the design flood elevation (DFE). Source: City of Boston.

The critical elevation data will also be useful for the planning efforts that are part of the Boston Harbor Gateway Connector project. The Boston Harbor Gateway Connector is "a multi-modal, multi-agency project to design and implement resiliency measures that integrate mobility, access, and quality of life improvements in the Charlestown Navy Yard" (Climate Ready Boston, 2023, p. 2). The Boston Harbor Gateway Connector will "reduce the risk of coastal flooding for vulnerable neighborhoods and national historic landmark sites through the development of a system of elevated public spaces and walkways along the waterfront" (Climate Ready Boston, 2023, p. 2). The area affected is the 130-acre Charlestown Navy Yard, a historic landmark, along with the whole Charlestown waterfront, which extends from the Charles to the Mystic Rivers. The agencies involved with the focus area include the National Park Service, City of Boston, Boston Planning and Development Agency (BPDA), Mass Department of Conservation and Recreation (DCR), and Massport. The area also includes the Boston Harbor Islands. One of the proposed strategies for coastal resilience involves ensuring there are building-level adaptations for structures that extend beyond the raised Harborwalk that would act as a flood alignment. The high-precision, high-accuracy geospatial data collected from the Charlestown geospatial mapping project would be key in providing critical elevation data at the building level and ground level and can be used to make data-driven resiliency decisions catered to specific buildings and locations. Additionally, the data will help serve the partnerships within the Boston Harbor Gateway Connector project, showing that the National Park Service is a leader in offering high-quality scientific information that benefits the surrounding community.

The window and finished floor threshold elevations have been incorporated into a coastal facilities vulnerability assessment that was already underway (Peek et al., 2024).

Meeting the Goals of Federal and Departmental Calls for Science-backed Adaptation Decisions

The Charlestown Navy Yard geospatial mapping project advances several of the initiatives at the executive, departmental, and agency levels. On January 20, 2021, President Biden issued Executive Order Number 13990: Protecting Public Health and the Environment and Restoring Science To Tackle Climate Change. The Executive Order states "the Federal Government must be guided by the best science and be protected by processes that ensure the integrity of Federal decision-making. It is, therefore, the policy of my [Biden's] Administration to listen to the science; to improve public health and protect our environment...to bolster resilience to the impacts of climate change; to restore and expand our national treasures and monuments" (Executive Office of the President, 2021). Having novel high-precision, high-

accuracy geospatial data allows NPS to make science-backed resiliency decisions to protect nationally significant natural and cultural resources.

In response to President Biden's executive order on climate change, Secretary of the Interior Deb Halaand announced four new Departmental Manual policies for the Department of the Interior on September 28, 2023, at the White House Summit on Building Climate Resilient Communities. The policies demonstrate the Department of the Interior's commitment to using science, Indigenous Knowledge, and landscape-scale management to inform Department decisions (Department of the Interior, 2023). Secretary's Order no. 3399 addresses a Department of the Interior-wide "approach to the climate crisis" (Haaland, 2021, p. 1). Following Secretary's Order no, 3399, there were four updates to the Department of the Interior's Departmental Manual in 2023, and the Charlestown Navy Yard geospatial mapping project helps advance the goals of each one.

Part 522 of the Department of the Interior Department Manual calls for adaptive management, which is "a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood" (Office of Environmental Policy and Compliance, 2023, p. 1). In the case of the Charlestown Navy Yard, acquiring high-accuracy, high-precision geospatial data can help inform adaptation management decisions, such as those outlined in Phase II of the Climate Ready Boston Plan. Part 523 of the Department Manual emphasizes the role of science in climate change adaptation, stating, "The Department will integrate climate change adaptation strategies into its policies, planning, programs, and operations, including, but not limited to, park, refuge, and public land management…protection and restoration of cultural, archeological, and tribal resources…scientific research and data collection…and infrastructure and other asset management" (Office of Policy, 2023, p. 3). Part 526 of the Departmental Manual explains how the Department will use this high-quality information "to improve understanding of current and future climate change impacts, inform planning and decision making, and coordinate appropriate responses to changing conditions" (Office of Policy Analysis, 2023b, p. 3). Most concretely, the Department of the Interior justifies the Charlestown Navy Yard mapping project in Part 604 of the Departmental Manual. It states, "The Department and its component Bureaus and Offices are committed to incorporating high-quality information into its decisions and will develop scientific information and tools to provide better information in areas of greatest uncertainty. This includes development, maintenance, and utilization of geospatial information systems and a common set of data and tools, and the training necessary to promote their effective use in development of landscape-level approaches" (Office of Policy Analysis, 2023a, pp. 3–4). Through the acquisition of novel geospatial data to inform adaptive management decisions and responses to climate change, the Charlestown Navy Yard and BOST are at the forefront of critical scientific work that aligns with recent executive and departmental documents addressing climate change.

Reflections on the Procedure

Overall, the data collection process went smoothly. All of the equipment worked reliably and within the expected range of accuracy. However, one of the difficulties of using the scanner in an urban setting is the presence of cars and people. Despite best efforts, such as beginning field work early in the morning, some parts of buildings were obstructed in the scan due to parked cars. The scanner was positioned in the location that would pick up the greatest number of points of interest (doorways, windows, and basement windows), but it was not always possible to collect data for every single point of interest due to parking alongside buildings and

an inability to completely block off the park from vehicular traffic. However, operating under the assumption that finished floor elevations are level and that window heights are also level, it safely can be assumed that any obstructed windows or doorways would have the same elevation as captured doorways or windows within a reasonable margin of error.

The irregular shape of the back of Building 265 also posed a challenge to getting a complete and accurate scan because of built-out structures and narrow staircases leading to basement doors. Additionally, the back of Building 265 is fenced in with a brick wall on two sides and a wooden picket fence on the third side, limiting the available space to position the scanner to complete multiple scans. The narrowness of the walkways and stairways leading to basement doors and the one-meter radius that the scanner requires to complete a scan limited the effectiveness of the scanner in such a tight space. Trying to shoot the scanner down a steep but narrow set of stairs to measure the elevation of the bottom of a specific basement door was a challenge. In this specific case, where there is an isolated point of interest, using the R12i GNSS receiver to get a few specific points in addition to the regular SX12 scan could be a potential solution. Each control point created using the GNSS receiver had millimeter-level accuracy elevation. When overlaid with the scan, the specific elevation points can show where the point of interest, such as the bottom of the basement door at the bottom of the stairs, lies in relation to the rest of the scan.

Moving cars posed a challenge while completing certain scans. The final scan was redone because a car pulled right in front of the scanner and stopped as it was scanning a critical part of the building. Because the scanner passes over an area of interest fairly quickly, there was not time to ask the person to move. Setting up traffic cones was only mildly effective at mitigating vehicular traffic while data was being collected. While redoing a scan is a potential solution, it is a time-consuming solution that has little guarantee of producing better data because the entire scan takes nearly fifteen minutes. Completing a focus scan instead of a full-dome scan is potentially a more reliable solution. Unlike a full-dome scan, which collects data up and down an entire vertical range as well as 360-degrees around the scanner, a focus scan collects data for a designated area that can be much smaller than the area a full-dome scan would cover. Because each scan is layered and colorized in Trimble Business Center, the focus scan seamlessly could be integrated with the full-dome scan.

As a National Park site, the Navy Yard has a significant amount of foot traffic, especially during the summer months, which is peak visitor season. While Trimble Business Center can remove people from the point cloud data, they still pose the potential to compromise the quality of the data. In several cases, people walked directly in front of the scanner while it was taking panoramic photographs or doing a scan. The necessary data was able to be extracted, but the data would be cleaner if there were fewer people. A potential solution would be to complete data collection at another time of year when there are fewer visitors to the Navy Yard. The scanner does not work well in the dark, so changing the time of day is not a plausible solution given the amount of time it takes to set up the scanner and complete a scan. Consequently, collecting data during the late fall, winter, or early spring could lead to cleaner data.

For long-term data collection, it is recommended that manhole covers, sewer drains, or pipe covers are avoided. During the last days of data collection, a utility crew was at the Navy Yard and removed the manhole cover that had a control point set on it. Because control points are georeferenced, the control point could no longer be used because there was no way to ensure that the manhole cover would be replaced in exactly the same location as it was when the point was set. For the sake of this project, the data collection occurred within a small enough time

frame where the risk of such issues was minimal. The scans using that control point had already been completed, and another control point could have easily been set if needed. However, ensuring control points are set in more permanent locations is an important consideration, especially if data collection will occur over a longer period of time.

Another consideration for data collection at the Navy Yard are the effects of the *USS Cassian Young* and the *USS Constitution* on data collection. Because both ships sit on the water, they are not entirely stationary. Consequently, the scanner should be pointed away from them when setting up a scan so that the ships are not the start or end of the 360-degree scan. The slight movement of the ships is enough to create a level or error at the scanner will think the entire scan will be out of tolerance. Orienting the scanner in a different direction at the beginning of the scan is a simple solution to the issue—the 360-degree nature of the scan means that the start and end point of the scan does not affect the scan itself. Scans that include one or both of the ships might return a higher level of error that can be attributed to the slight movements of the ships.

The data files are quite large, so storing the data in a way that protects its integrity while making it accessible is a challenge being addressed by the Northeast Region NPS geospatial staff. Because the data collection is a novel process and uses for the data are still forthcoming, there is no precedent on the best way to store the data or the best format for the data so that it is most accessible to GIS professionals, planning professionals, and climate change response staff. Currently, there is a zip file of all the data in the Trimble Business Center file format.

Conclusion

The Charlestown Navy Yard has undergone numerous transformations throughout its history, from the construction of multiple dry docks and facilities to landscape changes. When it comes to managing the park, "rehabilitation acknowledges the need to meet continuing or changing uses through alterations or new additions while retaining the property's historic character. It allows for repairs or alterations of the cultural landscape, and for improving the utility and/or function of landscape features" (Stevens et al., 2005, p. 10). NPS staff and park managers have been thinking critically about how to adapt the Charlestown Navy Yard to the threats of climate change while complying with local, departmental, and federal climate change goals and initiatives. The Charlestown Navy Yard geospatial mapping project has put the Charlestown Navy Yard at the forefront of using geospatial technology to make key science-back climate adaptation decisions. It serves as a model for other NPS sites to advance their geospatial data capabilities to make similar science-backed decisions as the NPS pursues its mission to "conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (National Park Service, 2021).

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Appendix

1. Control Points map layout

2. Priority 1 and Priority 2 Buildings with 2030s Projection of 9 inches of Sea Level Rise (1% Chance of Annual Flooding) map layout

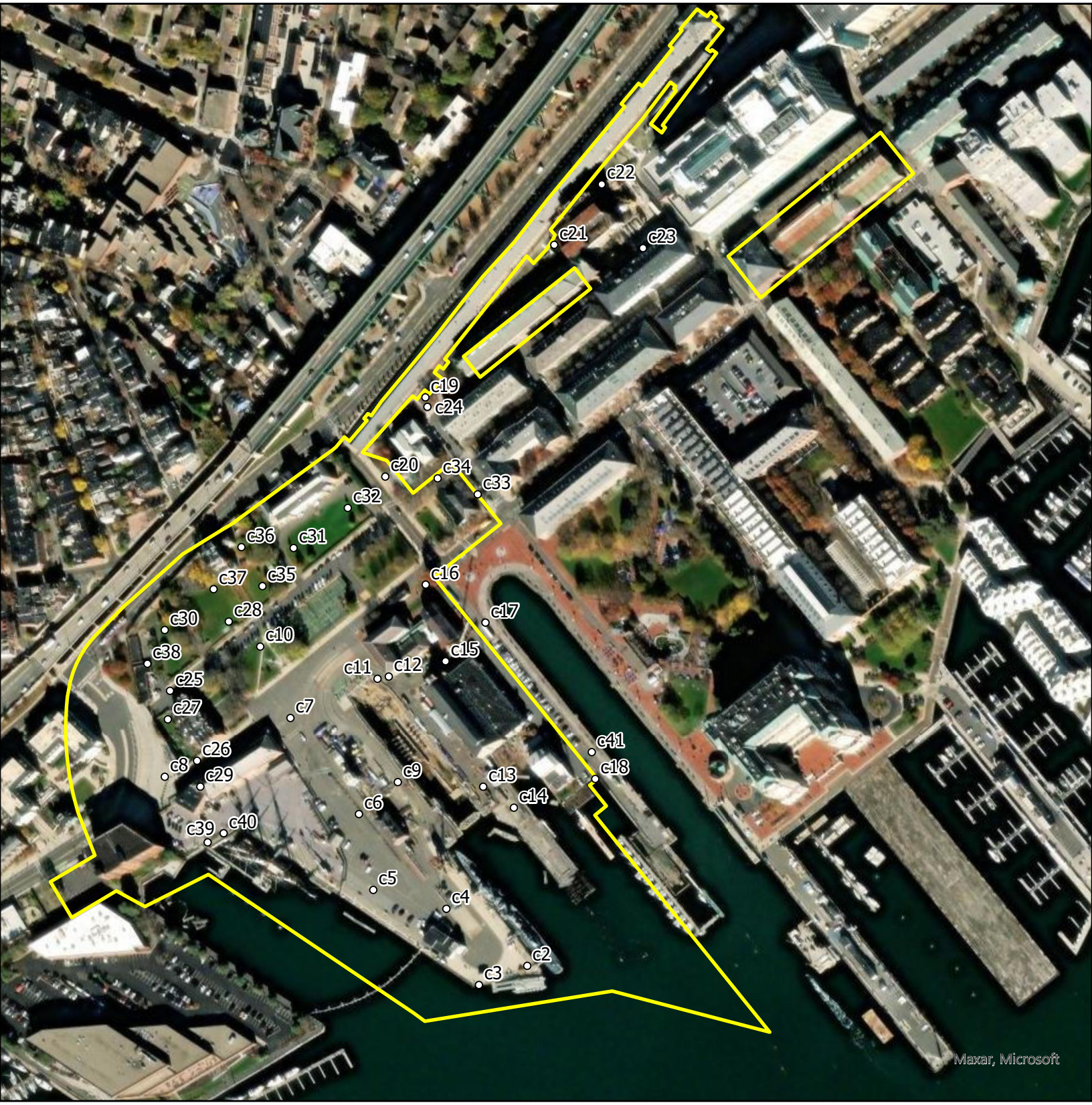
3. Priority 1 and Priority 2 Buildings with 2050s Projection of 21 inches of Sea Level Rise (1% Chance of Annual Flooding) map layout

4. Priority 1 and Priority 2 Buildings with 2070s Projection of 36 inches of Sea Level Rise (1% Chance of Annual Flooding) map layout

5. Priority 1 and Priority 2 Buildings with Projections of 9 inches, 21 inches, and 36 inches of Sea Level Rise (1% Chance of Annual Flooding) map layout

6. Priority 1 and Priority 2 Buildings with Projections of 9 inches, 21 inches, and 36 inches of Sea Level Rise (1% Chance of Annual Flooding) with Minimum Doorway Elevations map layout

Control Points



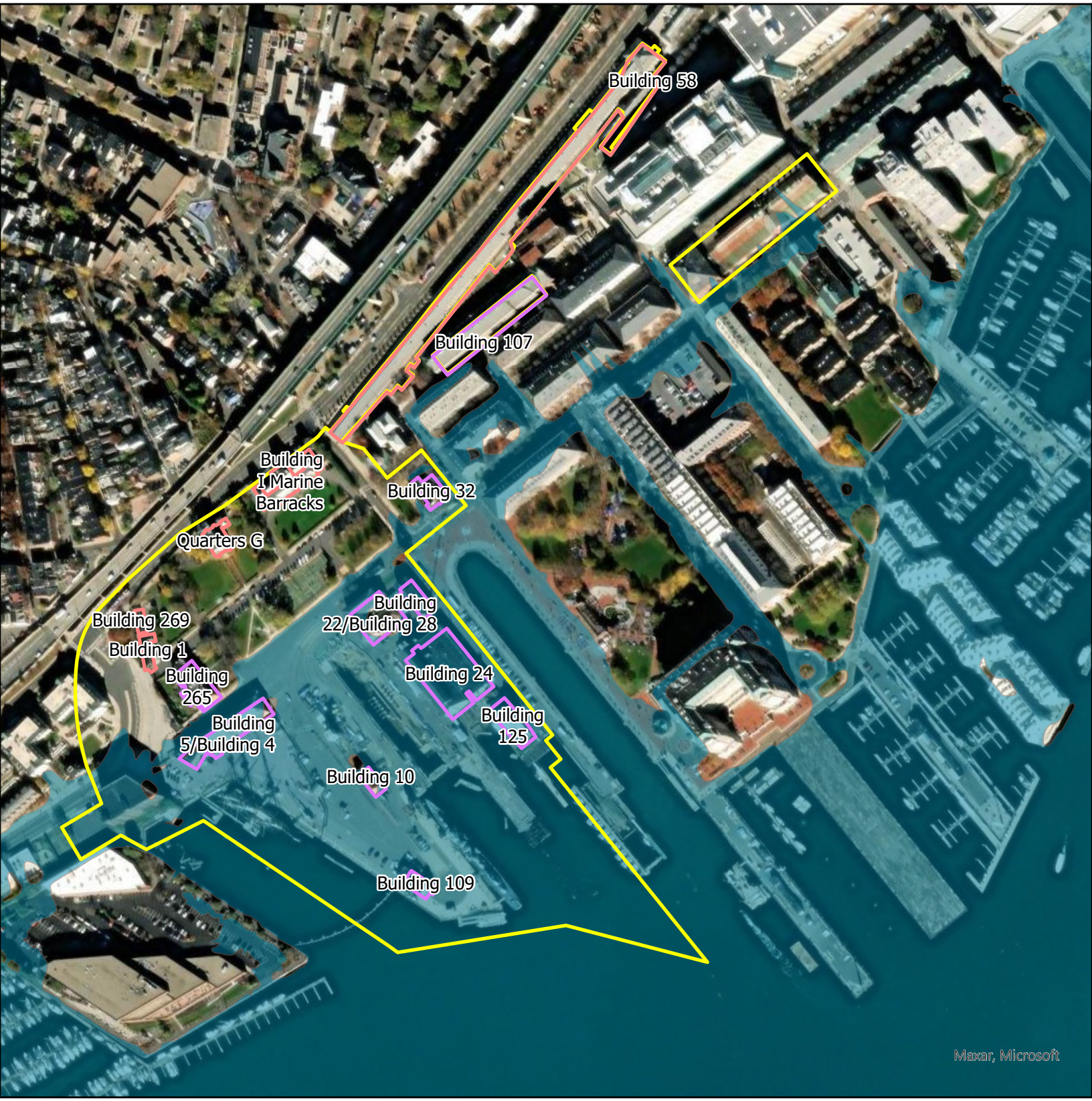
N

Control Points

Charlestown Navy Yard NPS Boundary

0 0.05 0.1 Kilometers

Priority 1 and Priority 2 Buildings with 2030s Projection of 9 inches of Sea Level Rise (1% Chance of Annual Flooding)



N

Priority 1 Buildings
Priority 2 Buildings
Charlestown Navy Yard NPS Boundary
9 inches Sea Level Rise (1% Annual Flooding)

0 0.05 0.1 Kilometers

Priority 1 and Priority 2 Buildings with 2050s Projection of 21 inches of Sea Level Rise (1% Chance of Annual Flooding)



N

Priority 1 Buildings

Priority 2 Buildings

Charlestown Navy Yard NPS Boundary

21 inches of Sea Level Rise (1% Annual Flooding)

0 0.05 0.1 Kilometers

Priority 1 and Priority 2 Buildings with 2070s Projection of 36 inches of Sea Level Rise (1% Chance of Annual Flooding)



N

Priority 1 Buildings

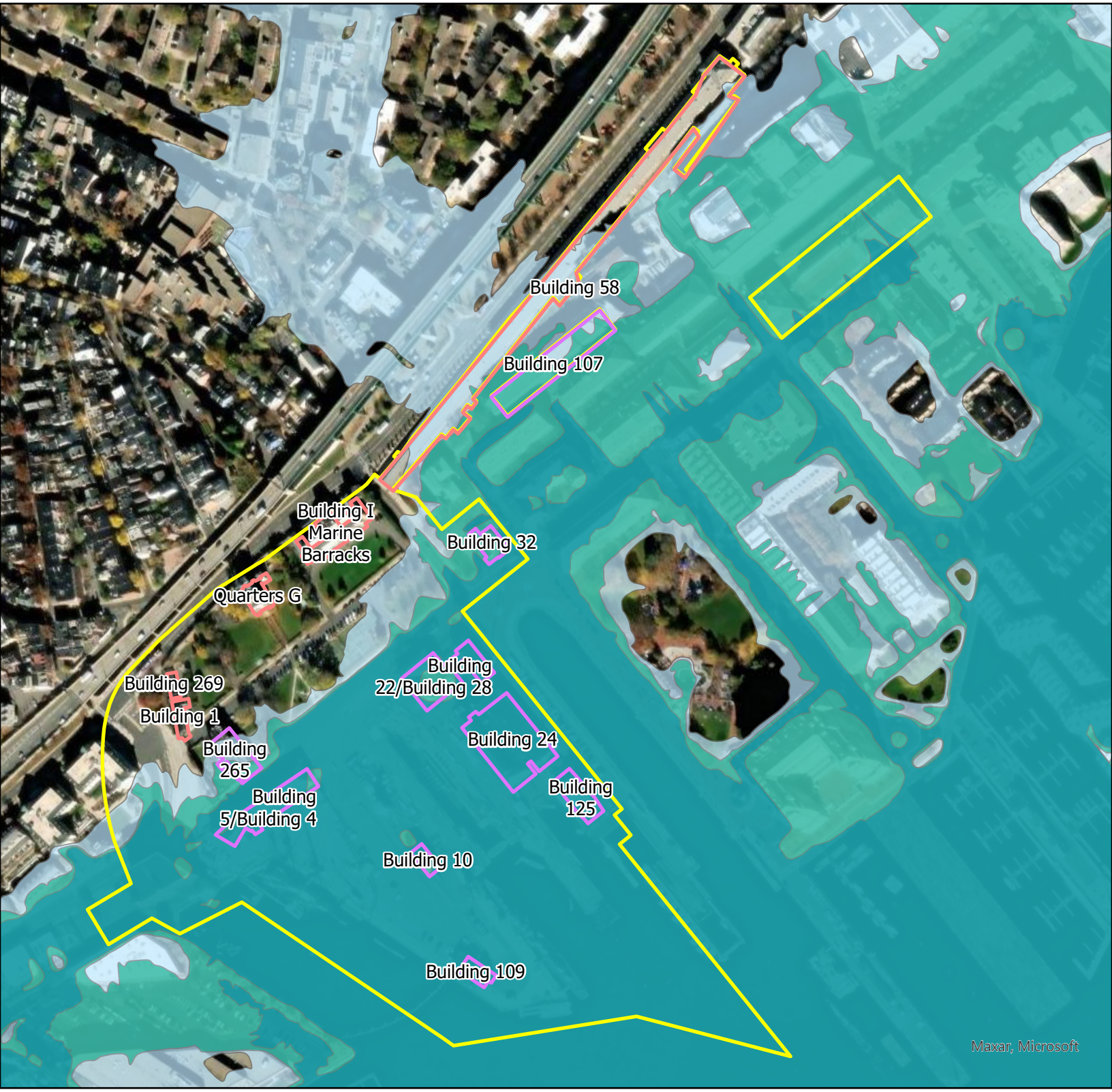
Priority 2 Buildings

Charlestown Navy Yard NPS Boundary

36 inches of Sea Level Rise (1% Annual Flooding)

0 0.05 0.1 Kilometers

Priority 1 and Priority 2 Buildings with Projections of 9 inches, 21 inches, and 36 inches of Sea Level Rise (1% Chance of Annual Flooding)

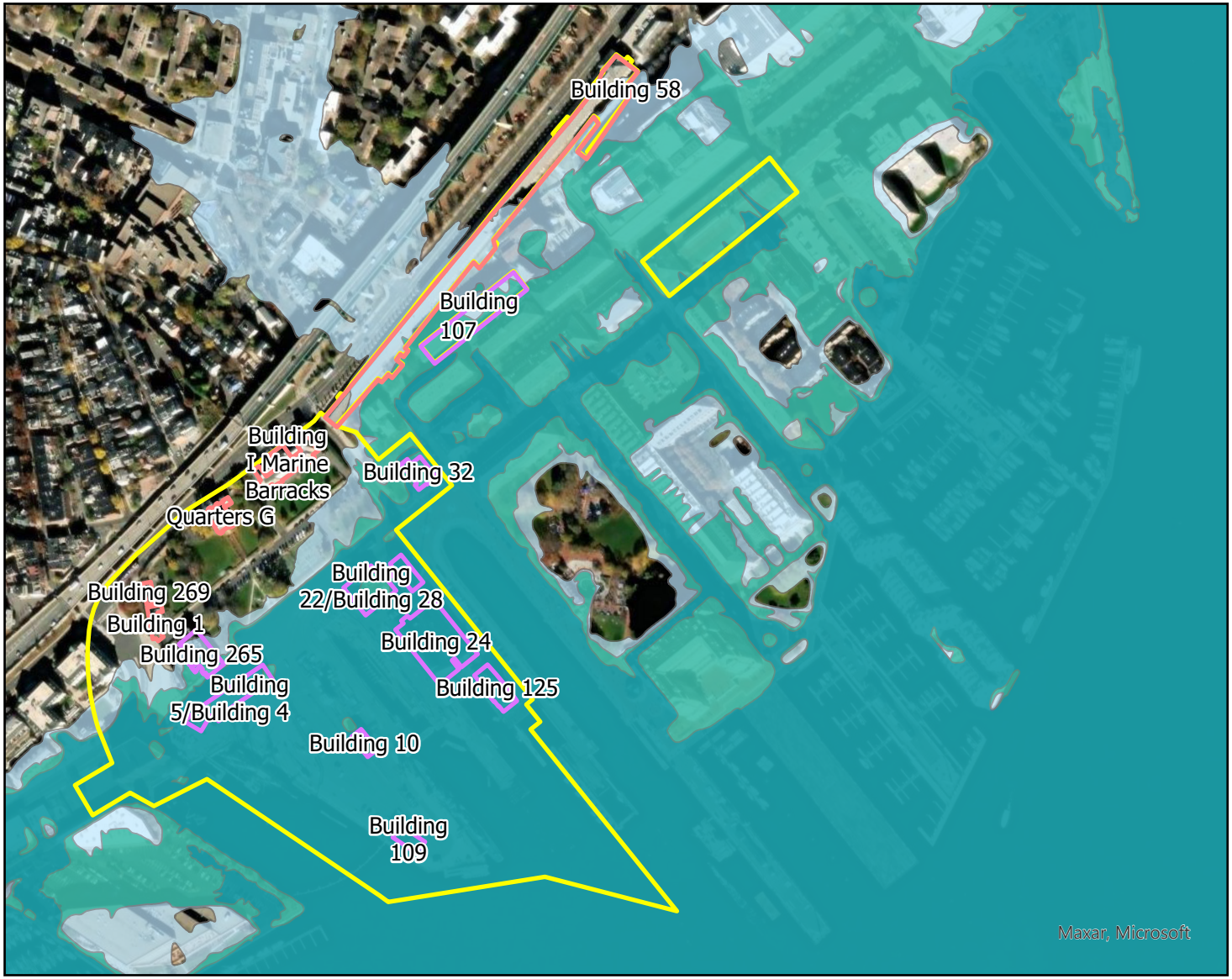


N

- Priority 1 Buildings
- Priority 2 Buildings
- Charlestown Navy Yard NPS Boundary
- 9 inches Sea Level Rise (1% Annual Flooding)
- 21 inches of Sea Level Rise (1% Annual Flooding)
- 36 inches of Sea Level Rise (1% Annual Flooding)

0 0.05 0.1 Kilometers

Priority 1 and Priority 2 Buildings with Projections of 9 inches, 21 inches, and 36 inches of Sea Level Rise (1% Chance of Annual Flooding) with Minimum Doorway Elevations



Building	Elevation (m above sea level)
Building 125	2.677
Building 24	2.717
Building 10	3.347
Building 22	2.915
Building 292	2.976
Building 109	2.98
Building 28	2.998
Building 4	3.002
Building 19	3.185
Building 5	3.198
Building 267	3.225
Building 107	3.347
Building M-39	3.666
Building 287	3.681
Building 32	3.801
Building 58	3.966
Building 1	4.531
Building 265	5.043
Building 269	5.502
Building I	6.37
Quarters G	8.487

N

Priority 1 Buildings
Priority 2 Buildings
Charlestown Navy Yard NPS Boundary
9 inches Sea Level Rise (1% Annual Flooding)
21 inches of Sea Level Rise (1% Annual Flooding)
36 inches of Sea Level Rise (1% Annual Flooding)

0 0.05 0.1 Kilometers