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Natural Resource Stewardship and Science

Northeast Coastal and Barrier Network Geomorphological Monitoring Protocol

Part III—Coastal Landform Elevation Models

Natural Resource Report NPS/NCBN/NRR—2018/1712

ON THE COVER
Otis Pike Wilderness Area, Fire Island National Seashore, NY.
Photograph by: Norbert P. Psuty

Northeast Coastal and Barrier Network Geomorphological Monitoring Protocol

Part III—Coastal Landform Elevation Models

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Executive Summary

Monitoring the three-dimensional changes in coastal topography was ranked as one of the most valuable and feasible programs to implement for the examination of coastal geomorphology, according to a review of Vital Signs in the coastal parks of the Northeast Coastal and Barrier Network (NCBN). Whether caused by erosion or accretion, changes in coastal topographical landforms vary both spatially and temporally. Understanding these variations is key to early recognition of potential problems affecting natural and cultural resources in coastal parks. For managers, an understanding of the spatial and temporal patterns of geomorphological change is vital to optimal management of any coastal park because the interface of marine and land systems: 1) is highly dynamic and driven by multiple forcing mechanisms; 2) results in alterations to resource dynamics at habitat and ecosystem levels; and 3) can eventually result in the loss of static resources.

The establishment of local, long-term monitoring programs provides metrics to help understand the processes and responses that are associated with the coastal evolution of the subaerial beaches, dunes, and bluffs within Areas of Special Interest in the parks. The Coastal Landform Elevation Model monitoring protocol will be applied within seven NCBN Parks. Monitoring will be accomplished with state-of-the-art Global Positioning System/Global Navigation Satellite System (GPS/GNSS) survey equipment that is used to collect high-density topographical data within areas of special concern to the parks. The areas of concern will contain high-quality benchmarks to be used as reference points for topographical data collection, providing a robust basis for long-term monitoring. Surveys conducted in accordance with standard operating procedures (SOPs) will generate coastal topographical datasets for Areas of Special Interest that will be organized and assembled by a data manager into a national database for subsequent retrieval and additional examination. Three-dimensional topographical data will be utilized to measure and describe the beach-dune or bluff system, and attributes will be compared and analyzed in both cross-shore and alongshore perspectives. These comparisons provide information about the temporal and spatial changes of the Areas of Special Interest in the parks. The overall goal is to create a replicable means of data gathering that is efficient, adheres to scientific principles, and meets the management needs of the coastal parks.

This monitoring protocol consists of a protocol narrative and 10 standard operating procedures (SOPs) which are listed in the Introduction and available as a separate document at irma.nps.gov.

Acknowledgments

As with other projects that are very broad in scope, there are many people who have assisted in the compilation of information and testing of the protocol. Others assisted in providing support to the theme of the project and in sharing their experiences. Their contributions have been very helpful in bringing forth this document. Special appreciation is extended to the following in the National Park Service: Sara Stevens, Program Manager of the Northeast Coastal and Barrier Network; Courtney Schupp and Neil Winn of the Assateague Island National Seashore; Mark Adams and Megan Tyrrell of the Cape Cod National Seashore; Mike Bilecki of the Fire Island National Seashore; Dave Avrin, Bruce Lane, Mark Christiano, Jeanne McArthur, Kathy Mellander, Hollis Provins, Chris Olijnyk, and Tony Luscombe of the Gateway National Recreation Area. In addition, recognition is extended to: Graham Giese and Mark Borrelli of the Center for Coastal Studies, Provincetown; Keith Noonan, Phil Karrber, Joe Petrocelli, and Gary Conk of the State of New Jersey Howard Lab crew; and members of the Rutgers team over the years consisting of Tanya Silveira, Monica Patel, Joelle Freeman, Michael Towle, Sean McLaughlin, Ally Huggins, Carlos Carvajal, Tucker Fullmer, Brian Kempf, Kyle Nicholas, Irina Beal, Joshua Greenberg, Katherine Ames, Elizabeth Haussner, Michael Endicott, Dan Soda, Paul Zarella, Peter Dennehy, Peter Shipton, Barry Shafer, Mario Resina, Aaron Love, William Hudacek, Jake McDermott, and John Gagnon.

List of Terms and Acronyms

1D—1 Dimensional
2D—2 Dimensional
3D—3 Dimensional
ASCII—American Standard Code for Information Interchange
ASI—Area of Special Interest
ASIS—Assateague Island National Seashore
ATV—All Terrain Vehicle
CACO—Cape Cod National Seashore
CSV—Comma-separated values
CORS—Continually Operating Reference Station
DEM—Digital Elevation Model
ESRI—Environmental Systems Research Institute
FDF—Field Data Form
FGDC—Federal Geographic Data Committee
FIIS—Fire Island National Seashore
FTP—File Transfer Protocol
FTSC—Field Technical Support Center
GAR—Green-Amber Red Risk Assessment
GATE—Gateway National Recreation Area
GEOID—Gravity for Earth, Ocean, and Ice Dynamics
GIS—Geographic Information System
GLONASS—Global Navigation Satellite System
GMP—General Management Plan
GNRA—Gateway National Recreation Area
GPS—Global Positioning System
GNSS—Global Navigation Satellite System
ID - Identification
IRMA—Integrated Resource Management Application
JSA—Job Safety Analysis
LiDAR—Light Detection and Ranging
LDT—Local Daylight Savings Time
LST—Local Standard Time
MHW—Mean High Water
MHHW—Mean Higher High Water
MLW—Mean Low Water
MLLW—Mean Lower Low Water
MOU—Memorandum of Understanding
MSL—Mean Sea Level
NAD—North American Datum
NAVD—North American Vertical Datum

NCBN—Northeast Coastal and Barrier Network
NGS—National Geodetic Survey
NGVD—National Geodetic Vertical Datum
NOAA—National Oceanic and Atmospheric Administration
NPS - National Park Service
NSRS—National Spatial Reference System
OPUS—Online Positioning User Service
ORV—Off Road Vehicle
PDF—Portable Document Format
PDOP—Position Dilution of Precision
PID—Permanent Identifier
POC—Point of Contact
PVC—Polyvinyl Chloride
QA/QC—Quality Assurance/Quality Control
RTK—Real Time Kinematic
RTN—Real Time Network
SOP—Standard Operating Procedure
TBC—Trimble Business Center
TIN—Triangulated Irregular Network
TSC –Trimble Survey Controller
URI—University of Rhode Island
USACE—United States Army Corp of Engineers
UTM—Universal Transverse Mercator
UTV—Utility Task Vehicle
VRS—Virtual Reference System
XML—Extensible Markup Language

Protocol Narrative

The following table lists all changes that have been made to this Protocol Narrative since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the project leader. The project leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page. For a complete set of instructions, please refer to SOP#9 – Revising the Protocol.

Version 1.00 – May 2018

Revision History Log:

New Version #	Previous Version #	Revision Date	Author (full name, title, affiliation)	Location in Document and Description of Change	Reason for Change
–	–	–	–	–	–
–	–	–	–	–	–
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Background and Objectives

Introduction

A major issue in all coastal parks is the dimension and direction of coastal change and the impact of that change on the natural and cultural resources of the park. Change is the outcome of the dynamic nature of the coast driven by a global rise in sea level and a local imbalance in sediment availability (negative sediment budget). Bird (1985) indicated that at least 70% of the world's sandy shorelines are eroding and the percentage is expected to increase because of sea-level rise and sediment manipulation by human actions. Working Groups within the Intergovernmental Panel on Climate Change suggest that global mean sea level will likely rise between 28 to 98 cm during the present century, depending partly upon varying carbon emissions pathways (Church et al. 2013). Coastal change will be a consequence of this inundation. New coastal geomorphological models are emerging that consider the effects of sea-level rise on shoreline change and landform evolution (Davidson-Arnott 2005; Psuty and Silveira 2010). The new models are both a guide to the potential effects of continuing global change and a plea to gather data appropriate to the testing and calibration of the models. They are harbingers of the concern and interest in the characteristics of the coastal system, in the shepherding of coastal resources, and in the datasets describing these resources (Van der Lee 2009).

The Northeast Coastal and Barrier Network (NCBN) was created by the National Park Service (NPS) in 2003 as part of the congressionally-mandated Natural Resource Challenge, to ensure the systematic collection and use of scientific data in managing the nation's parks (Stevens et al. 2005). Within this structure, the NCBN is developing a series of scientific protocols to address a variety of natural resource issues appropriate to coastal locations. This current document represents the third protocol for subaerial geomorphological monitoring in seven of the eight parks that comprise the NPS NCBN (Figure 1). The initial protocol (Part I – Ocean Shoreline Position) focuses on the collection and analysis of the ocean shoreline position. The second protocol (Part II – Coastal Topography) focuses on the collection and analysis of two-dimensional coastal topography as a means to characterize beach, dune, and bluff systems (Psuty et al. 2010a, Psuty et al 2012). The third protocol (Part III – Coastal Landform Elevation Models) is directed to collect and analyze three-dimensional coastal features in local areas of special interest and to generate digital elevation models and subsequently derive metrics of sediment volume changes and configuration displacement as the features evolve spatially through time.

This monitoring protocol consists of this protocol narrative and the following standard operating procedures (SOPs), available at https://irma.nps.gov/DataStore/Reference/Profile/2253970.

- Standard Operating Procedure (SOP) #1 – Equipment and Supplies
- Standard Operating Procedure (SOP) #2 – Establishment of Benchmarks, Survey Areas, and Database
- Standard Operating Procedure (SOP) # 3 – Survey Timing and Mission Planning
- Standard Operating Procedure (SOP) # 4 - Settings for Collection of Topography

- Standard Operating Procedure (SOP) # 5 - Conducting the Survey
- Standard Operating Procedure (SOP) # 6 - Initial Post-Survey Processing
- Standard Operating Procedure (SOP) # 7 - Data Analysis and Reporting
- Standard Operating Procedure (SOP) # 8 - Data Management
- Standard Operating Procedure (SOP) # 9 - Revising the Protocol
- Standard Operating Procedure (SOP) # 10 - Field Safety

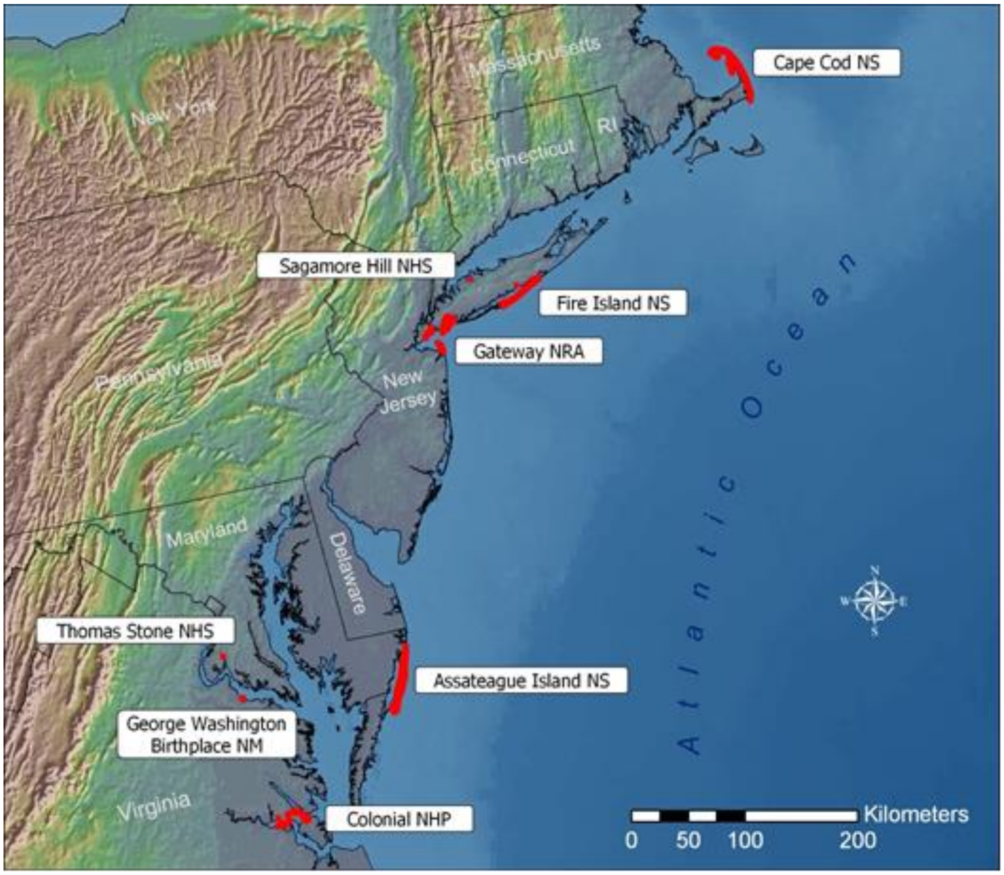

Figure 1. Locations of the NPS units in the Northeast Coastal and Barrier Network of the Inventory and Monitoring Program (image source: Dennis Skidds, NCBN).

Goal and Objective

A primary goal of the NCBN coastal geomorphological program is to provide information to park managers and to improve the understanding of the dynamic nature of coastlines, including the temporal and spatial patterns of change in NCBN parks that describe the evolutionary condition of marine and coastal areas. The ultimate objective is to support informed management decisions. Through the development and application of landform elevation models, the primary use of this monitoring protocol is to document the form and volume variability of coastal landforms within Areas of Special Interest in Network parks over seasonal, annual, and long-term (five years or more) scales.

The NCBN coastal geomorphology program and its protocols are based upon three underlying principles:

1. All protocols developed by the Network must have a scientific foundation. Collaboration with the scientific community will ensure that all geomorphological monitoring protocols are based on well-established scientific principles of coastal characterization, processes, and response. Because coastal geomorphology is a complex subject, valid interpretation of the data will require the active involvement of knowledgeable coastal scientists.
2. Data needs and applications must address significant park management issues. Park managers and natural resource staff were active participants in the planning and scoping process in the development phase of the geomorphological protocols. The objectives identified in this protocol reflect a consensus on issues considered relevant at the local park level. This protocol focuses on recording and assembling the geomorphological dataset to enable better-informed management decisions.
3. All protocols and their components must be feasible to implement at the Network level. Although the scientific and management value of the monitoring data are both critical factors in determining which vital signs or indicators are selected for monitoring, the practicality and feasibility of implementation across the Network are important as well.

Metrics of subaerial displacement and landform modification derived from application of the Shoreline Position and the Coastal Topography protocols are valuable indicators of coastal morphological change. Moreover, they are descriptors of coastal geomorphology applicable to large geographical areas either in the trace of the shoreline for the park, or a suite of profiles distributed at some alongshore interval. However, these representations are limited because the application of the Shoreline Position Protocol does not directly describe topography and the Coastal Topography Protocol does not consider planimetric dimensions. To supplement the two existing metrics, this Protocol establishes the calculation of volumetric change through the comparison of high-resolution elevation models for specific sites and portrays the three-dimensional changes in the subaerial coastal morphology. It fosters detailed descriptions and documentation of landform evolution. Furthermore, a direct and robust calculation of the sum of sediment transported into and out of the beach-dune or bluff system within an Area of Special Interest (ASI) (three-dimensional analysis focused on a limited area) can be achieved. The site-specific sediment budget is the primary driver of coastal change, incorporating trends of landward, seaward, and alongshore form and volume displacements in the beach-dune or bluff system. Beach, dune, or bluff erosion and migration are direct threats to natural and cultural resources, park infrastructure, and even to human safety, and are a major management issue in many parks. This landform-based monitoring program provides crucial information to the scientific understanding of the evolution of park coastal geomorphology, and it contributes to the scientific foundation for resource-management decision-making. Among the desired deliverables identified by coastal scientists and park managers were:

- Sediment budget calculations and inventories of total sediment volume buffering park infrastructure from direct interaction with coastal processes

- Metrics of changes in dimension and location of coastal landforms that may indicate changes in ecological habitat that, in turn, require management action

The Coastal Landform Elevation Models protocol includes a number of highly detailed standard operating procedures (SOPs). They are intended to ensure the consistency and repeatability essential to any long-term monitoring program. These SOPs will be modified and revised as technology improves and better methods for monitoring coastal geomorphological change are developed.

The Oceanside Coastal Ecosystem

The basis for the coastal geomorphological monitoring protocol is the beach-dune conceptual model (modified from Roman and Barrett 1999) that relates physical processes and cultural impacts (agents of change), vectors of change (stressors), and responses of the coastal ecosystem (Figure 2).

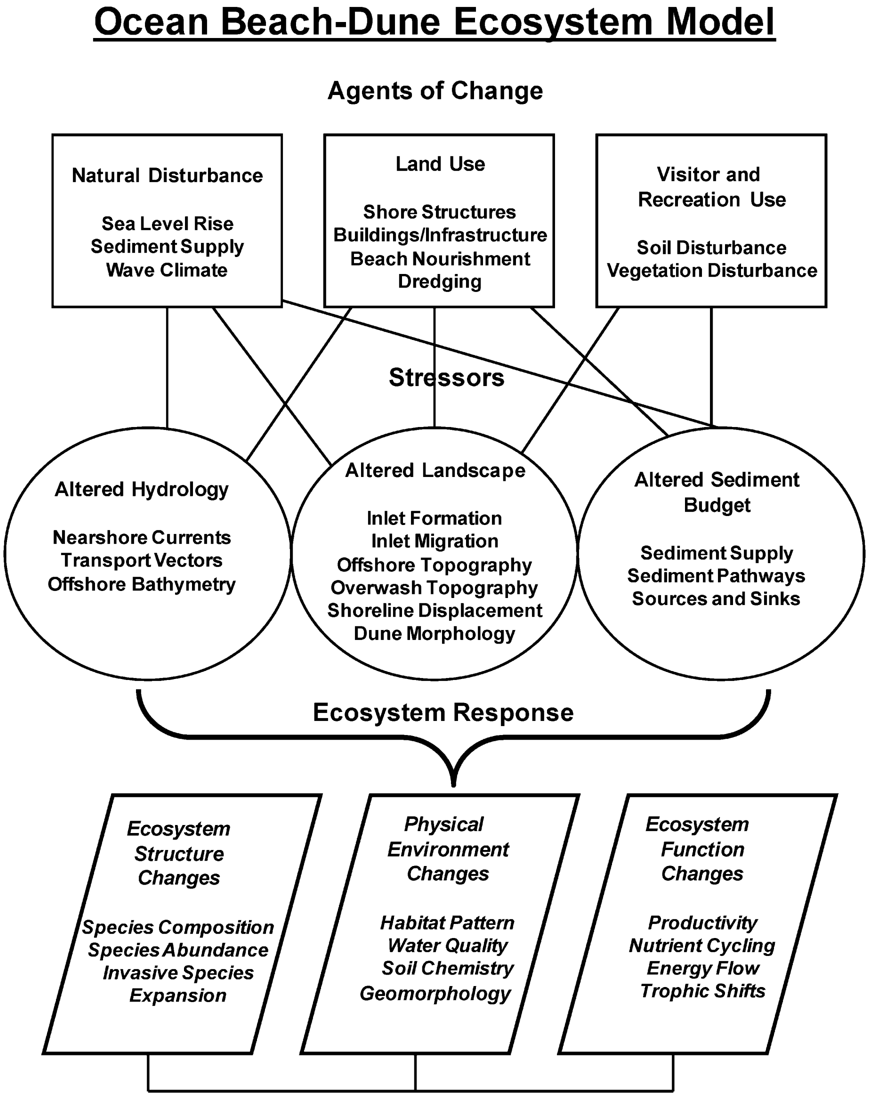

Figure 2. The Ocean Beach-Dune Ecosystem Model illustrates the relationships amongst the agents of change, stressors, and ecosystem response (adapted after Roman and Barrett 1999).

Fundamental to the model is an awareness that the coastal system is dynamic and that it is interacting at a variety of geographical and temporal scales. The model consists of an assemblage of natural and cultural agents that characterize the coastal landscape. As the relative magnitude of the agents vary, they cause alterations to the surface hydraulic processes and sediment budget, and consequently to the geomorphology. Furthermore, there is continuous interaction and feedback amongst the evolving components that drive additional changes and alterations. A primary manifestation of the alteration in the coastal system is a shift in shoreline position and modification of the beach, dune, and bluff topography. These coastal geomorphological changes result in an ecosystem response that incorporates changes in the physical environment and in the community structure and function (2).

The primary natural variables that drive geomorphological change are sea-level rise, sediment supply, and wave climate. These natural factors influence coastal geomorphological response at different temporal scales including individual events (storms), cyclic variations (seasonal), and annual and multi-year (long-term) trends (Carter 1988; Psuty and Ofiara 2002). One of the effects of sea-level rise is inland displacement of the shoreline and alteration of the coastal profile. When it is coupled with erosion produced by a prevailing sediment deficit, the rate of inland shoreline displacement is increased (National Research Council 1987; Warrick et al. 1993), and the elements of coastal topography evolve (Nicholls et al. 2007; Psuty and Silveira 2010). Whereas sea-level rise and sediment supply are the primary factors causing the long-term change, wave climate is responsible for the nearshore processes of waves and currents that steer the local sediment transport and consequently control the site-specific coastal configuration (Trenhaile 1997).

Local conditions such as the underlying geological framework, bathymetry, offshore topography, and sediment sources and sinks interact with the primary factors and the coastal processes to influence the characteristics and the rates and direction of the subaerial coastal system alterations (Carter 1988; Honeycutt and Krantz 2003). In addition to natural causes, coastal changes are often accelerated by human-produced perturbations such as dredging and channel relocation, groins and jetties, and beach and dune manipulation (Walker 1990; Nordstrom 2000). These human influences can cause alterations to waves, currents, and availability and mobility of sediment. Combinations of natural processes and anthropogenic modifications interact to cause significant morphological change affecting cultural and natural resources. Particularly, displacement of the coastal topography as well as changes in the width and/or volume of the beach may result in the destruction of cultural resources, facilities, and other infrastructure (Stevens et al. 2005).

Coastal ecosystem response may consist of adjustments to resource patterns and dynamics, and may eventually lead to the loss of fixed natural resources (Roman and Nordstrom 1988). These responses often elicit secondary changes in ecosystem structure or function. Structural changes in species composition or competitive interactions generally reflect landscape alterations in the quantity and quality of specific habitats. Similarly, functional changes in productivity or nutrient cycling may occur as a product of storm events and the associated reduction in habitat complexity. More subtle physical changes also include alterations in geo-chemical and hydrological conditions, such as groundwater quality and quantity. The magnitude and scope of the resultant coastal ecosystem response is complex, highly variable, and can often be cumulative. At the extreme, the response may include alteration of habitats and of core ecosystem processes, such as when the erosion of an existing coast may create new aquatic habitat, or when washover fans may fill in a wetland environment to create new terrestrial habitat.

The Evaluation of Vital Signs

Geomorphological change is important to the evolution of the coastal ecosystem and can present complex challenges to park management when it affects natural and cultural resources, such as recreational facilities or infrastructure. In order to identify the full range of scientific and management concerns, multiple scoping workshops were convened to consider issues of general importance and to make specific recommendations for monitoring. Throughout the scoping process, the lack of adequate data to track and respond to geomorphological change was consistently identified as a high-priority management issue.

Demonstrating the complexity of the coastal geomorphological process, twenty-nine potential monitoring variables (vital signs) of geomorphological change were identified at the workshops and eventually grouped into 14 vital signs (Stevens 2005). The indicators were evaluated and ranked for data value and feasibility of implementation at the Network level. Shoreline position and elements of the coastal topography were consistently identified to be of high information value and feasible to monitor with existing methods (Table 1).

Table 1. The fourteen Vital Signs identified during the Northeast Coastal and Barrier Network Geomorphological Change Workshops; they are ranked (low to high) for data value and feasibility of implementation at the Network level (Stevens 2005).

Geomorphological Change	Vital Sign	Monitoring Methods	Feasibility	Data Value
Shoreline Position	Shoreline position	1D, 2D, & 3D GPS/GNSS; Aerial Photography; LIDAR	high	high
Coastal Topography	Dune, beach, bluff, bluff morphology	LIDAR, Aerial Photography, 2D & 3D GPS/GNSS	high	high
	Edge of vegetation	LIDAR, 1D & 2D GPS/GNSS, Aerial Photography	high	high
	Landcover	LIDAR, 2D & 3D GPS/GNSS	high	high
	Overwash fans/flood plains	LIDAR; 1D, 2D, & 3D GPS/GNSS; Aerial Photography	medium	high
	Shore type	Aerial Photography, 2D & 3D GPS/GNSS	medium	medium
Anthropogenic Modifications	Locations of structures and disturbances	Aerial Photography; 1D, 2D, & 3D GPS/GNSS	medium	high
Marine Geomorphology	Sediment volume, Sediment size	Terrestrial and Marine Sediment Samples	medium	medium
	Geologic framework	Acoustic Survey, Seismic Survey,	low	high

Table 1 (continued). The fourteen Vital Signs identified during the Northeast Coastal and Barrier Network Geomorphological Change Workshops; they are ranked (low to high) for data value and feasibility of implementation at the Network level (Stevens 2005).

Geomorphological Change	Vital Sign	Monitoring Methods	Feasibility	Data Value
Marine Geomorphology (continued)	Depths	Core Samples	low	medium
	Depths	Acoustic Survey, Bathymetric LIDAR,	low	medium
	Depths	Sled survey	low	medium
	Migrating shoals & bodies	Acoustic Survey, Bathymetric LIDAR	low	high
Marine Hydrography	Tide range	Local & Regional Tide Gauge	high	high
	Relative sea level position	Water Level Gauge	high	high
	Wave and current characteristics	Local Gauge – Regional Gauge	low	high

Metrics of Coastal Change

Detailed knowledge of the hydrodynamic forcing of sediment mobilization, transport, and deposition, and measurements of morphological change and ecosystem response at the park level are key to understanding the coastal geomorphology of the NCBN parks (Allen 2000). This knowledge is basic to the understanding of coastal geomorphology within Areas of Special Interest in the NCBN parks. Tracking the evolution of coastal landforms through a quantitative analysis of local variations in sediment storage, coupled with a qualitative/quantitative assessment of landform evolution through time, provides the opportunity to understand how a coastal system has evolved, and continues to evolve. This approach, utilizing metrics derived from high-accuracy 3D topographical data, can reveal vulnerabilities to Park resources.

As described in Finkl (2004), the combination of spatial (alongshore) and temporal variables associated with sediment supply and sediment budget drive the evolution of coastal topography. This geotemporal relationship is at the core of periodic monitoring because measurements of topography depict the outcomes of sediment budget and landform features at a site. These metrics permit a temporal comparison of an entire site or any of its components (provided it is covered within the survey bounds). It is the combination of vectors of change in the spatial and temporal context that fuels the 3D geotemporal monitoring program and brings the alongshore and cross-shore sequence of process-response geomorphological features to the fore. The systematic collection of 3D topographical data within Areas of Special Interest (ASI) fosters the analysis of these morphological features through time and space. Understanding the dynamics of changes in these features over time, through standardized data collection, will provide a scientific basis for informed resource management (National Research Council 1995).

Many of the NCBN parks currently monitor aspects of their coastal topography and have extensive historical datasets that can be used for long-term comparison to support decisions on infrastructure protection as well as resource management (e.g. Psuty and Pace 2009; Rogers et al. 2009; Rodriguez 2004). The assemblage of reliable and consistent data enables robust statistical analysis, yielding a better understanding of episodes, cycles, and trends (Colwell and Thom 1994; Dolan and Hayden 1983).

The Area of Special Interest (ASI)

Criteria for Establishment

In the application of the study of vital signs, the coastal geomorphological change at specific sites comprising relatively small geographical areas (Area of Special Interest) can vary significantly from regional trends that are largely driven by regional sediment supply and sea-level rise. Thus, monitoring is focused at a defined local site for the purpose of developing a three-dimensional dataset that tracks vectors of subaerial change and impact. High rates of localized erosion can be a problem for sites containing natural or cultural resources. Specifically, natural conditions or anthropogenic constructions can influence vectors of physical forcing in a manner that generates localities of high erosion and affect the transport of material into or out of the local system. The ASI is typically established in such a site because intensive monitoring can reveal the drivers and directions of local sediment transport, sources, and sinks of material, and total rates of volumetric change. Sites that present an exposure or vulnerability of Park natural or cultural resources are prime candidates for establishing a 3D monitoring program because a better understanding of the site-specific trajectories of landform evolution provides a foundation for assessing adaptation and/or mitigation programs.

Supplementary to its value in assessing the exposure of Park resources, the Coastal Landform Elevation Model protocol may be applied to sites that merit intensive monitoring on the basis of the opportunity to improve knowledge of coastal processes and landform evolution, in response to a particular constructed or natural situation. The two initiatives of research and resource management are inextricably tied, as scientific knowledge pertaining to coastal geomorphological change promotes informed and responsible resource management decisions that concern Park shorelines and coastal areas at large. Collaboration among Park and scientific personnel can best identify areas of concern and interest to establish sites for programmatic monitoring according to this protocol.

Boundaries for the Area of Special Interest

Collection of topographical data for the purpose of tracking volumetric change of the coastal system through time is resource intensive. As a result, the planimetric area where the methodologies can be applied is limited, and a few considerations should guide the establishment of the monitoring boundaries.

Most importantly, the motivations that qualify an Area of Special Interest for intensive monitoring should be reflected in the genesis of the boundaries. The extent of the alongshore length of the area and its cross-shore width should ideally enclose any potential structural influences on the development of the impacted landforms, such as dune fencing or bulkheads, in addition to the landforms themselves. The alongshore length of the survey will be hundreds of meters to a few kilometers. Survey areas with an alongshore length less than ~100 m may provide little additional benefit to examining more than a representative cross-shore profile. Surveys longer than a few kilometers will likely be unmanageable utilizing the procedures herein.

Naturally, greater alongshore lengths of shoreline can be surveyed if lesser cross-shore distances are covered. However, the cross-shore extent of a survey should encompass the entirety of the active beach-dune or bluff system and it is recommended that the survey be extended inland far enough to accommodate erosion and landward migration of features. If infrastructure is at risk and is part of the basis for conducting the survey, it is recommended that the survey also extend landward to include it. Practically, most sites will require tens to hundreds of meters in cross-shore width and can be completed in one day.

For some situations, the application of this monitoring program provides information on the dimensions of change associated with littoral sediment transport cells. Transport cells are typically defined by the erosion of sediment occurring within a particular segment of a shoreline, and the subsequent deposition of that material in another. Surveying at least the subaerial portions of these transport cells, specifically their originations or termini, can provide some foundation for vectors of volumetric analyses that support practical application. This approach will provide a more complete representation of subaerial volumetric change within a site and the collected data can better translate to actionable information for management. Where possible, obstructions of sediment transport that result in a dearth of sediment supply to downdrift shorelines or a collection of updrift material should be used opportunistically in defining the survey areas. For example, potential Areas of Special Interest that have no external source of sediment should incorporate the entirety of an erosional section of the shoreline. These areas of local erosion will define the supply of sediment for the rest of the site, as well as the intra-site deficit. Similarly, coastal engineering structures in the Areas of Special Interest that collect sediment transported alongshore should be included to the downdrift extent of their influence if possible.

Examples of Areas of Special Interest in Gateway National Recreation Area (GATE)

The variety of sites and situations incorporated by ASIs is exemplified by the several monitoring locations in GATE (Figure 3). Three areas are exposed to the ocean processes (Critical Zone (Figure 4), Gunnison (Figure 4), and Fort Tilden (Figure 5), and five other areas are shielded to various degrees from the direct exposure to ocean conditions (Great Kills (Figure 6), Miller Field (Figure 6), Kingman-Mills (Figure 4), West Pond (Figure 5), and Plumb Beach (Figure 5). They each respond to the relative intensity of the energetics associated with their position and to the sediment supply reaching their position, as described in Psuty et al. (2010a). Similarly, monitoring of ASIs in other parks-will generate datasets on the vectors of topographical change pertinent to their sites and situations.

Figure 3. Location of the three management units and components of Gateway National Recreation Area (GATE).

Figure 4. Areas of Special Interest in the Sandy Hook Unit of Gateway National Recreation Area.

Figure 5. Areas of Special Interest in the Jamaica Bay Unit of Gateway National Recreation Area.

Figure 6. Areas of Special Interest in the Staten Island Unit of Gateway National Recreation Area.

Measuring Coastal Topography with Transects

Measurement of 3D subaerial coastal topography in the NCBN monitoring program is accomplished through the collection of topographical data along a series of transects with predefined spacing that run perpendicular to the shoreline (Table 2). The same transects are run in successive surveys to provide comparable data sets. Elevations of the unsurveyed areas between the survey transects are derived from the interpolated DEM produced from Delaunay triangulation and stored as spatial matrices of elevation data (raster Digital Elevation Models, or DEMs). These DEMs provide a framework for the systematic tracking of the variations in topography through space and time. State-of-the-art survey equipment and methodically implemented practices are used to ensure accuracy and consistency in data collection. The systematic and repeated collection of topographical data along predefined survey transects utilizing geodetic GPS/GNSS survey equipment tested against survey control benchmarks allows for a robust quantification of variations in coastal geomorphology through time.

Table 2. Transect Spacing at Areas of Special Interest in Gateway National Recreation Area.

Unit	AOI	Transect Spacing	Survey Frequency
Sandy Hook Unit	Critical Zone	30m transects	4x per year
	Gunnison Beach	25m transects	4x per year
	Kingman-Mills	15m transects	1x per year
Staten Island Unit	Great Kills	30m transects	4x per year
	Miller Field	15m transects	1x per year
Jamaica Bay Unit	Plumb Beach	20m transects	4x per year
	Fort Tilden	25m transects	2x per year
	West Pond	10m transects	2x per year

Basics of Topographical Data Collection

Acquisition of topographical data involves measurements of the earth's surface in its spatial location, as well as its elevation. The spatial location is measured in terms of coordinates - distances from a starting point measured along two axes: easting and northing, or X and Y (Figure 7). The elevation component is represented by Z, completing the 3-dimensional representation of a portion of the earth's surface. Elevation data are collected along multiple survey transect lines to provide 3D topographical data coverage encompassing an Area of Special Interest, with the elevations of unsurveyed locations between transects calculated through interpolation.

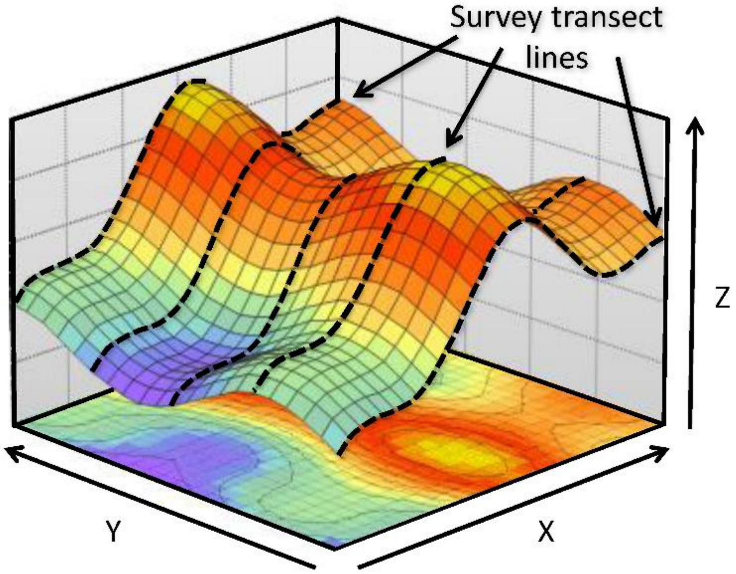

Figure 7. Three-dimensional characteristics of the coastal topography collected as a series of parallel transect lines.

For the purpose of the present protocol, easting and northing are measured in meters relative to the Universal Transverse Mercator (UTM) coordinate system. All the parks of the Northeast Coastal and Barrier Network are located in Zone 18 North, except for Cape Cod National Seashore; it is located in Zone 19 North. The North American Datum of 1983 (NAD83 2011) is the horizontal datum applied in this protocol. The National Spatial Reference System (NSRS) is the spatial standard used to locate the coastal topography in this protocol. As technology progresses, the spatial reference system undergoes periodic updates related to datum realizations, thereby causing adjustments in the coordinates of the surveyed points. The NOAA National Geodetic Survey (NGS) releases these updates for the USA. As the NSRS is updated, shifts in position will occur depending on location and will produce offsets in horizontal and vertical coordinates. The current horizontal datum used for this protocol is NAD83 (2011) (2010.0). The contemporary geoid model is GEOID12B. The horizontal datum and geoid model is subject to future change and specific attention needs to be paid to the datums that collected survey data are referencing so that comparisons of surveyed topography can be confidently undertaken. The current geodetic datums can be confirmed through the National Geodetic Survey website at: http://www.ngs.noaa.gov/ .

Elevation is measured relative to a base elevation, known as a vertical datum. The North American Vertical Datum of 1988 (NAVD 88), determined by the geoid model GEOID12B, is the most recent and most commonly used in the US. It is the vertical datum utilized for topographical measurements made through the application of this protocol. NAVD88 is a fixed datum, determined by geodetic leveling, established relative to a specific zero point that does not change through time. Before NAVD88 was established in 1991, the National Geodetic Vertical Datum of 1929 (NGVD29) was the vertical control datum widely used in the US.

Another type of vertical datum is the tidal datum, expressed relative to a mean water level obtained from tide observations conducted through the National Ocean Service over a 19-year time period (National Tidal Datum Epoch). This sequence includes all of the tidal variations caused by earth-sun-moon relationships and sea level change over this period. Tidal datums change with every tidal epoch, and the most common tidal datums used are listed and described in Table 3. An example of the relationship between the 1983-2001 tidal epoch datums and the NAVD88 and NGVD29 geodetic datums is represented on a typical beach profile, using the tide gauge measurements at Sandy Hook, NJ (Figure 8 and Table 4).

Table 3. Tidal datums as defined by the Center for Operational Oceanographic Products and Services (http://tidesandcurrents.noaa.gov/).

Tidal Datum	Description
Mean Higher High Water (MHHW)	Average of the higher high water height of each tidal day observed over the Tidal Epoch
Mean High Water (MHW)	Average of all the high water heights observed over the Tidal Epoch
Mean Sea Level (MSL)	Arithmetic mean of hourly heights observed over the Tidal Epoch
Mean Low Water (MLW)	Average of all the low water heights observed over the Tidal Epoch.
Mean Lower Low Water (MLLW)	Average of the lower low water height of each tidal day observed over the Tidal Epoch.

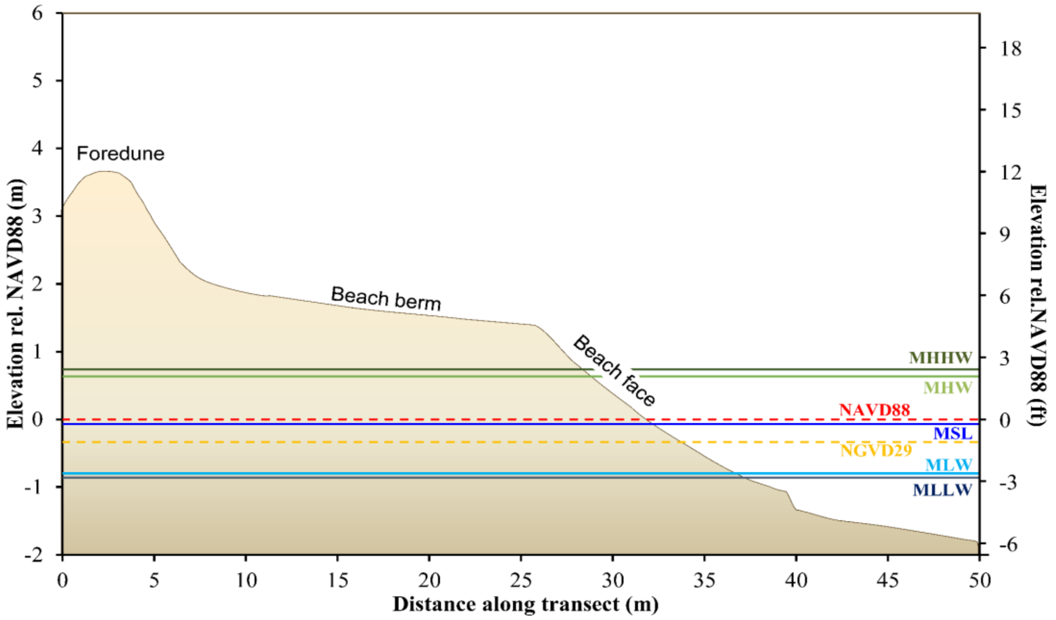

Figure 8. Typical beach profile showing the relationship of the 1983-2001 tidal epoch tidal datums to NGVD29 and NAVD88. (Source: NOAA tide gauge at Sandy Hook)

Table 4. Relationship of 1983-2001 Tidal Epoch water levels and NGVD29 to NAVD88. (Source: NOAA tide gauge #8531680 at Sandy Hook).

Elevation of tidal datums and NGVD29 relative to NAVD88	Meters	Feet
Mean Higher High Water (MHHW)	+0.734	+2.41
Mean High Water (MHW)	+0.634	+2.08
North American Vertical Datum of 1988 (NAVD88)	0.000	0.00
Mean Sea Level (MSL)	-0.073	-0.23
National Geodetic Vertical Datum of 1929 (NGVD29)	-0.332	-1.09
Mean Low Water (MLW)	-0.800	-2.62
Mean Lower Low Water (MLLW)	-0.858	-2.81

Field Methods and Equipment

The Global Positioning System (GPS/GNSS) and its use for topographical data acquisition is becoming increasingly important in geomorphological and morphodynamical studies (Baptista et al. 2008). GPS/GNSS methods rely on the broadcast of signals from a constellation of satellites that orbit around the Earth. Whereas most users are familiar with the constellation of navigation satellites that constitute the Global Positional System (GPS), developed and maintained by the U.S. government, GPS is now only one of many such constellations utilized by modern hardware. Others include the Russian GLONASS and European GALILEO constellations. Therefore, this document refers to the more generic GNSS (global navigation satellite system) in combination with the more familiar GPS throughout. This protocol will utilize Trimble geodetic GPS/GNSS survey equipment to exemplify procedures that are applicable with equipment from other manufacturers.

Four satellites are sufficient to provide real-time XYZ positions with an accuracy that ranges from several meters to centimeters, depending on the equipment. The most sophisticated GPS/GNSS equipment, referred to as survey-grade or geodetic, applies differential correction and can measure a position to within 1-2 cm in the horizontal dimension, and 2-4 cm in the vertical dimension. Differential correction involves the use of two GPS/GNSS receivers (base and rover) in constant communication, either through a radio or wireless internet connection. The base receiver works as the reference station, established at a point (benchmark) with known coordinates and elevation, sending real-time corrections to the rover receiver as it occupies successive points along a transect. The rover can be used up to a 20 km range from the base station, allowing for coverage of large areas for surveying. Measurement accuracy, however, drops approximately 1 cm per each 10 km distance from the base. In addition, terrain, buildings, and tree canopy can also obstruct the satellite or radio signal and make it difficult for the GPS/GNSS rover to acquire positions.

Geodetic GPS/GNSS Unit

For the purpose of this protocol, a geodetic GPS/GNSS unit and RTK survey style have been selected as the most suitable configuration for measuring topographical data along defined transects to calculate the seasonal and annual variation in coastal topography (Figure 9). This approach calculates centimeter accurate positions via differential correction in real-time and requires no post-processing.

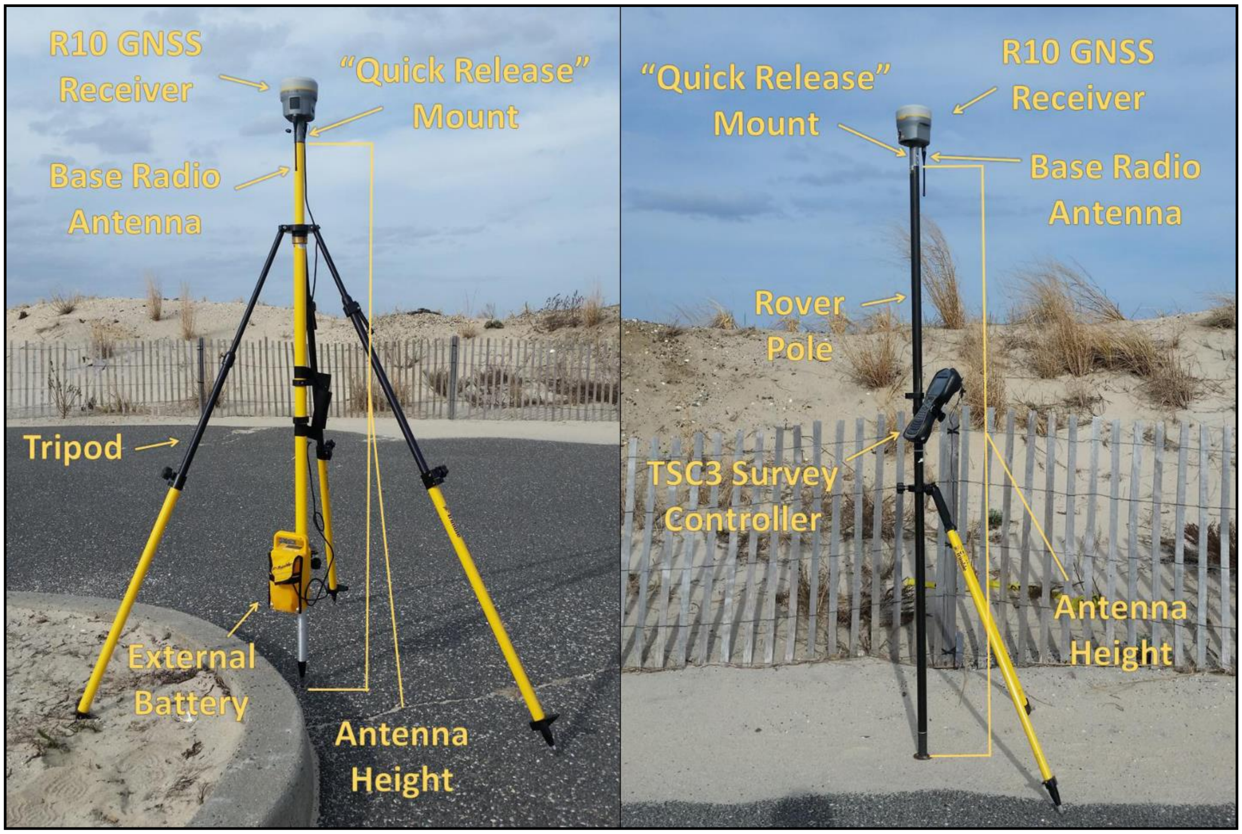

Figure 9. Trimble R10 GPS units and TSC3 controller (base receiver on tripod in image to the left, and rover receiver on pole in image at right) used for conducting topographical surveys at Gateway National Recreation Area (Sandy Hook, February 2016).

The geodetic GPS/GNSS equipment offers the best compromise between cost and quality of data. Topographical survey utilizing geodetic GPS/GNSS survey equipment with Real Time Kinematic differential correction (hereafter referred to collectively as RTK- GPS/GNSS) is a time-efficient method of collecting elevation data within the coastal landscape. Compared to LiDAR, it is less expensive and it allows for greater control over the timing of surveys. The equipment is highly portable, and the survey method allows access to remote areas without much constraint. The level of accuracy attained with the RTK- GPS/GNSS approach is adequate for the analysis of variations in beach and dune surfaces at a seasonal to annual scale, because this variation is on the order of tens of centimeters to meters. Furthermore, the GPS/GNSS field survey controller (a handheld field computer) allows for easy data collection and storage and provides the advantage of displaying results in real time. The controller also has the capability to display background layer files with the location of the benchmarks and survey transect lines, allowing field verification crucial to the field data collection in this protocol. Therefore, the combination of speed of conducting the survey, the real-time calculation and storage of highly accurate data points, and the consistent positioning and verification of the survey data along the transect lines supports the RTK- GPS/GNSS approach.

The geodetic GPS system should also be used to establish survey-quality positions for benchmarks and control points in the field by using the static surveying mode. The NGS Online Positioning User

Service (OPUS) provides free processing of GPS data files (measured according to guidelines) to generate coordinates that are highly accurate (http://www.ngs.noaa.gov/OPUS/).

Depending on the equipment, personnel available, the area to be covered, and local constraints, there are generally two principal ways to set up the geodetic GPS equipment for RTK surveys:

1. Base station and Rover(s): Uses one GPS receiver that is temporarily set up over a known location (control benchmark) and is sending differential corrections through a broadcasted radio signal to a second or multiple additional GPS receivers collecting data in the field.
2. Real-Time Network (RTN) and Rover(s): With an internet connection, the survey equipment can access an external network of reference stations known as the Continually Operating Reference System (CORS) network. The RTN system computes a Virtual Reference Station (VRS) in close proximity to the rover based on its position, and uses the VRS to compute real time corrections during the survey.

Additionally, a radio repeater may be setup and used to pick up the base station radio signal and broadcast the signal farther within the survey area. The NCBN parks have a number of TRIMMARK™ 3 radio modems that can be used for this purpose.

Benchmarks

The changes in elevation within the Area of Special Interest can be derived if the survey points are accurately measured relative to the same geodetic datum. Permanent structures, known as benchmarks or survey monuments, are used to mark reference locations in the field, helping the surveyors to confirm the accuracy of their measurements relative to the geoid and configuration of their equipment. Benchmarks, when practical, are established to be permanent and long-lasting structures that provide a robust basis for long-term monitoring using this protocol. Therefore, they are established in locations with a low probability of disturbance, natural or human induced. Ideal locations within a coastal setting are inland, away from the reach of the wave activity, usually behind the foredune or far from the bluff's edge, and at least a short distance from recreational zones or pathways.

It is preferable that benchmarks correspond to pre-existing professionally-installed structures, such as a National Geodetic Survey (NGS) or US Army Corps of Engineers (USACE) survey control monument. If no pre-existing structures exist, benchmarks may be established by the surveyors. Specifically, a PK nail into a solid surface or PVC pipe driven into the ground may be installed to mark the location of the reference point. The more sophisticated, professionally-installed survey monuments are stamped metal disks set into concrete or rock or attached to long stainless steel rods driven into the ground. These are typical of the benchmarks used by the NGS and the USACE (Figure 10a). They usually exhibit their ID and date of installation. In areas of loose sand, where the marker could be easily buried, there is usually a sign (witness post) marking its location (Figure 10b). Information on the NGS benchmarks (including description, coordinates and elevation, and directions to the benchmark) is available online through an interactive map viewer (http://www.ngs.noaa.gov/NGSDataExplorer/). Some of the USACE benchmark information has been integrated into the NGS database.

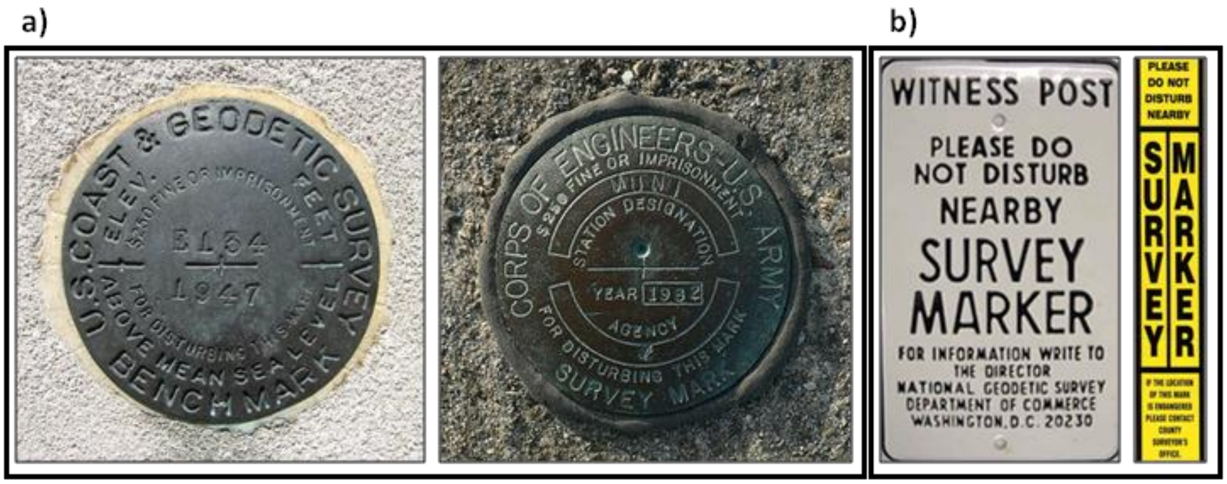

Figure 10. Examples of: a) metal disk survey benchmarks, and b) witness post label, established by USACE and NGS.

Besides being used to serve as a reference to test vertical and horizontal accuracy of the survey equipment that is used to collect data for coastal topography analysis, some benchmarks may also be used as control points to establish coordinates of a GPS base station used for Real Time Kinematic (RTK) correction. If a benchmark is used to establish a GPS base station, a second benchmark must be available to test the configuration of the equipment. Each Area of Special Interest will have at least one benchmark established according to the procedures described in SOP#2 - Establishment of Benchmarks, Survey Areas, and Database, and at least two benchmarks if a base station set-up is required to obtain RTK corrections.

Collection of Survey Transects to create a DEM

Successive measurements of the elevations of the coastal topographical surface are taken along pre-established shore-orthogonal survey transect lines with equal spacing of 5m – 30 m, with greater spacing in larger ASIs. The elevation measurements are taken at some distance or time interval, or wherever there is a change in the slope of the beach surface (Figure 11). The measurements of XYZ points along the transect provide a cross-sectional (2-D) representation of the beach, dune, or other geomorphological features (Figure 11). This process is repeated to collect topographical data along many shore-orthogonal survey transect lines at relatively short alongshore intervals to contribute datasets that form the basis of a DEM.

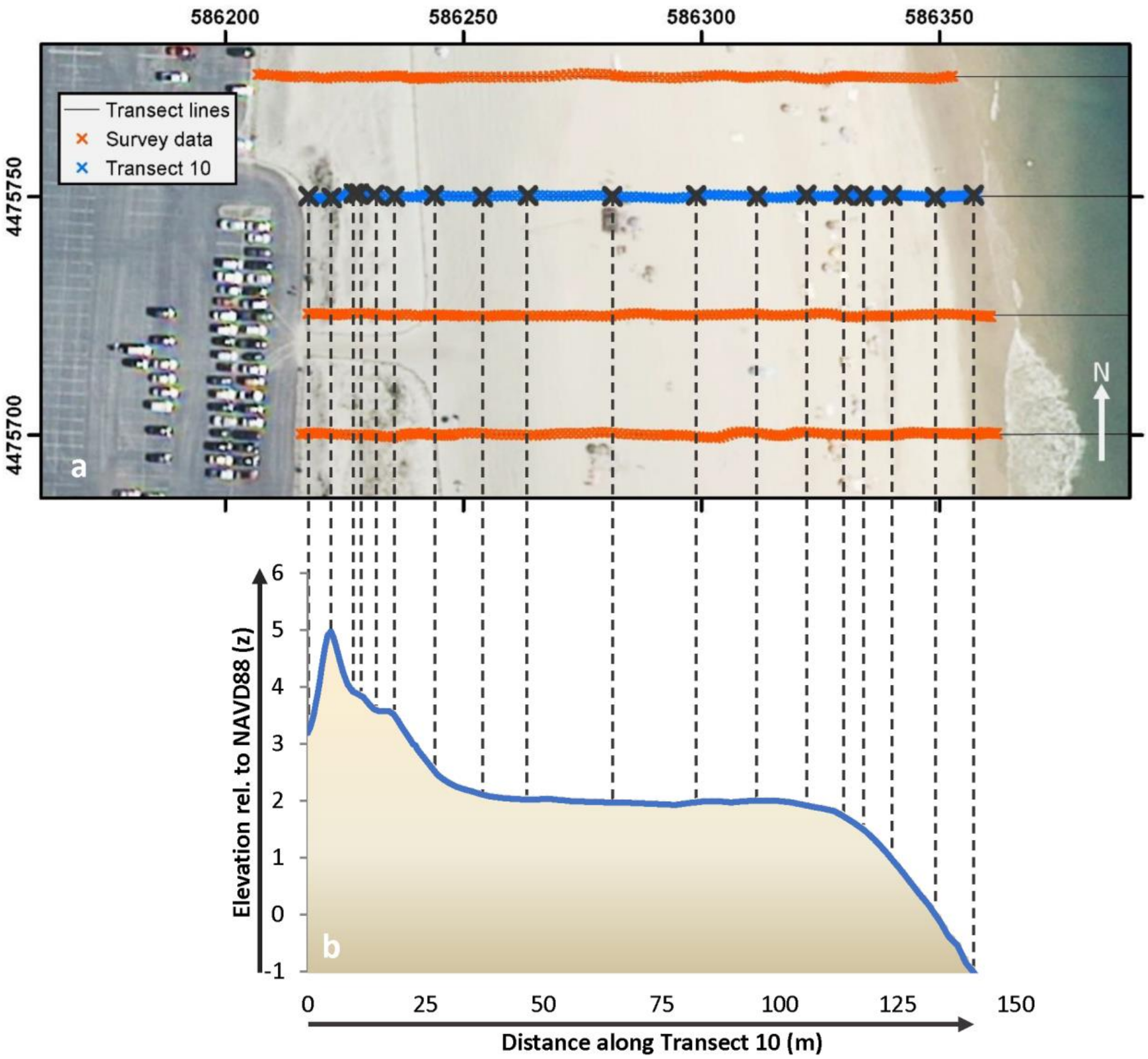

Figure 11. Collection of measurements of dune-beach topography along one survey transect that is a component of the DEM: a) planar view showing the XYZ measurements along four transect lines perpendicular to the general trend of the shoreline, b) cross-section view of the collected data portrayed as elevations along a single transect.

Survey Frequency and Timing

The morphology of the full beach-dune system changes with the seasonal variations in the wave-energy levels (Komar 1983). Commonly, winter storms produce higher and more energetic wave conditions leading to mobilization of the sediments in the beach face, berm, and dune, promoting the transfer of the sediment to a high berm (storm berm) adjacent to the foredune and to the subaerial portion of the beach (the beach face). At an extreme condition, the high berm is completely eroded and the foredune base is scarped. The offshore transfer profile configuration often incorporates a sand bar feature and is referred to as the winter profile (Figure 12). During the summer, waves are smaller and less energetic, and the sediment is transported back to the intertidal and subaerial portions of the beach (the beach face), leading to the widening of the berm and recovery of the dune. This profile configuration is referred to as the summer profile (Figure 12).

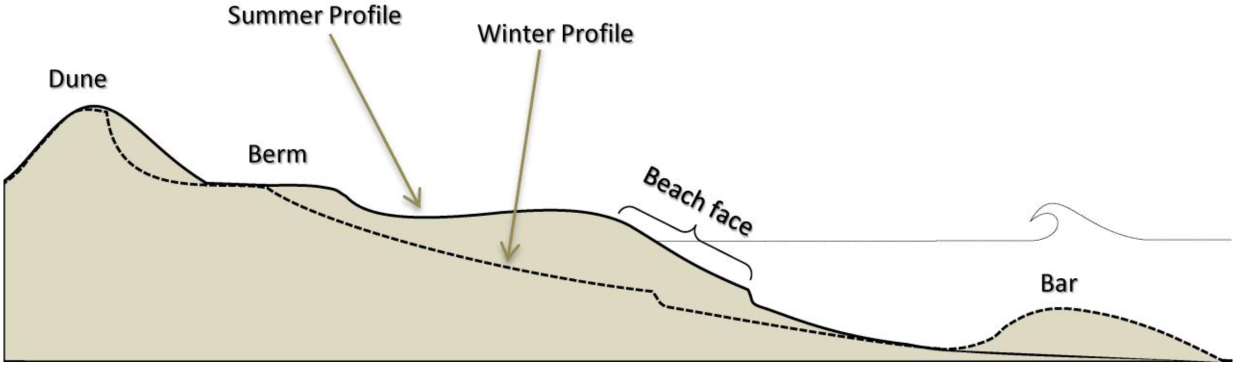

Figure 12. Changes in beach-dune profile morphology associated with seasonality of coastal energetics.

Bluff coastlines behave in a different manner. Because they are inherently erosional coastal features, bluffs respond to seasonal variations in the wave-energy levels by retreating at different rates. Bluff recession is usually accelerated in the winter when severe storms with higher wave energy impact the coast and promote scouring and slumping of the bluff face. The beach that may or may not exist at the base of the bluff will also change with the seasonal variability in the wave regime. The beach at the base of the bluff will be narrower during the winter and wider in the summer.

The configurations of the winter and summer profiles typically reach their peak expression around the end of the winter and the summer seasons, respectively. Likewise, bluff retreat and beach loss is maximized around the end of the storm season, typically the end of winter. In order to track this seasonal variation through temporal variations in volumes calculated from differences in elevation represented by the DEMs derived from the topographical data collections, 3D topographical surveys need to be conducted at least twice per year and timed to capture the general occurrence of the maximum seasonal (winter/summer) state. Four survey frequency options are presented in SOP#3 - Survey Timing and Mission Planning. Conducting the topographical surveys at a semi-annual frequency, the winter profile will be surveyed in mid-March to late April and the summer profile in mid-September to late October, with some adjustment related to traditional weather systems.

Field surveys are conducted within several days of the lowest of the low tide levels that are reached during spring tides. Conducting the survey during this condition promotes maximum exposure of the beach profile, and provides the opportunity to collect more data during the span of time that the beach face is exposed. The survey should be accomplished during the 6 hours around low tide, 3 hours before and 3 hours after the predicted time of low tide.

The topographical survey should be conducted when minimum satellite availability and satellite geometry specifications are met or exceeded (SOP#3 – Survey Timing and Mission Planning and SOP#4 - Settings for Collection of Topography). Timing of the surveys may also be affected by park specific issues such as the presence of species of concern or public activities that constrain the conducting of the topographical survey. Park management should always be consulted in advance when planning the survey. Details for timing and mission planning are provided in SOP#3 – Survey Timing and Mission Planning.

The topographical surveys will provide information that describes the volumetric change that the beach-dune/bluff system in an Area of Special Interest experiences from a seasonal, annual, and/or multi-year trend perspective, as well as the alongshore spatial variability of the volumetric change within the site during those temporal periods. Further, supplemental data collections may also be undertaken after a major storm event to provide information on the magnitude of short-term variations of the beach and dune in response to storms (Forbes et al. 2004). This information can be of great value to both park managers and coastal scientists. The protocol can and should be applied in pre-and-post-storm 3D topographical surveys whenever possible. Because numerous storms of varying intensity and duration are expected to affect a given park in a typical year, the decision of when to conduct these additional surveys is subjective and can be challenging. Local observation and judgment must be exercised in making the determination whether or not to conduct the supplemental surveys.

Field Methods

Field Season Preparations and Mission Planning

At the beginning of every year, the survey windows should be identified according to the monitoring design (SOP#3 – Survey Timing and Mission Planning). Tide prediction tables from the "NOAA Tides and Currents" website should be consulted and a list of potential survey dates and times should be established and prioritized. Satellite availability and satellite geometry predictions, available from the Internet, should also be taken into account in the survey window selection.

Prior to the survey, the field team should check the field equipment to make sure all the items are working properly and that all batteries are charging (SOP#1 - Equipment and Supplies). All the survey background files (SOP#2 – Establishment of Benchmarks, Survey Areas, and Database) must be uploaded into the field survey controller (SOP#4 – Settings for Collection of Topography). The field team must check the time of low tide for the days of the survey, and notify park personnel and neighbors of the activity (SOP#3 - Survey Timing and Mission Planning).

Conducting the Topographic Survey

Prior to the beginning of the survey, the GPS equipment must be set up to assure that the RTK corrections are being broadcast by the GPS base station or CORS and received by the rover over the area being surveyed. Depending on the method used, more than one base station might have to be set up, or repeaters might have to be used to extend the range of the radio signal. Once the GPS system is configured and working, the surveyor, or team of surveyors (each with a rover GPS unit), will refer to the field reference sheet and the field survey controller to locate the benchmarks that will be used for survey control measurements and the transects that are to be surveyed.

For quality-control purposes, the first measurement of the survey is a benchmark used as a survey control monument. If additional equipment, such as a survey wheel (Figure 13), is utilized to collect topographical data, then a pre-established quality control elevation transect is surveyed with that equipment installed and the survey equipment configured for its use. The establishment of this quality assurance (QA)/quality control (QC) transect line, a "QA/QC Transect", and the procedure for collecting is described in depth in SOP#2 – Establishment of Benchmarks, Survey Areas, and Database and SOP#5 - Conducting the Survey, respectively. After completing the survey quality control measures, the rover is then positioned on the first survey transect line shown as a background file in the screen of the field survey controller. Data are collected with the GPS rover receiver along the pre-established transect lines, starting either at the landward boundary of the survey area collecting data seaward to an elevation threshold that demarcates the seaward termination of the data collection, or between those boundaries in the opposite direction. Point measurements (XYZ) are taken at some distance interval (no more than 5 meters), or wherever there is a change in the gradient of the beach surface, and continue seaward to a pre-determined elevation relative to NAVD88. This elevation should define a position low on the beach face, and may be site specific and/or dependent on monitoring objectives (the electronic equipment is not designed to be immersed). If a survey wheel is used to collect the topographical data, a 1 second interval is typically set between the collection of individual data points (ca. 0.5-1.0 m spacing) as the surveyor walks the equipment along the survey transect. Additional details are included in SOP#5 **-** Conducting the Survey.

Figure 13. Survey wheel constructed to facilitate the efficient collection of 3D topographic data.

In areas with bluffs, the survey may have to be divided into two parts. The surveyor may have to survey the beach area during the low tide window, and survey the upper part of the bluff at another time to take full advantage of the exposed beach face.

Survey photographs are to be taken and georeferenced at specific, pre-determined transect lines within each Area of Special Interest to capture the general aspects of the topographical features present within the site. Additional details are included in SOP#5 **-** Conducting the Survey.

Post-survey Data Download and Initial QA/QC

Immediately upon completion of the survey and return to the office, the survey job is downloaded from the field survey controller to a computer hard-drive and a backup copy is created. The data should be retained on the field survey controller until quality checks can be made. The downloaded job is imported into the Trimble Business Center (TBC) software (or similar) and the data are exported to a CSV (comma separated values) text file and converted to ESRI shapefiles. The topographical data are plotted in ArcMap and the general alignment between the collected points and the pre-established transect lines are checked for accuracy assessment. An auxiliary file representing transect line buffer areas, for use during the survey and for post-survey QA/QC, was created and stored within the park's database (SOP#2 - Establishment of Benchmarks, Survey Areas). Additionally, the accuracy of the survey data is evaluated by comparing the collected coordinates of the benchmark(s) during the survey to the established benchmark coordinates. If special equipment is utilized to collect the topographical data, such as a survey wheel, the data collected along the QA/QC transect line are compared to the established coordinates for that line.

The photographs are transferred into the computer and renamed to reflect the ID of the photo location and date of the survey. The Field Data Form (FDF) is completed and reviewed. Following all of the quality control procedures and creation of metadata, the final dataset of the surveyed profiles (job files, TBC project, exported files, shapefiles, FDFs, and photographs) will be sent to the NCBN data manager. Additional details referring to data downloading and quality assurance are included in SOP#6 - Initial Post-Survey Processing.

Data Management

The NCBN Coastal Topography Monitoring Protocol generates a variety of data products that will be archived in a central relational database, overseen and controlled by the NCBN data manager (SOP#8 - Data Management). These datasets will be retrievable for broad-based usage and analysis. To better understand the structure of the archiving system and the type of information available, a User’s Guide to the database has been produced that describes the elements of the data input and the categories of Coastal Topography data. The User’s Guide also describes the procedures for retrieving information. Data storage and retrieval are vital elements of the NCBN coastal topography monitoring effort.

Data Analysis and Reporting

Generation of Spatial and Temporal Metrics of Volumetric Change

The topographical data collected in the field in the form of coordinates and elevation (XYZ) will be used to produce DEMs of the coastal topographical surface along the cross-shore extent of the transect lines within the alongshore extent of each Area of Special Interest. Construction of the DEMs utilizes a series of operations within ESRI ArcGIS software to facilitate a consistent volumetric comparison of topographical surveys for Areas of Special Interest. Additionally, the derived volumetric changes are calculated for compartments that subdivide the survey area to provide possibilities for detailed analyses of spatial patterns of coastal erosion and deposition of sediment within a site (Fig S7.7). The measured parameters are stored in data matrices that can be utilized to generate spatial portrayals of the geomorphological change. A step-by-step description is presented in SOP#7 on how to generate, from the topographical survey data, the DEMs that will represent the dimensions of the coastal landforms within Areas of Special Interest. Steps are also described for calculating volumetric changes from differences in elevation between those DEMs. Suggestions for the portrayal of the derivative data are also provided.

Uncertainty

Elevations of the unsurveyed areas between the survey transects are obtained through Delaunay triangulation, according to SOP#7. The interpolated models of the surface topography are stored as spatial matrices of elevation data (i.e., raster DEMs) that add additional uncertainty, beyond instrument error, into the DEM creations. To quantify this additional error, DEMs are created using Delaunay triangulation from survey data minus one transect. Spot elevations of the interpolated DEM elevation are compared to the actual surveyed elevations of the removed transect as an estimation of error and are repeated programmatically for each surveyed transect (Waters, 2017).Combining the error from the instrument and the error from the DEM creation yields an estimate of vertical uncertainty per square meter in the DEM. Detailed steps to calculate uncertainty can be found in Appendix B.

Data Analysis and Reports

The quantification of volumetric change generated from the topographical data can be utilized within one of two primary approaches through: 1) a calculation of net changes, or 2) the implementation of a trend analysis. The generation of data matrices with spatial and temporal dimensions will provide the option to generate metrics within either approach because the individual temporal comparisons within the matrices represent the absolute change and the matrices themselves facilitate a regression analysis for deriving trends of change through time. Further, the analyses may be applied to the entire area or to individual compartments. These matrices arrange information about the temporal and spatial changes in coastal geomorphology within an Area of Special Interest and enable tabular, graphical, and statistical portrayals of these data (SOP#7 - Data Analysis and Reporting).

At a minimum, a suite of summary statistics (mean, maximum, minimum, and standard deviation values) should be derived for each of the Area of Special Interest sites describing the dimensions of the erosion, deposition, and total volumetric change for compartments within the sites. The metrics should be supplemented by spatial portrayals of the volumetric change that will provide a basis for qualitative analyses of cross-shore change to supplement the quantitative approach to deriving alongshore spatial patterns of change. Further, site-specific patterns of accretion/erosion and migration of components of the beach-dune or bluff system can be assessed through the integration of the information describing the cross-shore and alongshore patterns of topographical change. Ultimately, the spatial relationship of topographical changes between compartments within the site may be correlated to assess local patterns of alongshore transport and local sediment budgets.

Annual reports will be produced to describe the seasonal changes as well as the year-to-year variations (SOP#7 - Data Analysis and Reporting). Longer-term reports will be produced at 5-year intervals to look at trends in the geotemporal changes in the park (SOP#7 - Data Analysis and Reporting).

Personnel Requirements and Training

Roles and Responsibilities

The NCBN is responsible for the development and implementation of the geomorphological protocol and will assign a Network staff-person as Project Lead. The project manager is responsible for coordinating protocol development as well as an implementation plan and schedule that is suited to the needs of the individual Network parks. The Project Lead will work closely with Network parks and their designated cooperators to develop and implement this protocol.

The Coastal Landform Elevation Models protocol is designed to be used by local staff in field data collection through the implementation of defined procedures in the conduct of the surveys. Consistent feature identification and measurement is important, and assignment of data collection to a single or small number of Network-trained observers is highly recommended.

The data management aspect of the monitoring effort is the shared responsibility of the field surveyor, the park and Network data managers, and the Network Project Lead. The field surveyor is responsible for field data collection, initial data download, and initial QA/QC. The field surveyor should work closely with the Network and/or park GIS specialist for additional post-processing, data verification and data validation, preliminary data editing, and export to the designated GIS format. The Network data manager is responsible for data documentation (metadata), data summary, basic analysis, and reporting. Ultimately, the NCBN geomorphological monitoring Project Lead has the responsibility to see that adequate QA/QC procedures are built into the database management system and that appropriate data handling procedures are followed.

Qualifications and Training

An essential component in the collection of coastal topography data is a knowledgeable, competent, and attentive field surveyor. The field surveyor must be able to identify the major topographical features along the survey transects and to consistently collect points that will reflect and portray those features. The field surveyor should have:

- A basic understanding of coastal processes, and familiarity with the appearance of the major coastal landforms
- Competence and experience in the operation of all equipment being used in the survey

The project manager needs to be knowledgeable in the data gathering methodology and is responsible for developing and delivering a training program to provide a scientific and technical foundation for consistent and accurate data collection by properly trained personnel at the park's level.

Frequency of the Training Sessions

Training shall be conducted prior to initial implementation of the protocol and thereafter at a minimum interval of once every two years, or as needed due to staff or procedural changes.

Target Audiences

The Network shall provide training for two persons at each park. This will establish a core of competent and qualified coastal topography surveyors with local knowledge. Training two persons per park also helps to reduce problems related to staffing or scheduling.

Training Syllabus

The purpose of training is to develop and maintain competence in the following:

1. Basic Coastal Geomorphology:
    a. Basic understanding of coastal process/response interaction
    b. Fundamentals of cross-shore and alongshore landform development
2. Field Season Preparations and Mission Planning:
    a. Seasonal timing, tides, and selection of the survey window
    b. Network of existing benchmarks and their establishment, creation of transect lines, creation of the QA/QC auxiliary files, and field reference sheets
    c. GPS scheduling
3. Using the Equipment and Conducting the Survey
    a. How to set-up the GPS equipment and start a survey job
    b. How to follow the transect lines in the field survey controller
    c. How to ID and collect the points
    d. Where to collect points
    e. Where and how to take the geotagged photographs
4. Post-survey processing
    a. Filling out the Field Data Form
    b. Data downloading and exporting
    c. Data backup
    e. Initial quality assurance/quality control (QA/QC)

As a requirement, every surveyor must be familiar with the safety measures and procedures outlined in SOP#10 – Field Safety for the Coastal Landform Elevation Monitoring Protocol.

Operational Requirements

Annual Workload and Field Schedule

Topographical surveys will be conducted during spring tides within assigned survey windows, and the frequency of surveys per year at a given site will determine the appropriate windows to apply. The unpredictability of extreme tide and weather events precludes the scheduling of surveys to specific annual dates.

The surveys require one person, although the survey could benefit from the use of one or more additional staff if qualified persons and the necessary equipment are available. Tide oscillation is a time constraint to the acquisition of the data, approximately limiting the daily survey time to the 6 hours around the predicted time of low tide. The variety of Areas of Special Interest will present different workloads because they have different geographical extents and may require different transect spacing. Additionally, site-specific constraints that have to do with access to the transect lines may limit the covered area for a given survey. Fencing, vegetation, and hazardous topography can slow the surveys because these obstacles often need to be avoided or traversed at the cost of additional time. For example, within the Great Kills Park of GATE's Staten Island Unit, a steep bluff prevents the continuous collection of topographical data along a transect. This means that the area below the bluff needs to be surveyed separately from the higher elevations, requiring two visits to the same profile. Equipment availability also may present constraints on survey times.

The duration of data collection for a certain Area of Special Interest is dependent on a variety of factors, including the number of surveyors in the field, the equipment used, the spacing of survey transects, and its areal size. For an area such as the Critical Zone at Sandy Hook, a location that spans 1.3 km alongshore and approximately 200 to 250 m cross-shore and contains a 25 m transect spacing, the durations provided in Table 5 can be expected given varying personnel and equipment configurations.

Table 5. Time to complete the Critical Zone, Sandy Hook, Gateway National Recreation Area 3D survey with varying resources assignments.

Personnel	Equipment distribution	Survey Duration
3 surveyors	3 survey wheels	2 h
	2 survey wheels, 1 rover pole	2 h 15 m
	2 rover poles, 1 survey wheel	3 h
	3 rover poles	4 h 15 m
2 surveyors	2 survey wheels	3 h
	1 survey wheel, 1 rover pole	4 h
	2 rover poles	6 h 30 m
1 surveyor	1 survey wheel	6 h
	1 rover pole	13 h

The pre- and post-survey workload is expected to be similar for all the parks. Across all sites, survey preparations and mission planning should take one workday to accomplish, and post-processing should take approximately one hour per site.

Facility and Equipment Needs

The minimum equipment needed for the field survey consists of a GPS receiver and a field survey controller, and second GPS receiver if a cell-network were not available. If two or more surveyors work simultaneously, field equipment requirements will increase accordingly. Should a park lack the proper equipment, the Network will attempt to arrange access to the items necessary to conduct the survey.

A computer and peripheral devices with appropriate ports and cables, RTK jobs processing software (e.g. Trimble Business Center) for download, initial QA/QC, and export to ESRI GIS format are required to complete the initial processing tasks. The GIS component consists of the ESRI ArcGIS software, for example. Office computing needs and other equipment items are detailed in SOP #1 – Equipment and Supplies.

Budget

The annual cost of monitoring will fluctuate depending on the specific Parks resources and needs. Table 6 presents a worksheet to aid in determining costs.

Table 6. Project cost worksheet to be used to determine monitoring costs per site. This budget worksheet and categories are from the Gulf Coast Networks Parks coastal monitoring protocol (Bracewell 2017).

Category	Sub-Category	Cost	Notes
Personnel	Minimum two person field crew per site	$4,226.88	Pay rate
	Data manager	$3,603.00	Pay rate
	Total Personnel Costs	$7,829.88	–
Equipment and Supplies	Survey benchmark installation	$7,000.00	Reference SOP #2 for Benchmark requirements.
	UTV/ATV/Boat Maintenance or Rental	$0.00	Provided by park
	GNSS RTK Rental or Purchase	$0.00	Provided by park
	Additional Field Supplies	$250.00	Reference SOP#1 for full equipment list.
	Additional survey benchmark installation	$7,000.00	Optional. Cost could occur during any year.
	Total Equipment Costs (Year 1)	$7,250.00	–
	Total Equipment Costs (Years 2+)	$250	–
Travel	Lodging	$0.00	–
	M&IE	$678.50	–
	Fuel	$280.00	–
	Total Travel Costs	$958.50	–

Table 6 (continued). Project cost worksheet to be used to determine monitoring costs per site. This budget worksheet and categories are from the Gulf Coast Networks Parks coastal monitoring protocol (Bracewell 2017).

Category	Sub-Category	Cost	Notes
Total	Total Annual Protocol Costs (Year 1)	$16,038.38	–
	Total Annual Protocol Costs (Years 2+)	$9,038.38	–

Procedure for Revising and Archiving Previous Versions of the Protocol

Over time, revisions to both the Protocol Narrative and specific Standard Operating Procedures (SOPs) are to be expected. Complete documentation of changes to the protocol and a library of previous protocol versions are essential for maintaining consistency in data collection and for appropriate treatment of the data during data summary and analysis. The relational database for each monitoring component contains a field that identifies the version of the protocol being used when the data were collected. The rationale for creating a narrative with supporting SOPs is based on the following:

- The Protocol Narrative is a general overview of the protocol that gives the history and justification for doing the work and an overview of the sampling methods, but it does not provide all of the procedural details. The Protocol Narrative will only be revised if major changes are made to the protocol.
- The SOPs, in contrast, are very specific step-by-step instructions for performing a given task. They are expected to be revised more frequently than the Protocol Narrative.
- When a SOP is revised, in most cases, it is not necessary to revise the Protocol Narrative to reflect the specific changes made to the SOP.
- All versions of the Protocol Narrative and SOPs will be archived in a Protocol Library.

The steps for changing the protocol (either the Protocol Narrative or the SOPs) are outlined in SOP #9 - Revising the Protocol. Each SOP contains a Revision History Log that should be filled out each time a SOP is modified to explain why the change was made, and to assign a new Version Number to the revised SOP. The project manager will be responsible for archiving the new version of the SOP and/or Protocol Narrative in the Long Term Ecological Monitoring Protocol Library.

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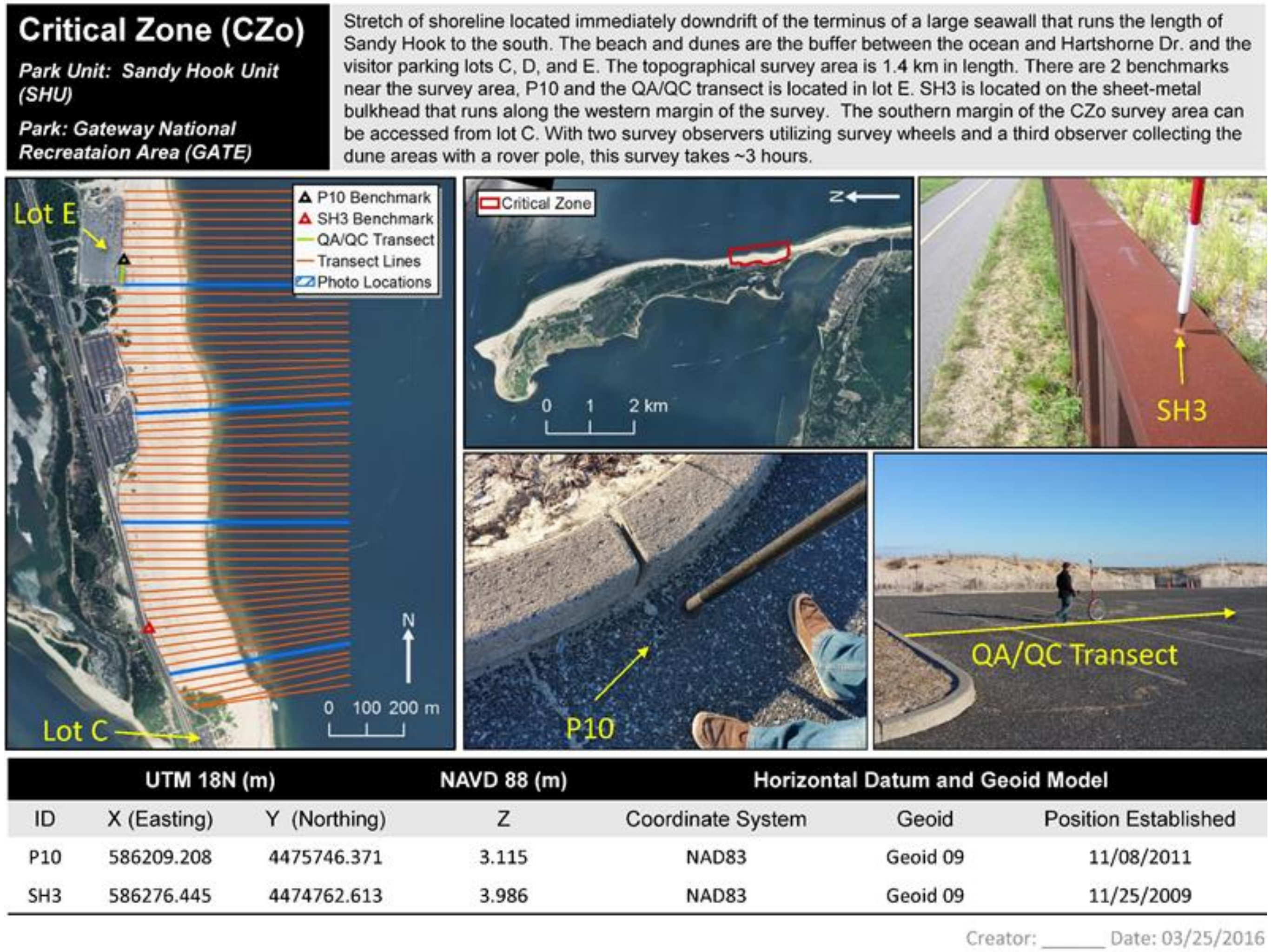
Appendix A: Sample Field Reference Sheet



Critical Zone (CZo)

Park Unit: Sandy Hook Unit (SHU)

Park: Gateway National Recreataion Area (GATE)

Stretch of shoreline located immediately downdrift of the terminus of a large seawall that runs the length of Sandy Hook to the south. The beach and dunes are the buffer between the ocean and Hartshorne Dr. and the visitor parking lots C, D, and E. The topographical survey area is 1.4 km in length. There are 2 benchmarks near the survey area, P10 and the QA/QC transect is located in lot E. SH3 is located on the sheet-metal bulkhead that runs along the western margin of the survey. The southern margin of the CZo survey area can be accessed from lot C. With two survey observers utilizing survey wheels and a third observer collecting the dune areas with a rover pole, this survey takes ~3 hours.

UTM 18N (m)			NAVD 88 (m)	Horizontal Datum and Geoid Model		
ID	X (Easting)	Y (Northing)	Z	Coordinate System	Geoid	Position Established
P10	586209.208	4475746.371	3.115	NAD83	Geoid 09	11/08/2011
SH3	586276.445	4474762.613	3.986	NAD83	Geoid 09	11/25/2009

Creator: ______ Date: 03/25/2016

Figure A1. Sample page of a Field Reference Sheet for Sandy Hook Unit, Gateway National Recreation Area.

Appendix B: Calculating Uncertainty

Uncertainty of Volumetric Change Calculation

The survey data can be used to generate a statistical estimation of the uncertainty associated with the calculation of elevation and volumetric change. This is accomplished by comparing directly measured topography with the topography calculated from the interpolation procedures of the protocol. The value of uncertainty will change from site to site depending on characteristics such as the area of the ASI, transect spacing, and the magnitude and variability of topographical relief. To obtain a metric of uncertainty for a given site, apply the following steps:

Vertical Uncertainty of a DEM

In ArcGIS or other GIS environments, follow the below steps to calculate uncertainty in a survey DEM. A recommendation is to complete the steps in an automated method (python script, model builder, etc) for time savings and consistency.

1. Steps 2 – 5 should be completed in ArcGIS, and can be automated using Model Builder (Figure B1, Figure B2).
2. Create a DEM of a survey dataset (steps S7.1.1 to S7.1.4) with data from a single transect omitted (***i***) from the set of *n* transects in the entire dataset (Figure B1).
3. Using the DEM dataset derived from the step above, record the elevations ($Z_{Protocol_j}$) *of the DEM* calculated at the spatial locations of where there is recorded survey data (*j*) along the omitted transect (Figure B2).
4. At the same spatial locations (*j*) where elevation was recorded from the DEM, record the measured elevation (Z_{Survey_j}) from the survey data collected on transect ***i***.
5. Iterate this comparison for all (*n* – 2) transects, omitting only the transects at the boundaries of the survey area. Recording the number of comparisons made on each individual transect ($\boldsymbol{m_i}$).
6. The data produced in steps 4 and 5 should then be appended into one feature class in ArcGIS using the "Append" tool and exported into Excel for the remaining steps.

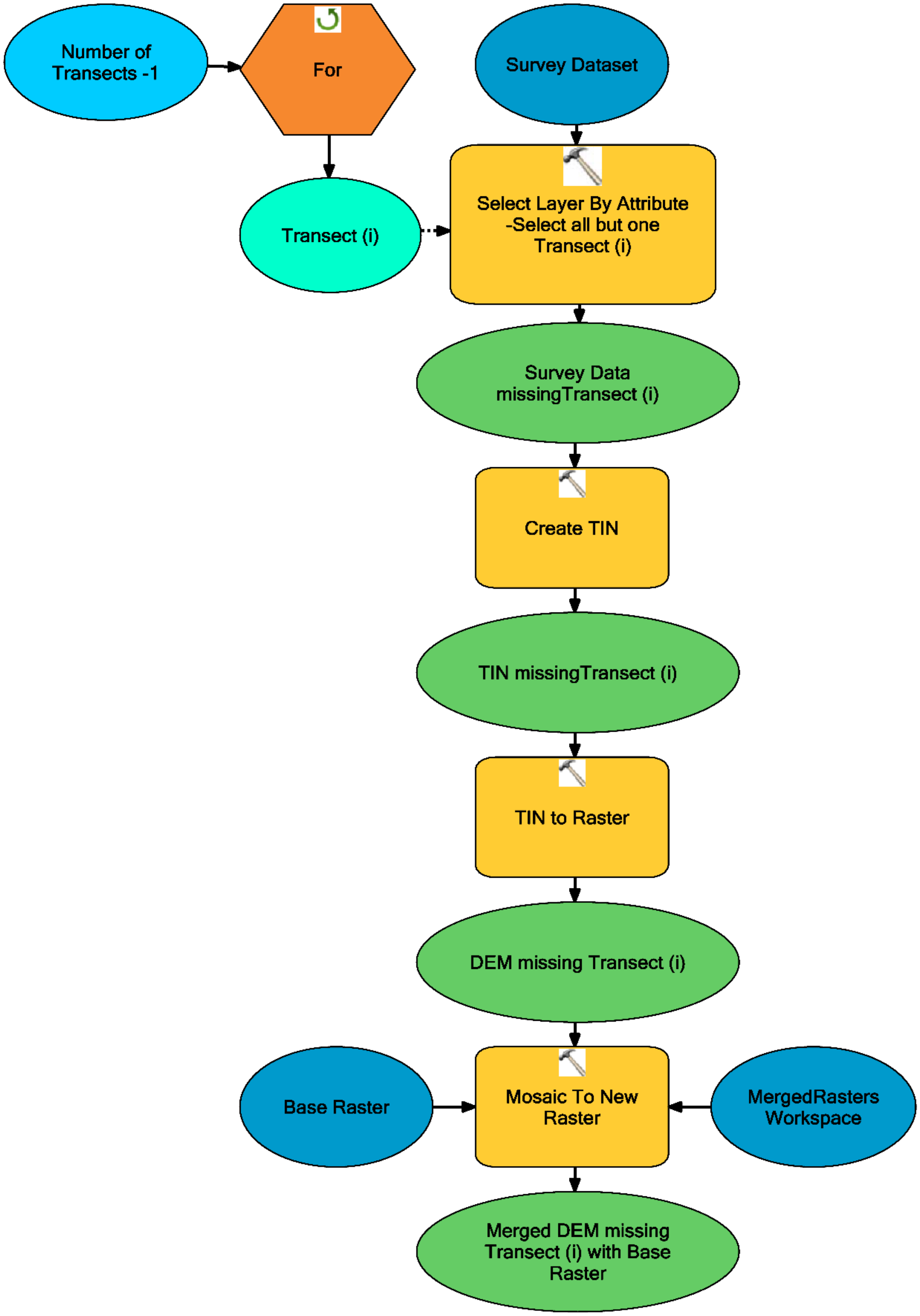


Figure B1. Example workflow for Model Building in ArcGIS to create DEM missing Transect (i) in Step 2.

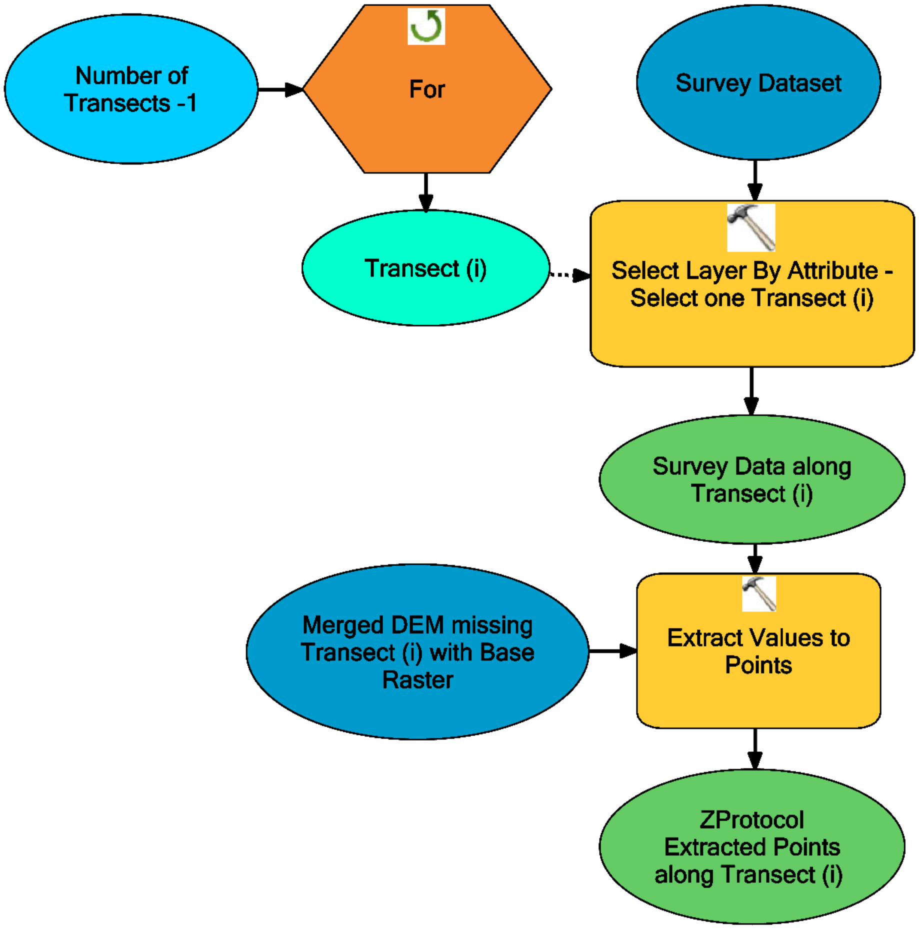


Figure B2. Example workflow for Model Building in ArcGIS extract elevations along Transect (i) from the DEM created in Step 2, described in Steps 3-5.

1. In excel (Figure B3) and using equation x, calculate the absolute value of the total difference between Z_{Survey_j} and $Z_{Protocol_j}$ per meter.

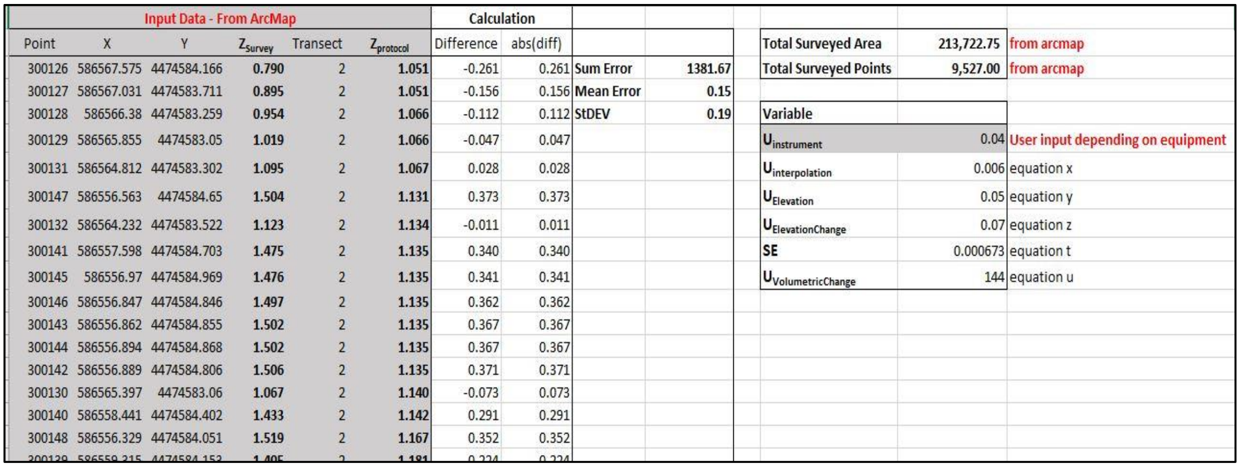
(equation x)

$$U_{interpolation} = \frac{\sum_{i=1}^{n-2} \sum_{j=1}^{m_i} \left| Z_{protocol_j} - Z_{survey_j} \right|}{area\ of\ ASI}$$

2. Using equation y, calculate an estimate of uncertainty per square meter for one survey DEM $U_{interpolation} + U_{instrument}$.

(equation y)

$$U_{Elevation} = U_{interpolation} + U_{instrument}$$



Input Data - From ArcMap						Calculation	
Point	X	Y	Z_{Survey}	Transect	$Z_{protocol}$	Difference	abs(diff)
300126	586567.575	4474584.166	**0.790**	2	**1.051**	-0.261	0.261
300127	586567.031	4474583.711	**0.895**	2	**1.051**	-0.156	0.156
300128	586566.38	4474583.259	**0.954**	2	**1.066**	-0.112	0.112
300129	586565.855	4474583.05	**1.019**	2	**1.066**	-0.047	0.047
300131	586564.812	4474583.302	**1.095**	2	**1.067**	0.028	0.028
300147	586556.563	4474584.65	**1.504**	2	**1.131**	0.373	0.373
300132	586564.232	4474583.522	**1.123**	2	**1.134**	-0.011	0.011
300141	586557.598	4474584.703	**1.475**	2	**1.135**	0.340	0.340
300145	586556.97	4474584.969	**1.476**	2	**1.135**	0.341	0.341
300146	586556.847	4474584.846	**1.497**	2	**1.135**	0.362	0.362
300143	586556.862	4474584.855	**1.502**	2	**1.135**	0.367	0.367
300144	586556.894	4474584.868	**1.502**	2	**1.135**	0.367	0.367
300142	586556.889	4474584.806	**1.506**	2	**1.135**	0.371	0.371
300130	586565.397	4474583.06	**1.067**	2	**1.140**	-0.073	0.073
300140	586558.441	4474584.402	**1.433**	2	**1.142**	0.291	0.291
300148	586556.329	4474584.051	**1.519**	2	**1.167**	0.352	0.352
300139	586559.315	4474584.153	**1.405**	2	**1.181**	0.224	0.224

Sum Error	**1381.67**
Mean Error	**0.15**
StDEV	**0.19**

Total Surveyed Area	**213,722.75**	from arcmap
Total Surveyed Points	**9,527.00**	from arcmap

Variable		
$\mathbf{U}_{\mathbf{instrument}}$	0.04	User input depending on equipment
$\mathbf{U}_{\mathbf{interpolation}}$	0.006	equation x
$\mathbf{U}_{\mathbf{Elevation}}$	0.05	equation y
$\mathbf{U}_{\mathbf{ElevationChange}}$	0.07	equation z
SE	0.000673	equation t
$\mathbf{U}_{\mathbf{VolumetricChange}}$	144	equation u

Figure B3. A sample of exported data from ArcGIS in Excel when calculating uncertainty.

Vertical Change Uncertainty between Two DEMs

1. An estimate of uncertainty in elevation change metrics is defined by the Root Mean Square Error (RMSE) between two survey-derived DEMS (equation z).

(equation z)

$$U_{Elevation\ Change} = \sqrt{\left(U_{Elevation_{survey1}}\right)^2 + \left(U_{Elevation_{survey2}}\right)^2}$$

2. Using equation t, determine the standard error, SE, for the calculation of uncertainty of elevation utilizing $U_{Elevation\ Change}$ obtained in S7.3.6.7 and the number of independent observations of topography, *p*.

(equation t)

$$SE = \frac{U_{Elevation\ Change}}{\sqrt{p}}$$

3. Multiply the SE by the area of the ASI to obtain the volumetric uncertainty of the survey (equation u).

(equation u)

$$U_{Volumetric\ Change} = SE \times Area\ of\ ASI$$

Through the establishment of elevation and volumetric uncertainty, a scale is provided for comparison of the metrics of change.

NPS962/147897, September 2018

National Park Service
U.S. Department of the Interior

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